Dioxins and dioxin-like PCBs in the UK environment

Consultation document

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Department for Environment,
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Foreword

This is a consultation document produced by the UK Government and devolved Administrations to seek the opinions of all stakeholders on the current situation regarding dioxins and dioxin-like polychlorinated biphenyls (PCBs) in the UK environment.

The aim of this paper is to review the current status of dioxins [taken here to include polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs)] and dioxin-like PCBs and to assess the effectiveness of policy measures taken so far. The paper considers what control measures have already been put in place to reduce both emissions of dioxins into the environment and human exposure, especially through the foodchain. The paper draws upon the wealth of recent information coming from scientific research, both in the UK and internationally, to improve our understanding of the formation, emissions, environmental transport and effects of dioxins and dioxin-like PCBs. In the international arena dioxins and dioxin-like PCBs have been highlighted as priority substances in many fora and UK commitments to these are summarised. While the paper draws on scientific literature and assessments, it is not intended to include a full assessment of all available scientific information and the interested reader is referred to more detailed Government reports and scientific papers throughout the text.

The paper provides the background and context for the development of UK policy on dioxins. Alongside a partial regulatory impact assessment it will serve as a focus for all stakeholders to consider what further actions are required to continue the trend of reducing environmental and human exposure to dioxins and dioxin-like PCBs in line with Government policy.

This paper is based on the discussions and recommendations of an Interdepartmental Group (IDG) set up to consider the subject of dioxins and dioxin-like PCBs. The IDG included representatives from the Department for Environment, Food and Rural Affairs (formerly DETR and MAFF), the Department of Health (DH), the Food Standards Agency, the Department of Trade and Industry (DTI), the Health and Safety Executive (HSE), the National Assembly for Wales (NAW), the Environment Agency, the Northern Ireland Department of the Environment (NIDOE), the Scottish Executive and the Scottish Environment Protection Agency (SEPA). Technical assistance was provided by Mr Patrick Dyke of PD Consulting, Professor Kevin Jones, Dr Ruth Alcock and Dr Andy Sweetman of Lancaster University and Dr Debbie Buckley-Golder and Dr Mike Woodfield of AEA Technology.

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Executive Summary

The environment and health

1. Dioxins and dioxin-like PCBs are a group of structurally related chemicals which persist in the environment, may bioaccumulate in food and human tissues and are toxic. They are considered to have similar mechanisms of toxicity and so are grouped together when considering potential risks even though they originate from different sources.

2. Assessments of the risk of exposure to dioxins and dioxin-like PCBs have been carried out by a number of international bodies, including the World Health Organisation (WHO), the Scientific Committee on Food (SCF) for the EU, and the Joint FAO/WHO Expert Committee on Food Additives (JECFA). In 2000 WHO recommended a tolerable daily intake (TDI) of between 1 and 4 picograms WHO-TEQ per kilogram of body weight, SCF has recommended a tolerable weekly intake (TWI) of 14 pg WHO-TEQ per kg of body weight, and in 2001 JECFA recommended a tolerable monthly intake of 70 pg WHO-TEQ per kg of body weight.

3. In 2001, the toxicity of dioxins and dioxin-like PCBs was reviewed in detail by the UK independent advisory Committee on the Toxicity of Chemicals in Food, Consumer Products and the Environment (COT). They considered the recommendations of WHO and SCF and other relevant recently published information and recommended that the TDI be set at 2 pg WHO-TEQ per kg of body weight. This is important as it changes the basis against which regulatory targets and risk assessments are set.

4. The major route of human exposure to dioxins and dioxin-like PCBs is through the food chain, although some individuals may also be exposed through environmental or occupational exposure. Dietary exposures to dioxins and dioxin-like PCBs in the UK is similar to levels of exposure in other industrialised countries. Mean adult dietary exposure is 1.8 picograms WHO-TEQ per kilogram of body weight per day which is close to the recent COT-recommended TDI. However, estimates of dietary exposure for toddlers and children and particular adult groups in the UK indicate that this limit is exceeded so we need to reduce dietary exposure. In the short term this could be addressed by setting limits for some foods but in the longer term can be achieved only by reducing dioxin and dioxin-like PCBs emissions to the environment.

5. Although levels of dioxins and dioxin-like PCBs in human breast milk (reflecting maternal exposure and body burden) have fallen significantly, breast-fed infants are still exposed to high levels and exceed all recommended TDIs during the period of breast-feeding. Despite this the Department of Health has advised that breast feeding should be encouraged and promoted on the basis of convincing evidence of its benefits to the overall health and development of the infant.

6. Dioxins and dioxin-like PCBs are a global problem. They may undergo long-range environmental transport, moving from warmer to colder climates through air and other media, and it is important that action to control them is taken at an international level. Transboundary movement of dioxins and dioxin-like PCBs can occur directly through environmental transport processes or indirectly in feed and foodstuffs imported from overseas. Future UK policy should consider the impact of overseas sources on the UK dioxin and dioxin-like PCBs burden and the impact of our emissions overseas.

What has already been achieved?

7. Dioxins and dioxin-like PCBs are being addressed as a high priority in a number of international fora including the United Nations Environment Programme (UNEP) Stockholm Convention on Persistent Organic Pollutants (POPs), the United Nations Economic Commission for Europe (UNECE) Convention on the Long Range Transboundary Air Pollution (LRTAP) Protocol on POPs, and the Oslo and Paris Commission (OSPAR) Convention for the Protection of the Marine Environment of the North East Atlantic. The UK has obligations under these to continue to reduce emissions of dioxins and dioxin-like PCBs and for the production of source inventories, action plans and continued environmental monitoring.

8. We have already taken a number of measures which have significantly reduced emissions of these substances. For dioxins these have included:

   - controls on industrial processes such as municipal waste incineration, metal processing plants, power stations and chemical manufacturing plants;
   - controls on open agricultural burning;
   - marketing and use controls;
   - and controls on vehicular emissions.

9. For PCBs various controls have been put in place since 1972 culminating in European Council Directive 96/59/EC on the disposal of PCBs and PCTs which requires the phasing out of remaining identifiable PCBs.

10. This has been reflected by a substantial decrease, during the last 10 years, in emissions to the environment and in the concentration of these chemicals in food:

    - approximately a 70% reduction in emissions of dioxins to air;
    - approximately a 60% reduction in emissions of PCBs to air;
    - and approximately a 70% reduction in the levels in food.

11. However, given the persistence of this group of chemicals it will be some time before the true impact of the control measures is realised. Measures already taken in the UK to reduce emissions of dioxins and dioxin-like PCBs have focussed on those processes (eg incineration) identified as producing the most emissions and therefore having the greatest impact. Any further measures will also have to focus on a wide range of smaller diffuse sources which will be more difficult to control and possibly costly to implement. For measures addressing domestic or open burning issues substantial public support will be required.

12. The UK Government continues to support a substantial amount of monitoring and scientific research to underpin policy development on dioxins and dioxin-like PCBs. This should continue as an invaluable tool for identifying areas for future action. It is important that future research programmes are carried out in a co-ordinated and integrated manner with full co-operation of all funding bodies and input from stakeholders.

Future action

13. Development of UK dioxins policy will impact on a number of Government initiatives and requires consideration and consultation with a wide range of experts and stakeholders. It is

clear that further action is required, at least until we have demonstrated additional reductions in exposure. There are a range of options available and an assessment of likely costs and demonstration of benefits will be required. **We see this paper as a first step in such a consultation exercise**.

14. We request comments and opinions on the following:

- the development of a national **Dioxins Action Plan** to reduce overall exposure to dioxins and dioxin-like PCBs – the focus of such a strategy and the indicators which could be used in reviewing its progress;
- establishment of a **Dioxins Strategy Group**, its function and the stakeholder involvement;
- the further reduction of emissions of dioxins and dioxin-like PCBs from **industrial processes**, in particular on measures which would bring about reduced emissions in the most cost-effective manner;
- dioxins emissions from **open burning** and other **diffuse sources** and the actions which should be taken to reduce these in a cost-effective manner;
- dioxins and dioxin-like PCBs in **food** and what measures could be taken to reduce levels in the short to medium term and the factors to be considered in determining the cost-effectiveness of these;
- the arrangements in place for **monitoring** and the **collection** and reporting of data on emissions of, and exposure to, dioxins and dioxin-like PCBs

15. This is the first general consultation on dioxins since 1989 and, as indicated above, this paper is the first step in developing a strategy for dioxins and dioxin-like PCBs. The section on future action highlights the areas in which further measures might be taken and is the basis for discussion and comments. Although no firm proposals are made this document is accompanied by a **partial regulatory impact assessment** to assist consultees in forming a viewpoint on the different areas. When a dioxins strategy is developed, on the basis of the consultation, a full regulatory impact assessment will be conducted.

1. Introduction

1. This paper reviews and assesses the current state of knowledge on the group of toxic chemicals known as 'dioxins' – polychorinated dibenzo-*para*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) – and 'dioxin-like' polychorinated biphenyls (PCBs) in the UK environment. An assessment is made of the effectiveness of the control measures put in place to reduce environmental and human exposure, and the background and context for the development of UK dioxins policy is provided. Unless specified otherwise the term 'dioxins' is used in this report to include PCDDs and PCDFs.

2. Dioxins are ubiquitous pollutants produced in small quantities in most combustion processes and as by-products in some industrial chemical processes. They are persistent and found in all environmental compartments. Concern about the effects of dioxins arose initially from their high acute toxicity in some species of laboratory animals and because of the clinical effects (chloracne) of human exposure to one particular dioxin (2,3,7,8-TCDD) in industrial accidents. Some dioxins substituted in the 2,3,7,8 positions have been shown to have a range of adverse toxicological effects in laboratory animals including on the immune system, reproduction and development and cancer. Some dioxins have been listed as putative hormone (endocrine) disrupters.

3. PCBs were manufactured for use in a wide range of applications between the 1930s and mid-1970s. At that time they were considered to be safe and were popular because of their extreme thermal, electrical and chemical stability. We now know that these same properties make PCBs extremely persistent in the environment and that they may bioaccumulate in fatty tissues in humans and animals. Some PCB congeners[1] have the potential to exhibit similar toxicological effects to 2,3,7,8-TCDD.

1.1 Background

4. In 1989 the Government published Pollution Paper No. 27 entitled 'Dioxins in the Environment'[2], the report of an Interdepartmental Working Group on Dioxins. This gave a broad introduction to dioxins including physical and chemical properties, behaviour in the environment, uptake into the food chain and subsequent human exposure. Pollution paper No. 27 also included advice from the independent advisory Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT) on the toxicity of dioxin and recommended tolerable daily intakes. The related toxicity of the dioxin-like PCBs was not recognised at that time and therefore they were not included in the report.

5. Pollution Paper No. 27 established a framework for policy on dioxins which consisted of the following three elements:

   - to identify and control sources of dioxins;
   - to monitor levels in the environment and establish the levels of human exposure; and
   - to keep the assessment of the adverse health effects up-to-date.

6. Since 1989 a great deal of research has been carried out on dioxins and a number of significant changes have been made at international, national and local level to reduce

[1] A congener is a specific compound in a family of structurally related chemicals.
[2] Dioxins in the Environment, Pollution Paper 27, HMSO, 1989.

emissions and human exposure to these compounds. Emissions have been reduced by regulatory action as well as changes to infrastructure and industrial practices.

1.2 Scope of the paper

7. This paper reviews the current state of knowledge on dioxins and dioxin-like PCBs, the effects of regulatory actions taken to date and, in the light of recent changes in the assessment of the toxicology of these compounds, assesses the success of the existing policy measures. It also seeks to place the UK position on dioxins in an international context. The need for additional measures to reduce the levels of these substances in the environment and food is considered, and proposals for future action are made.

1.3 Structure of the paper

8. The format is designed to reflect the three strands of UK Government policy outlined in Pollution Paper No. 27 (1989)[2] and is set out in Diagram 1. Section 8 on future action needs to be considered in the light of both the preceding sections and the partial regulatory impact assessment.

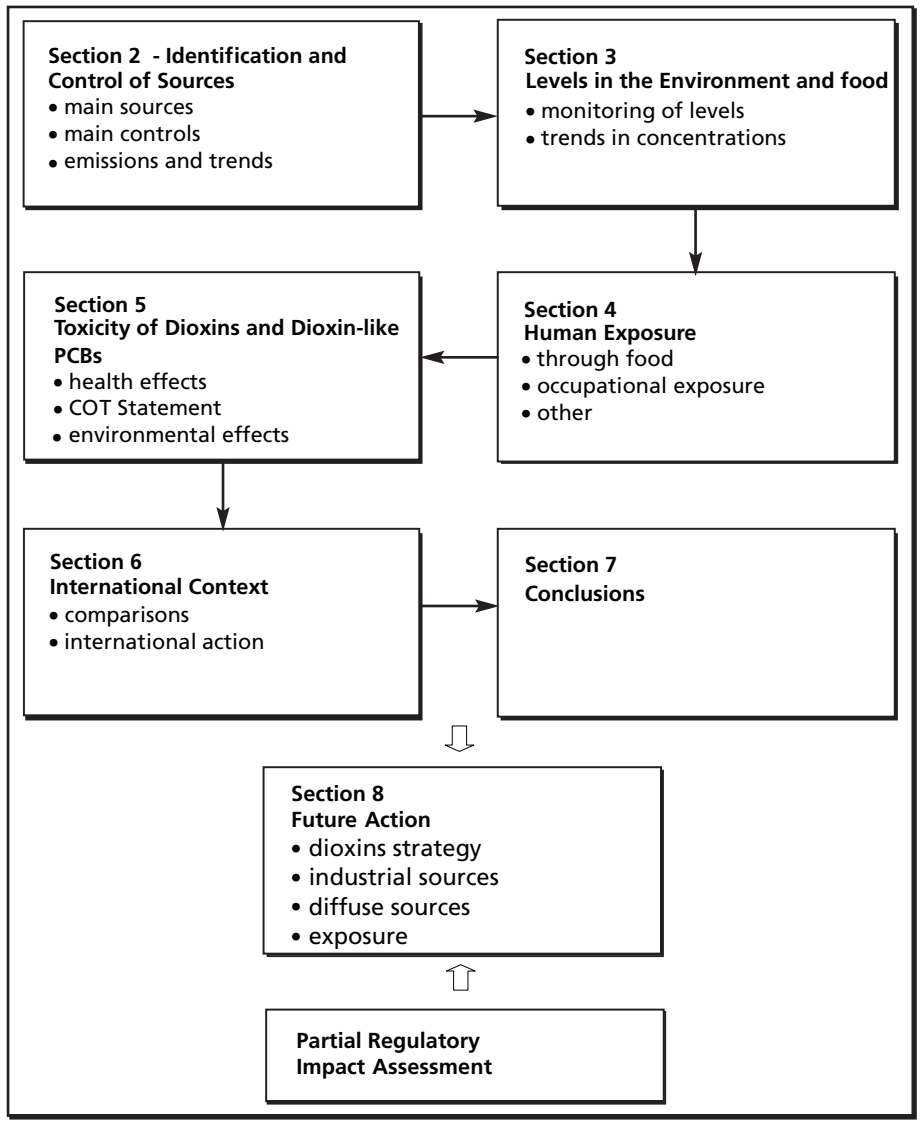


Diagram 1

2. Identification and Control of Sources

2.1 Toxic equivalency and terminology

9. Dioxins and dioxin-like PCBs are families of structurally related compounds. Details of their chemical structures (see Annex 1) and properties have been widely published[2,3]. Dioxins and dioxin-like PCBs are never found as individual congeners but occur as complex mixtures with only some congeners exhibiting 2,3,7,8-TCDD-like toxicity. In order to simplify the handling of data on these compounds and to give a single measure of the toxicity of a sample, various systems for weighting the amounts of individual congeners in a mixture have been used. These 'toxic equivalency' schemes provide a series of factors that are applied to the measured concentrations of each congener of interest to give a measure of overall toxicity of a mixture. The toxic equivalent concentration (TEQ) is broadly the amount of 2,3,7,8-TCDD that would give the same overall effect.

10. The most widely used system until recently was that proposed by the North Atlantic Treaty Organisation, Committee on Challenges to Modern Society (NATO/CCMS) in 1988 which gives factors for the 17 dioxin and furan congeners with 2,3,7,8-TCDD-like toxicity. The results are often quoted as I-TEQ to denote International Toxic Equivalent.

11. Several systems of toxic equivalence factors (TEFs) have been compiled for the 'dioxin-like' PCBs. The most widely used, and that adopted by the UK in 1997, was recommended by the World Health Organisation (WHO) European Centre for Environment and Health/ International Program for Chemical Safety (ECEH/IPCS) task force in 1994[3].

12. In 1997 the WHO held an expert meeting that proposed a revised scheme of TEFs for dioxins and dioxin-like PCBs[4]. This scheme was adopted in the UK by COT and is likely to be more widely adopted internationally. This new WHO-TEF scheme differs slightly from the I-TEF scheme for dioxins and from the previous scheme for PCBs (see Annex B). For the purposes of this paper only those dioxins and dioxin-like PCBs assigned TEFs by the WHO in 1997 have been included. The WHO-TEF scheme adopted by the COT is used in preference in this paper. However, since the scheme is relatively new and many data are still reported using the I-TEF scheme, this is noted where it occurs in the text. We regard all such schemes as giving indicative values for use in regulation and risk assessment, not as definitive measures of toxicity.

2.2 Dioxins

2.2.1 Sources

13. Dioxins have never been produced intentionally, other than in very small quantities for laboratory-scale research, but they may be found as trace by-products from a number of industrial and non-industrial processes. The mechanisms by which dioxins may be formed in these processes were reviewed in Pollution Paper No. 27 (1989)[2] and advances in

[3] Ahlborg *et al*. (1994). Toxic equivalency factors for dioxin-like PCBs. Report on a WHO-ECEH and IPCS consultation, December 1993. *Chemosphere*, **28**, No 6, 1049–1067.

[4] Van den Berg *et al*. (1998). Toxic Equivalency Factors (TEFs) for PCBs, PCDDs, PCDFs for Humans and Wildlife. *Environmental Health Perspectives*, **106**, No 12.

understanding the formation mechanisms have been published in the scientific press[5,6]. The processes that produce dioxins as by-products can be classified as follows:

- **combustion processes** – all forms of combustion, both industrial and domestic, may release dioxins if chlorine is present, even in trace quantities. This includes the incineration of wastes (including municipal, medical and hazardous wastes), the combustion of solid and liquid fuels including coal, oil and wood both on a large-scale, such as in electrical power generation, and on a small-scale in domestic stoves and fires, and a range of other combustion processes such as garden-refuse burning, bonfires and accidental fires;
- **other thermal processes** such as those used in the processing of metals, including sinter plants, electric arc furnaces, and non-ferrous metals processing;
- **certain chemical production processes** such as the production of polychlorinated aromatic pesticides and herbicides eg 2,4,5-trichlorophenoxy acetic acid (2,4,5-T) and pentachlorophenol (PCP); the production of chlorinated phenols; and in the oxychlorination of mixed feeds to make certain chlorinated solvents and vinyl chloride;
- **reservoir sources** – soils and sediments which have been contaminated in the past may release low concentrations back into the atmosphere over extended periods of time;
- **natural formation** – there is some evidence of natural formation of dioxins from some biochemical processes such as in compost or in the gut of cows. Theories of geochemical formation have been expounded following the discovery of unusual patterns of dioxins in clays and sediments from Germany, US and Australia[7,8]. The contribution to overall emissions from natural sources is unknown.

14. These sources can be categorised into large-scale industrial processes regulated by the environment Agencies under Integrated Pollution Control (IPC) or Pollution Prevention and Control (PPC); smaller-scale industrial processes regulated by local authorities and, in Scotland, the Scottish Environment Protection Agency under Local Air Pollution Control (LAPC); and a range of other processes which do not fall under either system of regulation. The last category is diverse and includes some smaller industrial processes, vehicle traffic, the use of pesticides, accidental fires, the burning of rubbish or garden waste by householders and natural events such as forest fires.

15. The 2001 outbreak of foot and mouth disease in the UK resulted in the disposal of many carcasses of slaughtered livestock. Where this was not possible by rendering or incineration, open burning on pyres was used for carcasses over 5 years of age and for younger cattle and sheep that could not be disposed of in landfill or other burial sites. As with the burning of any organic material this will have contributed to the UK emission of dioxins and the Government has undertaken considerable work to estimate quantities released and to provide advice to enable people to minimise their exposure. This was done by modelling emissions and monitoring of levels around pyres. Results from this monitoring are published on the Food Standards Agency web-site (www.foodstandards.gov.uk). Levels of dioxins in soil, herbage and food were mostly within the expected range and/or similar to levels at

[5] R Addink and K Ollie. (1995). Mechanisms of formation and destruction of polychlorinated dibenzo-p-dioxins and dibenzofurans in heterogeneous systems. *Environ. Sci. Technol.*, **29**, 1425–1435.

[6] K Tuppurainen, I Halonen and P Ruokojarvi. (1998). Formation of PCDD/Fs in municipal waste incineration and its inhibition mechanisms: A review. *Chemosphere*, **36**, 1493–1511.

[7] R Alcock, K Jones, M McLachlan, A Johnston. (1999). Response to comment on ''Evidence for the presence of PCDD/Fs in the environment prior to 1900 and further studies on their temporal trends''. *Environ. Sci. Technol.*, **33**, 206–207.

[8] N Green, J Jones, A Johnston & K Jones. (2001). Further evidence for the existence of PCDD/Fs in the environment prior to 1900. *Environ. Sci. Technol.*, **35**, 1974–1981.

control farms. Advice on foot and mouth disease is published on the DEFRA web-site (www.defra.gov.uk/footandmouth) and guidance on public health aspects has been published by the Department of Health (www.doh.gov.uk/fmdguidance/).

2.2.2 Controls

16. A number of important measures have been put in place to control the release of dioxins to the environment. The most significant include the following:

- **Controls on industrial processes**

17. Emissions from major industrial processes are controlled under the Environmental Protection Act (EPA) 1990 and the systems of IPC – which is progressively being replaced by the Pollution Prevention and Control Regulations which implement Integrated Pollution Prevention and Control (IPPC) Directive 96/61/EC[9] – and Local Air Pollution Control (LAPC). Specific controls are in place for several processes which have resulted in significant reductions in dioxins emissions, in particular from municipal solid waste (MSW) incineration plants. In 1996 these incinerators became subject to stricter controls on their emissions, with a limit of 1.0 nanogram I-TEQ per cubic metre of gaseous releases being set, and resulted in the closure of many of the older incinerators which could not be satisfactorily upgraded. Emissions from municipal waste incinerators, which were the major source of dioxins release to air in the UK with around 600 g I-TEQ per year in 1990, have been reduced to around 2 g I-TEQ per year in 1999, less than 1% of total UK releases.

18. An even stricter emission limit of 0.1 nanogram I-TEQ per cubic metre of gaseous releases will be introduced for waste incinerators under the Waste Incineration Directive 2000/76/EC which was adopted in December 2000. This will apply to all new municipal waste incinerators by 28 December 2002, and to existing plant by 28 December 2005, although the Environment Agency and SEPA consider that most current installations can already meet these requirements without excessive cost and therefore applies these standards as a *minimum* requirement. The Agency intends to review the performance of existing plant before the Directive applies. SEPA is of the view that, for all new plant, the best available technique should generally be regarded to be the requirements of the Waste Incineration Directive.

19. The Waste Strategy for England and Wales published in 2000[10] has indicated the possible need for a greater reliance on incineration with energy recovery for municipal waste management and to cope with the introduction of the Landfill Directive 1999/31/EC which will result in a move away from landfill as a disposal option. ''*Wise about Waste: the National Waste Strategy for Wales*'', published in June 2002, similarly indicated that local authorities may wish to consider incineration of waste with energy recovery as an alternative to landfill for the disposal of residual waste, following discussions with their local communities and once alternatives such as reducing waste, recycling and composting, etc. have been implemented. Concern has been expressed that a greater number of incinerators with energy recovery will be built in the UK and that this could lead to increases in emissions of dioxins. However, as already indicated, the emission limits on new incinerators are very stringent and this means additional releases will be low. Releases from each proposed plant will be assessed on a case by case basis and the overall effect will be monitored and controlled.

[9] Pollution Prevention and Control (England and Wales) Regulations 2000. SI 1973; Pollution Prevention and Control (Scotland) Regulations 2000. SSI 323.

[10] Waste strategy 2000 for England and Wales published by the former DETR is available on the DEFRA web-site.

20. EPA 1990 and the IPC regime has resulted in overall process controls for a range of other industrial sources including metal processing plants, power stations and chemical manufacturing processes. It has been estimated that releases from these processes have reduced from 212 g I-TEQ in 1990 to 81 g I-TEQ in 1999. The Environment Agency continues to work with these industrial sectors to identify where further reductions can be achieved.

- **Controls on accidental fires and open agricultural burning**

21. The cessation of most agricultural burning such as stubble and straw burning has greatly reduced a major source of uncontrolled combustion so that accidental fires are now considered to account for the majority of emissions from this source sector. The release of dioxins from accidental fires and other uncontrolled sources can only be estimated from published figures, however given their significance (estimated to be around 20% of annual emissions) a study has been commissioned to investigate releases from such sources to assist in the development of emission factors and activity statistics for the National Atmospheric Emissions Inventory[11].

- **Marketing and use controls**

22. Controls on the marketing and use of certain chemicals that had been found to be contaminated with dioxins have been put in place. These include PCBs- containing oils, the herbicide trichlorophenoxyacetic acid (2,4,5-T) and the wood preservative pentachlorophenol (PCP).

- **Controls on vehicular emissions**

23. The use of lead in petrol required the addition of 1,2-dichloroethane scavengers which contributed to emissions of dioxins in vehicular exhaust fumes. The removal of lead from petrol and the general move to unleaded fuel has reduced emissions from this sector from around 28 grams I-TEQ per year in 1990 to less than 4 grams I-TEQ per year in 1999, around 1% of total UK releases[11].

- **Others**

24. Other reductions have occurred as a result of changed industrial and non-industrial practices which were not brought about primarily to reduce emissions of dioxins, for example the reduction in the use of coal both industrially and to heat domestic premises.

25. As the major identified sources of dioxins are controlled or eliminated by regulatory controls and process changes the smaller, more diffuse, and harder to control sources start to assume greater significance. As an example, studies in the USA have shown that the combustion of domestic rubbish in barrels (akin to burning rubbish in a dustbin) may release high levels of dioxins, of the order of 1000 g I-TEQ per year[12]. UK studies[13,14,15] also indicate that the atmospheric concentration of dioxins increases dramatically during the period of the 5th November 'Bonfire Night' celebrations with the estimated release of dioxins due to bonfires and fireworks being up to around 14% of total UK annual emissions. Identifying and controlling these small diffuse sources is likely to be more difficult than has been the case so far in tackling large industrial point sources.

[11] UK Emissions of air pollutants 1970–1998: a Report of the National Atmospheric Emissions Inventory. Goodwin *et al*, DETR Report 2000.

[12] 'The Inventory of Sources of Dioxins in the United States', REVIEW DRAFT, US EPA 1998.

[13] Alcock R, Gemmill R and Jones K. (1998). Improvements to the UK PCDD/PCDF and PCB atmospheric emissions inventory following an emissions measurement programme. *Chemosphere,* **38**, 759–770.

[14] P Dyke, P Coleman & R James. (1997). 'Dioxins in Ambient Air, Bonfire Night 1994', *Chemosphere,* **34**, vol 5–7.

[15] R G M Lee, N J L Green, R Lohmann & K C Jones. (1999). Seasonal, Anthropogenic, Air Mass and Meteorological Influences on the Atmospheric Concentrations of PCDD and PCDF: Evidence for the Importance of Diffuse Combustion Sources. *Environ. Sci. Technol.,* **33**.

2.2.3 Emissions and trends

26. In 1993 an inventory of UK dioxins sources was produced for Her Majesty's Inspectorate of Pollution (HMIP)[16] which considered a range of IPC regulated and non-IPC regulated industry and non-industry sources and was the basis for the UK entry in a European inventory of sources compiled on behalf of the European Commission[17].

27. Annual estimates from 1990 onwards of dioxins released from IPC regulated industry, non-IPC regulated industry and non-industry sources in the UK are published in the National Atmospheric Emissions Inventory[18]. In addition, the Environment Agency's Pollution Inventory reports annual dioxin emissions from IPC regulated industries in England and Wales (www.environment-agency.gov.uk). The NAEI indicates that total UK emissions of dioxins were 345 g I-TEQ during 1999 and in the same year releases from Environment Agency regulated IPC processes in England and Wales totalled 85 g I-TEQ. These inventories estimate only releases of dioxins to the atmosphere as these are considered to be most likely to have an impact on human exposure. An inventory for IPC processes in Scotland is currently being produced. In Northern Ireland data are collected against the same substance list as in England and Wales.

28. Any comparison of data from the Pollution Inventory and NAEI should be treated with caution as they are compiled in different ways. The Pollution Inventory uses data submitted annually by operators of Agency regulated IPC-processes in England and Wales whereas the NAEI is based upon emission estimates for industrial processes for the whole of the UK and includes smaller non-IPC regulated processes and non-industrial processes. Inventories indicate that the major sources to air of dioxins in the UK in 1999 were metal processing and accidental fires (Figure 1). Emissions from these have already been reduced, as indicated in the control section.

29. The inventory of dioxin releases to land and water, published by the Environment Agency in 1997[19] was among the first to be produced anywhere. The inventory was based upon emission estimates for 1993 and at that time releases to land were put in the range 1,500–12,000 grams I-TEQ per year, the bulk of which was in material that was disposed of to landfill. Estimation of releases to land has received very little attention and this range was, therefore, large because the data were uncertain. Major contributions to land were thought to have come from the use of pentachlorophenol which may have been contaminated with low levels of dioxins (especially in imported goods) and the disposal of incineration residues to specially designed landfills. Releases to water were even more difficult to estimate and more information is needed to assess sources of exposure to this medium reliably.

30. **Figure 1** shows how the contribution to overall emissions from the different source sectors has changed between 1990 and 1999. **Figure 2** shows overall trends in releases from each major source category and how total releases of dioxins to air have reduced since 1990. The overall impact of control measures is hard to assess with accuracy but it has been estimated that overall UK emissions have been reduced by around 70% between 1990 and 1999[11]. A general decline in human exposure from food has also been demonstrated (see Section 5) giving some indication of the effectiveness of the measures taken.

[16] A Review of Dioxins Emissions in the UK, DOE/HMIP/RR/95/004, 1995, also G H Eduljee and P H Dyke. (1996). 'An updated inventory of potential PCDD and PCDF emission sources in the UK'. *Science of the Total Environment*, **177**.
[17] Identification of Relevant Industrial Sources of Dioxins and Furans in Europe, Landesumweltamt Nordrhein Westfalen, 1997.
[18] National Atmospheric Emissions Inventory (www.naei.org.uk).
[19] A review of dioxin releases to land and water in the UK (1997) Environment Agency R&D Publication 3.

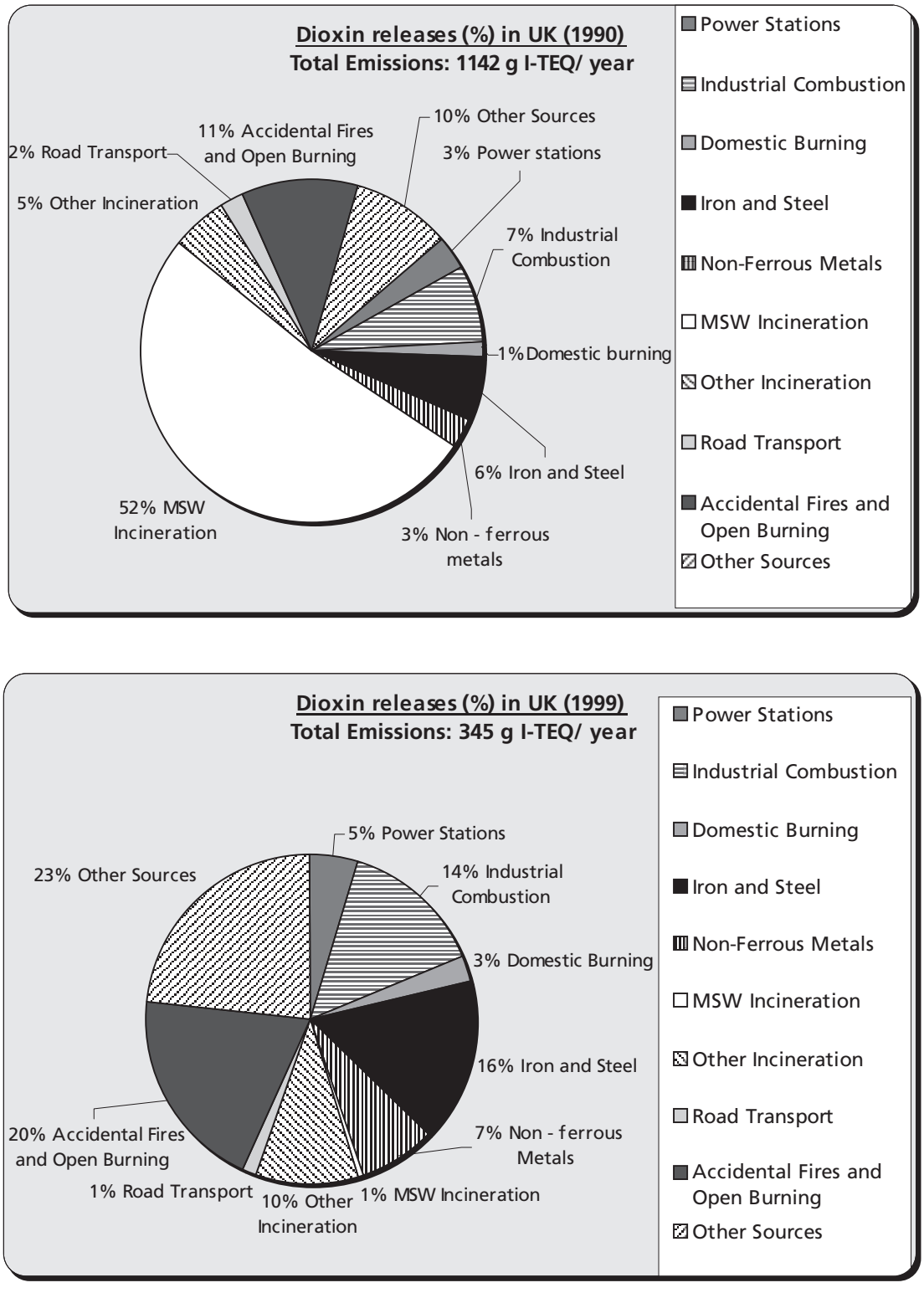


Figure 1: UK dioxin emissions to air (1990 and 1999).

31. As already indicated, the most significant reductions have been brought about by increased controls on industrial processes through introduction of IPC, with the latest figures for IPC processes in England and Wales for 1999 (85 g I-TEQ/annum) indicating that releases from this sector have continued to decrease. Contributions from non-IPC processes or domestic sources have not shown a similar level of decline and therefore their relative contributions to total UK emissions have increased.

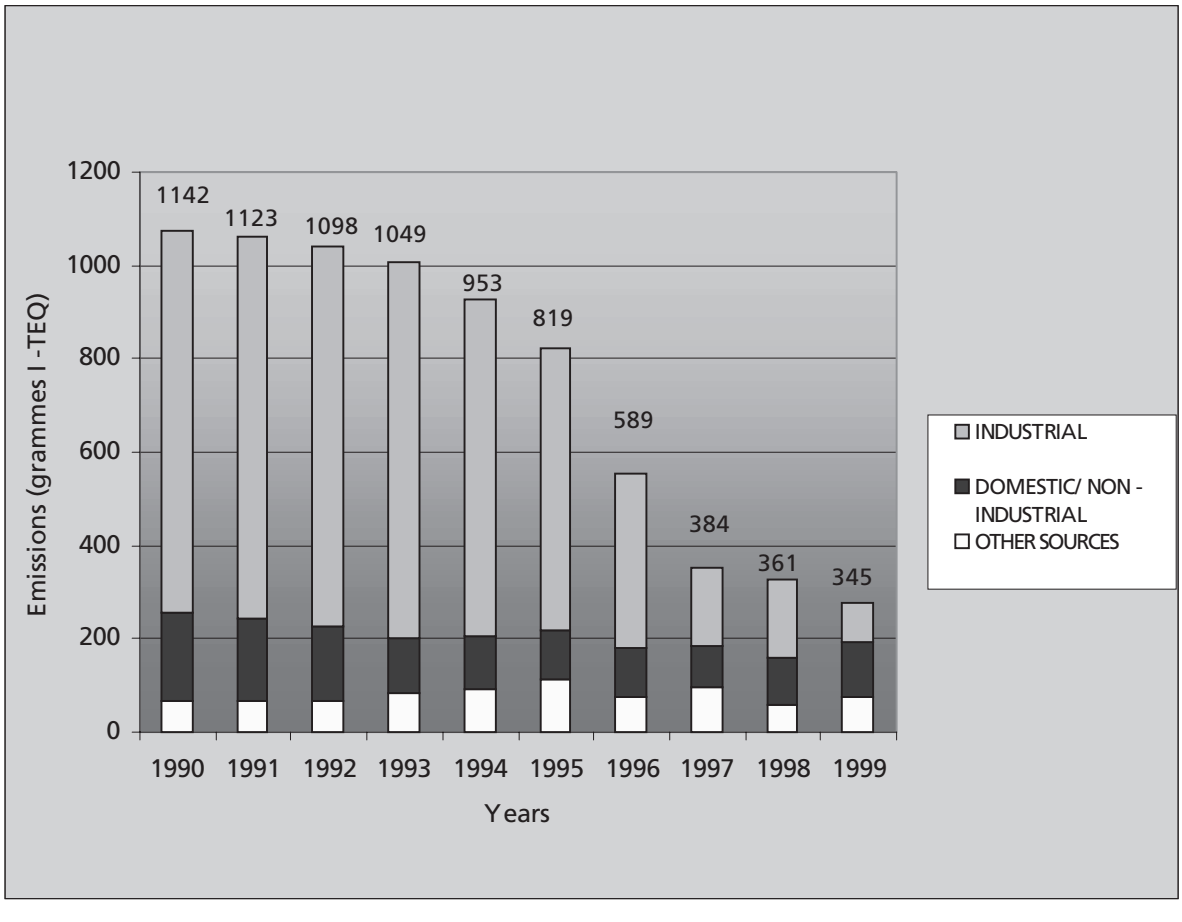


Figure 2: Trends in dioxins emissions to air in UK (grammes I-TEQ per year). From NAEI data for 1990 to 1999[18].

2.3 PCBs

2.3.1 Sources

32. In contrast to dioxins, PCBs were manufactured in large quantities and found a wide range of applications due to their high thermal, chemical and electrical stability. They were first produced commercially around 1930 and approximately 66,500 tonnes were manufactured in the UK between 1951 and 1976[20]. Of this, around 27,000 tonnes were exported to other countries where it would have been used in a range of products. There are no figures available on quantities of PCBs imported into the UK. Commercial PCBs were manufactured by the direct chlorination of biphenyl leading to the production of oils containing mixtures of PCB congeners with between 21% and 60% chlorine. Commercial PCB mixtures were sold under a variety of trade names, the most common in the UK being the 'Arochlor' range. While this paper focuses on only those PCB congeners with 'dioxin-like' properties, sources will release a range of congeners, many of which will not possess such properties.

33. Prior to the mid-1970s PCBs were used in a wide range of applications, including the following:

- **'closed' uses of PCBs** – in the UK around 14,000 tonnes of PCBs were used in the manufacture of sealed electrical equipment such as capacitors, transistors and electrical switching gear. It has been estimated that around 2,000 tonnes of PCBs were exported

[20] Department of the Environment, Waste Management Paper No 6 – Polychlorinated Biphenyls, HMSO, 1994.

inside such equipment. It was estimated by the UK hazardous waste incinerator operators in the mid-1990s that around 4,500 tonnes of the PCBs used in closed applications had already been destroyed leaving around 8,000 tonnes of PCBs still sealed inside electrical equipment. This could be contained within around 40,000 to 50,000 tonnes of waste oil inside up to 450,000 large capacitors and around 800 medium and large transformers. Smaller capacitors, containing just a few grams each of PCB, will remain in electrical appliances such as fridges and strip-lighting;

- **'open'-uses of PCBs** – around 25,000 tonnes of PCBs were used in a diverse range of products such as carbonless-copy paper, as a plasticiser in some plastics manufacture, in most coating and covering applications including paints and varnishes, in many building materials including sealants, in some pesticides and herbicides and, at one time, in chewing gum. The open use of PCBs ceased in the 1970s, although it is possible that some products such as building sealants may still be in place in older properties. A significant amount of the PCBs in the environment will have arisen from the past use of these products.

Releases to the environment will also occur from:

- **reservoir sources** – PCBs will be released to the atmosphere from historically contaminated soils or sediments or from landfills which may contain PCB from previous disposal of electric appliances. Some measurements indicate that release of 'historic' PCB back into the environment may be the most significant contribution to the current atmospheric burden in the UK[21];
- **industrial and non-industrial combustion processes** –PCBs may be formed as a trace by-product during combustion processes in a similar manner to dioxins, although this is uncertain. The relative importance of these sources is not fully understood and the Environment Agency has initiated work to improve knowledge in this area by monitoring for PCBs in the stack emissions from some industrial processes.

2.3.2 Controls

34. The sale of PCBs for use in open applications was prohibited in 1972 and their manufacture and use in new plant and equipment were prohibited in 1986 under the *Control of pollution (supply and use of injurious substances) Regulations 1986* (SI 1986 No. 902) as amended. Since that time the only remaining uses have been PCBs sealed inside older existing equipment.

35. Council Directive 96/59/EC requires the phasing out of remaining identifiable PCBs no later than 2010, although as a signatory to the 1990 North Sea Treaty, the UK has agreed to act much earlier than this. The *Environmental Protection (Disposal of Polychlorinated Biphenyls and Other Dangerous Substances) (England and Wales) Regulations 2000* (SI 2000 no.1043) came into force on 4 May 2000 to implement the provisions of the PCB Directive. The equivalent Northern Ireland Regulations are *The Environmental Protection (Disposal of Polychlorinated Biphenyls and other Dangerous Substances) Regulations (Northern Ireland) 2000*.

36. These required holders of PCBs to register any contaminated equipment (including any transformer, capacitor or receptacle containing residual stocks) of greater than 5 litres in volume with the Environment Agency or with the Scottish Environment Protection Agency by 31 July 2000. In Northern Ireland registration with the Department of the Environment

[21] Coleman P, Lee R, Alcock R and Jones K. (1997). Observations on PAH, PCB and PCDD/F trends in UK urban air 1991–1995. *Environmental Science and Technology*, **31**, 2120–2124.

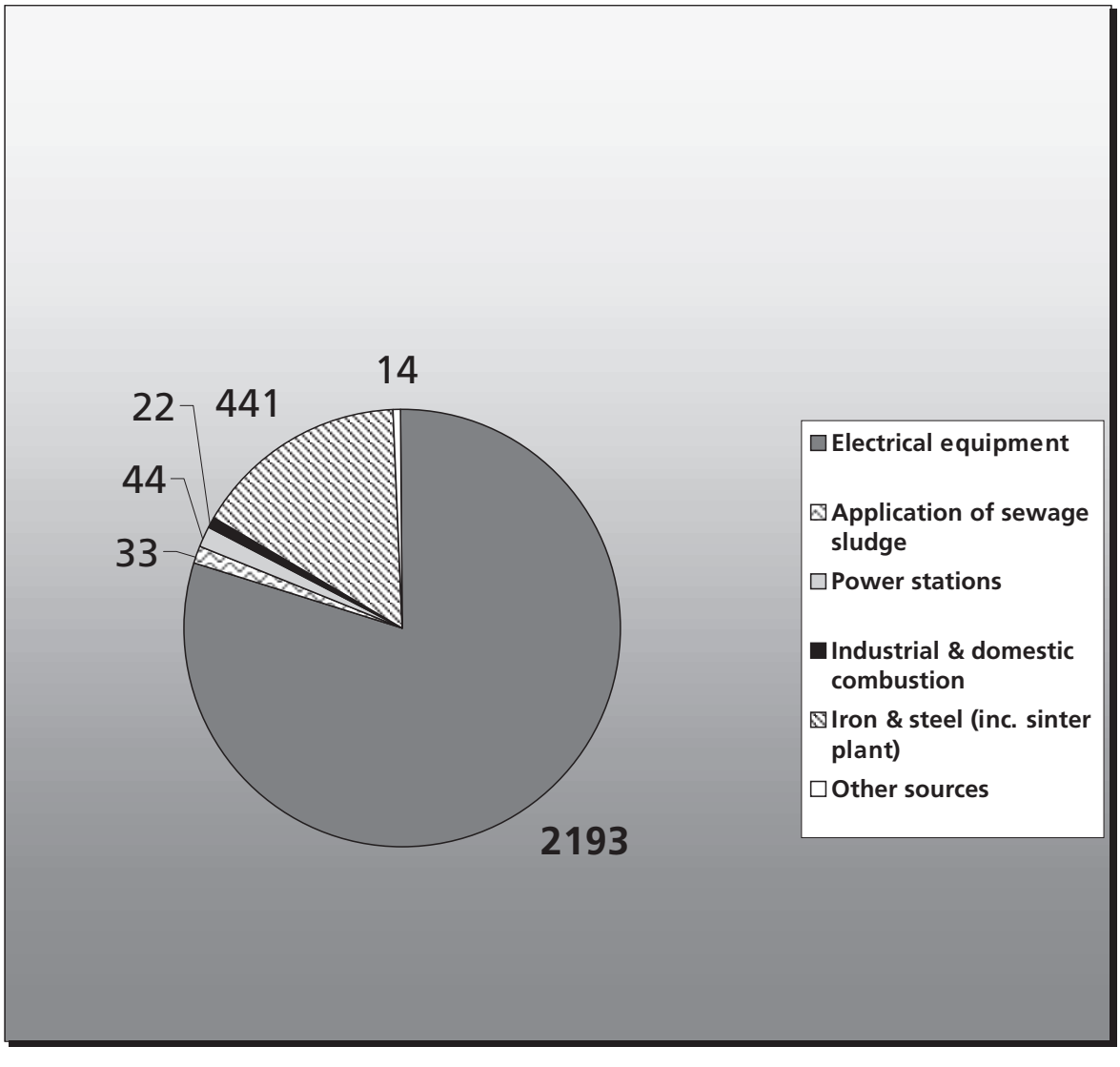


Figure 3: Total PCB released to air in UK in 1998 (kg) taken from NAEI estimates (2000).

was required by 31 October 2000. In addition, actions were required to label such equipment and to make arrangements for final disposal (at one of the UK waste management facilities licensed to handle PCBs) or decontamination of PCB holdings by 31 December 2000 or by 31 March 2001 in Northern Ireland.

37. Electrical transformers may be held until the end of their useful life once registered, provided they are decontaminated or contain less than 500 parts per million of PCBs. However these too must be disposed of prior to 2010. Equipment of less than 5 litres should still be collected and removed separately when they are taken out of service so that safe disposal can be achieved. The PCB Directive does not cover concentrations of less than 50 parts per million of PCBs.

38. The environment Agencies now hold registers of all remaining PCB holdings in the UK which is available on request from local Agency offices. An initial review of the register showed that 320 companies had registered their equipment and the total number of holdings is more than 43,000 items accounting for a rough estimate of 1,200 tonnes of PCB. This is less than the anticipated remaining volume but it has not yet been possible to verify the figures. These registers will allow more accurate inventories of PCB sources to be produced.

39. As already indicated, this paper only addresses PCB congeners that are classified as 'dioxin-like' but any action to control the release of PCBs would include all congeners.

2.3.3 Emissions and trends

40. Inventories of PCB emissions are usually reported as total PCBs and include those congeners which do not exhibit dioxin-like activity. Emission inventories for PCBs were produced for DETR in 1995[22] and extended to address all media in 1997[23]. Both were based on activity statistics for 1993. The main sources are shown in **Figure 3** (note that this figure includes all congeners not just dioxin-like PCBs). PCB inventories are very uncertain as accurate data are limited and it is not possible to provide values in terms of WHO-TEQ because congener specific data are not available. However it was estimated that in 1993 around 6,000 kilograms of total PCBs were released to the environment with the largest on-going sources judged to be leaks from electrical transformers and capacitors still in use and the fragmentising and disposal of scrap metal.

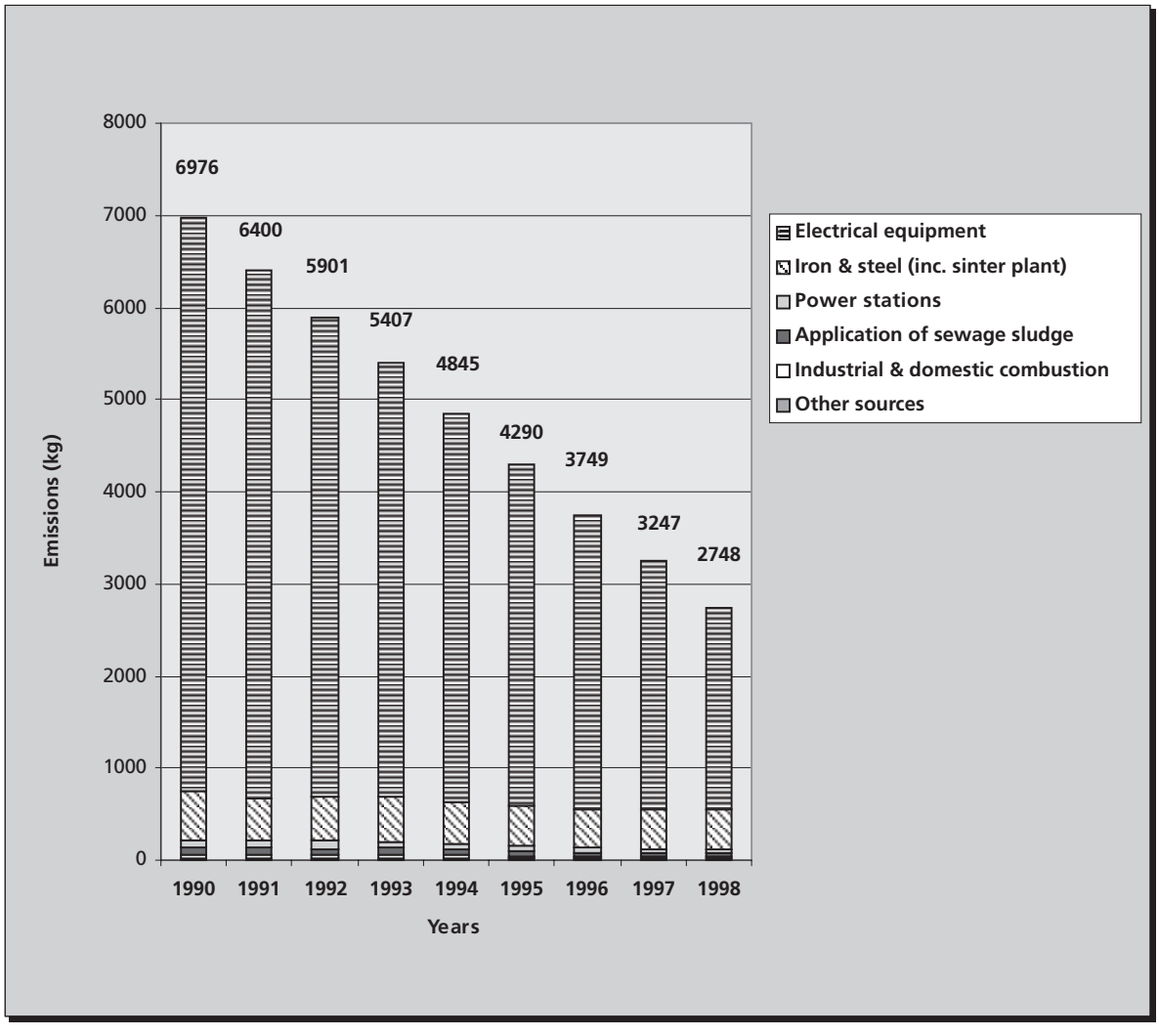


Figure 4: Trends in total PCB emissions in the UK for 1990 to 1998 from NAEI[9].

[22] Report on the Abatement of Toxic Organic Micropollutants (TOMPs) from Stationary Sources, AEA Technology 1995.
[23] Dyke P & Stratford J. (1998). Updated Inventory of PCB Releases in the UK. *Organohalogens*, **36**.

41. Further study is needed to gain a better estimate of all sources[24]. As indicated above, information on the number of electrical transformers and capacitors remaining in existence is now held by the environment Agencies because holders of such equipment were required to register it under the EC PCB Directive. Secondary releases of historically released PCBs are not included in emission inventories but are considered to contribute significantly to overall releases.

42. Estimates of PCB emissions in the UK between 1990 and 1998 have been published in the National Atmospheric Emissions Inventory[18]. The estimates assumed a steady phasing-out of PCB containing equipment during this period. Since 1999 speciated data have been incorporated into the emission estimates which will allow reporting of the 'dioxin-like' PCBs as WHO-TEQ. A summary of the NAEI data is shown in **Figure 4**.

43. This shows that estimated emissions of PCBs into the environment have decreased steadily for the last decade. It may be anticipated that this trend will continue especially in light of the phase-out of remaining PCB equipment. Environmental concentrations of PCBs reflect a combination of on-going releases and redistribution of previously released pollutants although in many places the general background is dominated by the latter[21].

[24] It is hard to compare estimates of releases of PCB since there is no standard protocol for analysis or reporting of the concentrations.

3. Levels in the Environment and Food

3.1 Concentrations in the environment

44. Low levels of dioxins and PCBs can be detected in all environmental media due to their persistence and ability to disperse widely. A great deal of data in this area now exist with the UK Government and others sponsoring substantial research to assess and monitor environmental levels and assess human exposure. Annex D contains a list of research recently carried out and on-going in this field.

45. Highly sensitive and specific analytical techniques are required when measuring the levels of dioxins in environmental media because of the large numbers of isomers and congeners, and the biological activity of some isomers at low levels. Effective clean-up procedures are also required because the presence of interfering compounds may be significant at such low levels. The result of this is that analysis for dioxins is time-consuming and costly.

46. Research on environmental samples has shown that the results of monitoring are heavily influenced by the nature of the samples taken so it is very important to ensure that study designs take adequate account of this. For this reason it may be inappropriate to compare results from different studies.

47. A report published in October 1999 by AEA Technology for the European Commission and DETR[25] included a collation of data on environmental concentrations of dioxins in Member States. A summary of the information on average levels of dioxins in various environmental media in the UK is shown in Table 1. These data were collected for a limited number of sites and are reported for different years so are not directly comparable and do not necessarily reflect current levels. However, they give some idea of the relative magnitude and range of concentrations observed in the various media, with concentrations in air being orders of magnitude lower than in other media.

48. Air monitoring, supported by DEFRA and the devolved Administrations, produces data from a series of ambient air sampling stations at a number of locations, both urban and rural, across the UK. Data from these stations can be accessed at www.aeat.co.uk\netcen\airqual\data\nonauto\tomps.html.

Table 1: Summary of data on levels of dioxins in various environmental media in the UK (taken from AEAT, 1999[24])

Media	Mean	Min	Max
Soil rural locations	5.2 ng I-TEQ/kg	0.78ng I-TEQ/kg	17ng I-TEQ/kg
Soil urban locations	28 ng I-TEQ/kg	4.9ng I-TEQ/kg	87ng I-TEQ/kg
Air ambient rural	10 fg I-TEQ/m3	1.7 fg I-TEQ/m3	18.3 fg I-TEQ/m3
Air ambient urban	103fg I-TEQ/m3	20 fg I-TEQ/m3	281 fg I-TEQ/m3
Sewage sludge	61ng I-TEQ/kgdw	8 ng I-TEQ/kgdw	192 ng I-TEQ/kgdw
River sediments	16.7ngI-TEQ/kgdw	2 ng I-TEQ/kgdw	123 ng I-TEQ/kgdw

Note: concentrations in air are given in femtogram quantities while those in other media are in nanogram quantities.

[25] Compilation of EU Dioxin Exposure and Health Data, AEA Technology 1999.

49. A UK national soil survey[26] of concentrations of dioxins and PCBs showed a range of concentrations in soils and found a clear distinction between rural and urban sites. It should be noted that since this survey was carried out there have been substantial improvements in analytical methodology for monitoring dioxins and PCBs which now makes this survey rather out-dated. A follow-up survey, funded by the Environment Agency, the Food Standards Agency, DEFRA, the Scottish Executive and the Northern Ireland Department of the Environment to monitor both soil and herbage using modern protocols has recently been commissioned.

50. In general, areas of high intensity industry or of high density population tend to have higher concentrations of dioxins and PCBs in the air and soil. Rivers in such areas are likely to have concentrations in sediments higher than background levels.

51. Certain locations in the UK have been found with high localised contamination, for example around the Coalite Chemical works near Bolsover[27], around some older municipal waste incinerators[28], and near to the chemical plants at Runcorn[29]. In these examples an industrial process has been identified as the likely source and appropriate action taken. Contamination at Bolsover was linked to the operation of a hazardous waste incinerator which has subsequently ceased operation, and the operator was prosecuted by the Environment Agency for failing to use best practicable means to operate the plant. However, elevated dioxin levels remain in the soil at some locations near the plant and in some river sediments downstream. The older technology incinerators have also ceased operation. However, because dioxins and dioxin-like PCBs are persistent some current environmental contamination may be due to practices which are no longer carried out.

3.2 Trends in environmental levels

52. One important aspect of environmental monitoring is that it provides opportunities to examine trends in contamination. Sediments from lakes and oceans have been widely studied in this context as well as archived samples of herbage and soil which were collected and stored under controlled conditions and come from a well understood source or environment.

53. The former Department of the Environment commissioned a review of data on time trends of dioxins, which was published in 1996[30]. This drew on available UK and overseas data to build a picture of changes in environmental concentrations during the last 150 years. Although the findings from sediment studies showed considerable variation in some cases, many North American and some European studies showed contamination rising to a peak in the 1970s and falling thereafter. Testing carried out on archived samples of soil from long term experiments at Rothamsted Experimental Station showed a steady rise in soil concentrations with a trebling of the toxic equivalent concentration of dioxins between 1855 and 1980. Analysis of grass samples showed relatively stable levels from 1861 until about 1950 when levels went up markedly. Levels appear to return to pre-1950 concentrations in the late 1980s. The authors inferred that combustion derived sources had provided a baseline

[26] Determination of PCBs, PCDD and PCDF in UK soils – HMIP 2nd Technical Report, Cox and Creaser, 1995.
[27] Environmental Monitoring of Dioxins and Furans in Air, Deposition and herbage around the Coalite Works, Bolsover, Derbyshire, Environment Agency, undated.
[28] A Study of Dioxins and Furans in Soil around Four Municipal Waste Incinerators in Hampshire, Environment Agency, 1997.
[29] Regulation of Dioxin Releases from the Runcorn operations of ICI and EVC, Environment Agency 1997.
[30] Dioxin Inputs to the Environment: A Review of Temporal Trend Data and Proposals for a Monitoring Programme to Detect Past and Future Changes in the UK, Jones K C & Alcock R E, Lancaster University, 1996.

of contamination throughout the period onto which was added a pulse of contamination from the manufacture and use of chloroaromatic compounds.

54. A further assessment of time trends of both dioxins and PCBs in the environment was carried out by Lancaster University as part of a study to assess the feasibility of making projections for the future trends in human exposure (see Section 4). This showed that PCBs had increased rapidly in the environment as use increased, and decreased when controls were put in place. It has been suggested that we are now seeing a levelling off in the fall of PCB concentrations in the environment which may reflect the recycling of historical releases.

3.3 Concentrations in food

55. The Food Standards Agency (and formerly the Ministry of Agriculture, Fisheries and Food (MAFF)) carries out monitoring of the food supply for dioxins and PCBs. These Total Diet Surveys (TDS) are based on an analysis of retail foods prepared as if for consumption and combined into composite samples representative of a defined food group in amounts reflecting their relative importance in the typical UK diet. The latest available data for Total Diet Survey food group samples taken in 1997 are shown in Table 2. This shows that dioxins and PCBs, which are fat soluble, are generally found in higher concentrations in foods with higher fat content such as meat, fish and milk.

56. In response to a recommendation by the COT in 1989, MAFF also undertook a programme of measurement of dioxins and PCBs in cows' milk from individual farms around potential sources to establish whether adverse impacts were occurring. Cows' milk was selected since this is a good indicator of general environmental levels as it responds rapidly to changes in air and vegetation concentrations of pollutants, and is consumed by a large section of the population. None of the results indicated a public health risk but follow-up studies were

Table 2: Concentrations of dioxins and dioxin-like PCBs in Total Diet Survey food group samples taken in 1997

Food Group	Concentration (nanogram WHO-TEQ per kilogram of fat)		
	Dioxin	Dioxin-like PCB	Total TEQ
Carcass meat	0.80	1.07	1.87
Offals	6.29	2.47	8.76
Meat products	0.77	0.61	1.38
Poultry	1.01	1.31	2.32
Fish	2.40	4.53	6.93
Oils and fats	0.44	0.36	0.80
Potatoes	0.53	0.17	0.70
Milk	0.83	0.74	1.57
Milk products	1.12	0.88	2.00
Eggs	0.77	0.64	1.41
Misc cereals	0.43	0.38	0.81
Bread	0.74	0.28	1.02
Nuts	0.44	0.13	0.57
Sugar/preservatives	0.97	0.33	1.30
Fruit products	0.008	0.002	0.010
Green vegetables	0.002	0.002	0.004
Other vegetables	0.012	0.005	0.017
Canned vegetables	0.009	0.004	0.013
Fresh fruit	0.014	0.005	0.019

Note: Fruit and vegetables have a negligible fat content so for these items the data presented is on a fresh weight basis.

undertaken where unusual or unexpected results were found. Results of these surveys are available on the Food Standards Agency website[31].

57. Similar programmes in other parts of Europe have identified particular incidents of contamination. In 1997 elevated levels of dioxins in cows' milk in Germany were traced to contaminated animal feed prepared using citrus pulp pellets imported from Brazil and the European Commission quickly imposed a limit on the maximum contamination in imported pellets (Directive 98/60/EC). The authorities in Brazil have taken measures to eliminate the primary source of contamination which was identified as a supply of industrial lime from a single supplier[32].

58. In 1999 high levels of dioxins and PCBs were found in food in Belgium after the authorities were alerted by poisonings of poultry on some farms. In order to limit exposure controls were placed on the movement of live animals, birds and hatching eggs, as well as on the export and sale of a range of Belgian products including eggs, poultry meat, pork, beef and derived products. A series of measures were also put in place by the European Union designed to ensure that no further contamination of the food supply would occur. The contamination was traced to a small quantity of PCB transformer oil (under 40 litres) entering an animal feed production facility along with recycled cooking oils. The total amount of dioxin involved has been estimated to be around 1 gram I-TEQ[33].

3.4 Trends in levels in food

59. Concentrations of dioxins and dioxin-like PCBs in Total Diet Survey (TDS) food group samples taken in 1997 can be compared to those found in 1982 and 1992 samples. Some selected data for the more significant food groups are given in Table 3. The full dataset is available in the Food Standards Agency Food Surveillance Information Sheet number 4/00 (September 2000).

60. Table 3 shows that, in general, there has been an overall decline in concentrations. Looking at this data in more detail, concentrations of dioxins were generally lower in most food groups in 1997 than those found in 1992 and 1982. This is most noticeable in the poultry, offals, milk

Table 3: Combined dioxin and dioxin-like PCB concentration in selected TDS food group samples from 1982, 1992 and 1997

Food group	Concentration (nanogram WHO-TEQ per kilogram of fat)		
	1982	1992	1997
Carcass meat	5.04	2.01	1.87
Offals	19.05	13.21	8.76
Poultry	8.18	2.74	2.32
Fish	17.07	7.75	6.93
Milk	7.88	3.61	1.57
Eggs	11.12	2.91	1.41

[31] MAFF Food Surveillance Information Sheets – http://www.foodstandards.gov.uk/maff/archive/food/infsheet/index.htm see for example – No. 44, October 1994, No. 100, June 1997, No. 107, June 1997, No. 123, August 1997.

[32] Carvalhaes C, Brooks P & Krauss T. (1999). Lime as the source of PCDD/F contamination in citrus pulp pellets from Brasil. *Organohalogens,* **41**, p 137.

[33] A Bernard, C Hermans, F Broeckaert, G De Poorter, A De Cock, G Hounis. (1999). Food contamination by PCBs and dioxins – an isolated episode in Belgium is unlikely to have affected public health. *Nature,* **401**, 231–232.

and eggs food groups. This reflects the corresponding decrease in emissions of dioxins into the environment. However, in the case of dioxin-like PCBs there were slight increases in the concentrations between 1992 and 1997 in most of the food groups, especially in carcass meat and poultry, but decreases in the milk and egg food groups. The reason for the apparent increase in some food groups is not clear but may reflect a levelling off in the fall of PCB concentrations in the environment generally and the increasing significance of the recycling of historical emissions.

3.5 Concentrations and trends in human milk

61. Measurements of dioxins and PCBs in breast milk are co-ordinated in a WHO programme covering several countries. The latest available data for UK samples were published by MAFF[34] and are included in Table 4. Samples of human milk were obtained from 20 and 23 mothers in Birmingham and Glasgow respectively in 1993 and from 20 mothers in Cambridge in 1994. The samples were pooled for analysis and the results were compared to data for human milk samples collected in 1987-88.

62. The results of this work indicated that the levels of dioxins may have decreased between 1987/88 and 1993/94.

Table 4: Concentrations of dioxins and dioxin-like PCBs in samples of human milk collected in 1987/88 and 1993/4 (MAFF, 1997)[33]

Year	1987–88		1993–94		
City	B'ham	Glasgow	B'ham	Glasgow	Cambridge
Dioxins*	37	29	21	21	24
PCBs*	–**	–**	10	12	10
Dioxins & PCBs*	–	–	31	33	34
Fat content	2.8%	3.4%	3.1%	3.4%	3.2%

* Concentrations (ng I-TEQ/kg milk fat) are calculated using the International TEF scheme for dioxins and a previous scheme for PCB.

** Dioxin-like PCBs were not analysed in the samples collected in 1987–88.

[34] MAFF, Food Surveillance Information Sheet No. 88, May 1996, Dioxins in Human Milk; FSIS No. 105, June 1997, Dioxins and PCB in Food and Human Milk.

4. Human Exposure

63. Human exposure to dioxins and PCBs can be through air, water and soil, food, dermal contact and in occupational settings. Several studies have shown that, at least in contemporary industrialised countries, more than 90% of exposure of the general population to these compounds is through food.

4.1 Exposure from food

64. To estimate consumer exposure to dioxins and dioxin-like PCBs, the Food Standards Agency, and previously MAFF, use the Total Diet Surveys mentioned in 3.3. Exposure of population subgroups based on analysis of the 1982, 1992 and 1997[35] TDS food group samples and dietary habits, expressed in WHO-TEFs, are shown in Tables 5a and b. Table 5a shows mean dietary exposure while Table 5b shows data for high level (97.5 percentile) dietary exposures[36].

65. The calculation of UK exposure figures assumes that congeners below detection limits are present at the detection limit[37]. This is referred to as an *upper bound* estimate. In other countries different assumptions may be used, for example, in the USA non-detected congeners are often assumed to be present at half the detection limit, and this means that UK figures may be higher than those reported elsewhere.

66. Exposures to dioxins and dioxin-like PCBs from the UK diet have fallen significantly since 1982, with the population average decreasing by more than an estimated 70% between 1982 and 1997. Exposure of the different age groups will vary due to different consumption patterns and body weights. In addition changes in the average diet will, over time, impact on exposure.

67. Estimated *mean* dietary exposures to dioxins and PCBs for adults are within the Tolerable Daily Intake (TDI – see Section 5) of 2 pg/kg bw/day recommended by COT. However, estimated *high* level dietary exposure for adults is above this limit. For toddlers and schoolchildren both mean and high estimated dietary exposures exceed the COT recommended TDI.

4.2 Exposure from human milk

68. Elevated exposures to dioxins and related compounds can arise within subgroups of the population. In particular, breast fed infants may receive a high intake during the period of breastfeeding, although Government health advisors continue to emphasise that breastfeeding should be encouraged on the basis of convincing evidence of the benefits of human milk to the overall health and development of the infant.

[35] Food Standards Agency Food Surveillance Information Sheet Number 04/00 Dioxins and PCBs in the UK diet: 1997 Total Diet Study Samples, September 2000.

[36] In order to protect the population as a whole the majority of exposure estimates conducted by the FSA are based on consumers who eat large quantities of the specific foods under consideration – defined as those individuals within a critical group who consume the food at the 97.5th percentile of the food consumption distribution.

[37] Analytical detection limit is the lowest concentration of a chemical that is measurable with confidence by the analytical method used. For compounds such as dioxins and dioxin-like PCBs which are present at very low levels and require very sensitive analysis, the detection limit achieved can vary between the individual congeners.

Table 5a: Summary of estimated *upper bound* mean dietary exposures of all age groups to dioxins and dioxin-like PCBs in 1982, 1992 and 1997 (picograms WHO-TEQ per kilogram of body weight per day)

Age group	Estimated mean dietary exposure (pg WHO-TEQ/kg bodyweight/day)								
	1982			1992			1997		
	Dioxins	PCBs	Dioxins + PCBs	Dioxins	PCBs	Dioxins + PCBs	Dioxins	PCBs	Dioxins + PCBs
Toddlers:*									
1.5–2.5 years	15	7.9	23	5.0	2.6	7.5	2.6	2.6	5.1
2.5–3.5 years	12	6.6	19	4.2	2.1	6.3	2.3	2.2	4.4
3.5–4.5 years (boys)	11	5.9	17	3.7	1.9	5.6	2.1	1.9	4.0
3.5–4.5 years (girls)	11	5.8	17	3.7	1.9	5.6	2.1	1.9	4.0
Schoolchildren*	5.6	3.0	8.6	2.0	1.0	3.0	1.2	1.0	2.2
Adults*	4.6	2.6	7.2	1.6	0.9	2.5	0.9	0.9	1.8

Table 5b: Summary of estimated *upper bound* high level dietary exposures of all age groups to dioxins and dioxin-like PCBs in 1982, 1992 and 1997 (pg WHO-TEQ/kg bodyweight/day)

Age group	Estimated high level dietary exposure (pg WHO-TEQ/kg bodyweight/day)								
	1982			1992			1997		
	Dioxins	PCBs	Dioxins + PCBs	Dioxins	PCBs	Dioxins + PCBs	Dioxins	PCBs	Dioxins + PCBs
Toddlers:*									
1.5–2.5 years	34	16	49	8.9	5.0	14	5.2	4.9	10
2.5–3.5 years	27	14	41	7.5	4.0	11	4.3	4.1	8.4
3.5–4.5 years (boys)	22	11	33	6.0	3.3	9.2	3.6	3.4	6.9
3.5–4.5 years (girls)	24	11	34	6.6	3.2	9.6	3.8	3.4	7.2
Schoolchildren*	10	5.2	15	3.2	1.6	4.7	1.9	1.7	3.5
Adults*	8.3	4.6	13	2.8	1.6	4.3	1.6	1.6	3.1

Note: Combined dietary exposures to dioxins and dioxin-like PCBs may not equal the sum of the separate exposures due to rounding.

* Average and high level dietary exposures (toddlers, schoolchildren and adults) estimated using food consumption data from the dietary surveys of individuals.

69. In 1993 estimated dietary intakes by breast-fed infants were approximately 170 picograms I-TEQ per kilogram of body weight per day at age 2 months falling to 39 picograms I-TEQ per kilogram of body weight per day at 10 months. The exposure that breastfed babies receive is determined by the body burden and exposure of their mothers. There are indications that body burdens peaked in the early/mid 1960s and have decreased since. This trend is expected to continue but we are unable to predict with any confidence when body burdens will reach a level such that exposure of breastfed infants will be below the TDI.

70. DEFRA, Department of Health, HSE and the Food Standards Agency commissioned work to establish a UK human milk bank to examine exposure of breast fed infants to dioxins, dioxin-like PCBs and a range of other chemical contaminants. A pilot study is underway at Leeds University to determine the collection, storage and analytical methodologies required to establish what will be an important UK resource. In addition, a survey of dioxins and PCBs in infant formulae is in progress which will allow the dietary exposure of formula fed infants to be estimated.

4.3 Occupational exposure

71. Occupational exposure to dioxins or PCBs will be in addition to that received from other sources such as food. Significant occupational exposure might occur in workplaces where higher than usual concentrations of dioxins and PCBs are present or generated. Health and Safety at Work legislation lays down a series of requirements on employers which will apply to situations at work where exposure to PCBs and dioxins may occur under the Control of Major Accident Hazard Regulations 1999 (COMAH) and the Control of Substances Hazardous to Health Regulations 1999 (COSHH).

72. The COMAH Regulations apply to premises where larger quantities (1kg or more) of certain dioxins are present (which includes anticipated presence) or which may be generated during the loss of control of an industrial chemical process. Schedule 1 to the COMAH Regulations identifies these dioxins and their quantities are calculated in toxic equivalents using the I-TEF scheme (shown in Annex B).

73. The COSHH Regulations apply to all premises where exposure to hazardous substances, including dioxins and PCBs, may occur. COSHH requires employers to:

- assess risks to health arising from exposure to hazardous substances;
- prevent or adequately control exposure;
- ensure control measures are used, maintained, examined and tested;
- in some instances monitor exposure and carry out appropriate health surveillance;
- inform, instruct and train employees.

74. There is a specific exposure limit set for PCBs in workplace air . Employers must ensure that the concentration of PCBs in workplace air, averaged over an 8 hour period, is reduced as low as reasonably practicable below the Maximum Exposure Limit (MEL) of 0.1 mg/m^3. As PCBs can also be absorbed into the body through unbroken skin, they have a skin 'Sk' notation and appropriate ways to prevent skin contamination should also be considered.

75. A recent assessment by HSE has identified those industries with the highest potential for occupational exposure to dioxins. As existing industry data were limited, on-site sampling was carried out, using both static samplers (for background exposures) and an experimental personal sampler (for exposures in the worker breathing zone). The industries considered were:

- **metal recycling** – dioxins may be generated when scrap metal contaminated with organic matter, eg plastics and paint coatings, is heated. Visits were made to a number of metal recyclers and measurable dioxin levels were found. The highest values were in aluminum recycling with air levels in one workplace of up to 70 pg/m^3 (TEQ), while air samples taken in a worker's breathing zone measured 25 pg/m^3 (TEQ), averaged over an 8 hour shift. However, values at a second aluminum factory and other metal recyclers were significantly lower. HSE is working with the recycling industry to bring about improved controls in order to reduce dioxin exposure;
- **incineration and landfill of ash** – workers at incinerators will be exposed to dust from the waste and bottom ash. Bottom ash contains levels of dioxins similar to urban soils and is normally landfilled. The Environment Agency report, ''*Solid Residues from Municipal Waste Incinerators in England and Wales*'', published July 2002, concluded that, subject to guidance and appropriate specifications, bottom ash can potentially be a valuable secondary aggregate. Such use is being further assessed. Fly ash removed from the stacks

by gas-cleaning plant does contain higher levels of dioxin (up to approximately 3000 ng dioxin/kg ash) but exposure is very limited as the ash is enclosed. Workers may be exposed during maintenance of the precipitators or bag filters but this is for a short period and personal protective equipment must be worn. Fly ash is landfilled as special waste due to its alkaline nature and is disposed of in a wet condition. An assessment of occupational exposure is on-going;

- **cement manufacturing** – in this process, chalk and clay-like materials are mixed along with smaller quantities of other additives, and roasted to produce a calcium silicate clinker. This is cooled over grates and ground with gypsum to produce cement. There is no waste ash produced in this process as all solid materials go into the cement. Background air samples from a cement manufacturer did not show increased levels of dioxin, and the cement produced was found to contain levels of dioxins comparable to garden soil;
- **burning and cutting** – some building site operations involve high temperature cutting of contaminated metals. HSE sampled for dioxins at a cutting operation in a railway tunnel. This was in some ways a worst case scenario as ventilation inside the tunnel was restricted. Personal samples from the operatives contained no detectable dioxins. Static samplers were positioned to intercept the dark smoke from the cutting operations, but levels of dioxins were low and only a little above the expected ambient levels.

4.4 Exposure from air, water and soil

76. There is very little information available to quantify uptake through air, water and soil. Atmospheric emissions of dioxins may be deposited on grass, soil and water and enter the foodchain, and it is considered that this exposure route is far more significant to average human exposure than inhalation or dermal contact. It is possible that local exposure could be increased from a particular source, such as contaminated land, but there is little available information to quantify such exposures.

77. Recently there have been a number of reports, particularly from Sweden, of elevated concentrations of PCBs in indoor air[38,39] although these included many congeners with non-dioxin like activity. These levels probably resulted from the extensive past use of PCBs in a range of construction and decorating materials such as building sealants, paints and varnishes. There is some evidence to suggest that this is particularly the case for housing built before the 1970s when PCBs were widely used in open applications. It is often not possible to determine which older construction materials may have contained PCBs but as they have not been in general use for many decades it is likely that most will have failed and have been replaced.

4.5 Trends in future exposure

78. To assist in this review of dioxins and dioxin-like PCBs in the UK, a project was undertaken by the University of Lancaster to assess the relationship between past emissions and human

[38] PCBs in sealants – big or small problem? English translation of Swedish report produced by Naturvardsverket for the Swedish EPA (1997).

[39] Currado, G M & Harrad, S J. (1998). Comparison of Polychlorinated Biphenyl Concentrations in indoor and outdoor air and potential significance of inhalation as a human exposure pathway. *Environmental Science and Technology*, **32**, 3043.

exposure and to consider the feasibility of projecting future exposures[40]. This made the first real attempt to develop a model framework linking emissions to the atmosphere, via the foodchain, to human exposure and tissue concentrations. An executive summary of this work is at Annex F.

79. In order to model emissions and exposure it was necessary to make a number of assumptions, including treating the UK as a well mixed system and assuming that human exposure was *via* air emissions entering meat and milk *via* vegetation and fish from water. The uncertainites surrounding these assumptions, combined with incomplete information on sources of dioxins and PCBs, meant that only broad indications could be drawn from the modelling exercise.

80. However, it is clear from the available data that emissions of dioxins and PCBs have been reduced due, in part at least, to deliberate controls, and that this has been reflected in declining levels in the environment and a reduction in consumer exposure. There are still significant uncertainties about sources (both historical and current) and about elements of the transfer into food, and further work is required to fully consider the exposure of population sub-groups. However, this project has helped to identify the gaps in our understanding of the relationship between emissions and exposure.

[40] PCDD/Fs and PCBs in the UK: Quantifying the link between emissions and human exposure in the past, the present and the future (March 2000) Executive Summary Report on Contract EPG 1/5/121.

5. Toxicity of Dioxins and Dioxin-like PCBs

5.1 Human health effects

81. A wide range of adverse effects have been associated with the exposure of laboratory animals to dioxins including dermal toxicity, immunotoxicity, reproductive effects and teratogenicity, endocrine disruption and carcinogenicity. Most studies have been carried out on 2,3,7,8-TCDD as this is considered to be the most toxic dioxin congener.

82. There is a proven association between exposure to high levels of dioxins in humans and chloracne. Studies on humans who have been exposed to high levels of dioxins as the result of accidents or occupational exposure have reported a range of effects such as increased risk of cancer, changes in biochemical parameters such as in enzyme levels, and increases in mortality from cardiovascular disease, although there remains considerable uncertainty about the direct causal link with dioxins. Studies of exposed children have reported subtle effects including neurodevelopmental delays, neurobehavioural effects and effects on thyroid hormones.

83. Of the full range of PCBs present in commercial mixtures only a few have dioxin-like toxicity. The toxicity of the dioxin-like PCBs is extrapolated from studies on 2,3,7,8-TCDD, there being no studies on the effects of human exposure to PCBs alone. A number of toxic effects of commercial PCB mixtures and individual congeners have been documented in laboratory animals. The most critical effects determined from animal experiments are those on the skin (chloracne), the immune system, reproduction and on post-natal behavioural development. Non dioxin-like PCBs are not included within the scope of this consultation paper.

5.1.1 Previous COT considerations

84. The Committee on the Toxicity of Chemicals in Food, Consumer Products and the Environment (COT) and its sister Committees on carcinogenicity (COC) and Mutagenicity (COM) have considered dioxins on a number of occasions. In 1989 the Committee made a comprehensive statement on the health hazards of dioxins[2]. At that time there was not enough evidence available to set a tolerable daily intake (TDI) for dioxins and the COT recommended that the toxicity of dioxins should be kept under review and that measures should be taken to reduce inputs to food in order to reduce human exposure.

85. COT reconsidered the issue in 1991 when UK exposure data were published and endorsed the use of a TDI of 10 pg I-TEQ/kg bw that had previously been recommended by WHO. However, in view of the estimated long elimination half-lives of this class of compounds, the Committee said it would be appropriate to regard the TDI as a time-weighted average tolerable intake. Since that time COT has kept the issue under continuous review and examined data on human health effects and exposure assessments as these data have become available.

86. In 1995 COT reviewed the early draft assessment of the health effects of dioxins published by the US EPA[41] (5.1.2) and concluded that there was no additional evidence presented that

[41] US EPA's external review draft reassessment of dioxins – Health assessment document for 2,3,7,8-TCDD and related compounds (first produced in September 1994).

required a change to their previously recommended TDI. In 1997 COT considered data presented by MAFF on the levels of dioxins and dioxin-like PCBs in food, breast milk and fish oils[42]. They concluded that the TDI of 10 pg I-TEQ per kg bw should be widened in scope to include those PCB congeners which were thought to act in a similar manner to dioxins.

87. In 1998 the Committee endorsed the findings of a meeting of experts convened by the World Health Organisation European Centre for Environment and Health (WHO- ECEH) which proposed revisions to the TEF scheme for dioxins and dioxin-like PCBs[3] and the UK adopted the use of the WHO-TEFs scheme (See Section 2.1 and Annex B).

88. In 2000 the Committee considered the finding of a MAFF study on levels of dioxins and PCBs in marine fish[43]. It advised that, although it was possible that intakes for some subgroups of the population could exceed the new WHO recommended TDI, that UK adults should continue to follow the Committee on Medical Aspects of Food Policy (COMA) advice to eat at least two portions of fish per week, one of which should be oily, as part of a balanced diet.

5.1.2 Recent international evaluations

89. In 1997, the International Agency for Research on Cancer (IARC), which classifies chemicals on their likelihood of causing cancer in humans, concluded that using limited human epidemiological and extensive animal studies, 2,3,7,8-TCDD should be classified as a known human carcinogen. Other congeners were classified as potential human carcinogens due to a lack of evidence[44]. The UK Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment (COC) reviewed these findings and concluded that there were insufficient data to show a causal link but that it would be prudent to classify 2,3,7,8-TCDD as a probable weak human carcinogen[45]. The Committee reviewed this again in 2001 and concluded that TCDD should be regarded as a probable human carcinogen.[46]

90. In 1998 the WHO European Centre for Environment and Health (WHO- ECEH) and the International Programme on Chemical Safety (IPCS) conducted a re-evaluation of the TDI for dioxins and dioxin-like PCBs and recommended a TDI of 1-4 pg WHO-TEQ per kg bw. In addition it was recognised that subtle effects might be occurring in the general population where typical intakes are in the region of 2-6 pg WHO-TEQ/kg bw/day. The review and its background papers were not published until summer 2000[47].

91. The EU's Scientific Committee on Food (SCF) Task Force on Dioxins also undertook a reassessment of the TDI for dioxins and dioxin-like PCBs. The findings of this work were published in December 2000 and reviewed in 2001[48] and recommended that, because of very long half-lives in the human body, the tolerable intake should be expressed on a weekly rather than a daily basis. A tolerable weekly intake (TWI) of 14 pg WHO-TEQ/kg bw was

[42] Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment. (1997). Statement on the Health Hazards of PCB.
[43] Dioxins and PCBs in UK and Imported Marine Fish, Food Surveillance Information Sheet 184, MAFF.
[44] IARC (1997) Monographs on the evaluation of carcinogenic risks to humans. Volume 69. PCDDs and PCDFs, Lyon, pp 33–343.
[45] Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment. (1998). Statement on 2,3,7,8 Tetrachlorodibenzo-p-dioxin. COC/99/S1.
[46] Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment. (2001). Statement on the Carcinogenicity of 2,3,7,8-tetrachlorodibenzo-p-dioxin. COC/01/S2.
[47] Van Leeuwen and Younes MM (eds). (2000). Assessment of the health risks of dioxins: re-evaluation of the tolerable daily intake (TDI). Food additives and Contaminants.
[48] SCF conclusions are available of their web-site at http://europe.eu.int/comm/food/fs/sc/scf/out78_en.pdf

established, based on a lowest observed adverse effect level (LOAEL) for developmental effects in male rat offspring. This was the first time that such an assessment had been made at a European level rather than at the EU member state level, and was precipitated by the Belgian food contamination incident (see Section 3.3).

92. The Joint FAO/WHO Expert Committee on Food Additives (JECFA) considered dioxins and dioxin-like PCBs in June 2001 and proposed a provisional tolerable monthly intake (PTMI) of 70 pg WHO-TEQ/kg bw based upon the lowest LOAEL and a NOAEL for developmental effects in male rat offspring[49].

93. Following on from the draft assessment published in 1994, the US EPA released a pre-publication copy of its revised draft assessment in June 2000. This has since been undergoing a period of public consultation and consideration by the US EPA's Science Advisory Board (SAB). The findings of the SAB review were expected to be published before the end of 2001 with the US EPA expected to release its final document shortly after. As it stands the draft document consists of three parts[50]:

- Estimating exposure to dioxin-like compounds
- Health assessment for 2,3,7,8-TCDD and related compounds
- Integrated summary and risk characterisation

5.1.3 COT Statement on tolerable daily intakes (2001)[51]

94. In 2000 the COT was asked to review the risk assessments of dioxins carried out by the WHO, the SCF and the US-EPA. It concluded that it would be appropriate to conduct its own evaluation of the data, informed by these assessments and other information such as the statement on carcinogenicity by the COC[46], before reconsidering the TDI for dioxins. In 2001 the COT:

- concluded that dioxins and dioxin-like PCBs have the potential to cause a wide range of adverse health effects. Those most likely to be associated with low levels of exposures relate to the developing embryo/fetus;
- recommended a TDI of 2 pg WHO-TEQ/kg bw per day be established based upon effects on the developing male reproductive system mediated *via* the maternal body burden;
- considered that this TDI is adequate to protect against other possible effects, such as cancer and cardiovascular effects;
- noted that the most recent intake estimates for the UK population are 1.8 pg/kg bw/day for the average consumer and 3.1 pg/kg bw/day for the 97.5th percentile consumer (based on the 1997 TDS) and that dietary intakes are decreasing;
- noted that there are no short-term measures that can be used to decrease the body burden of dioxins and dioxin-like PCBs in humans because of their long half-lives and widespread presence at low levels in food;
- noted that, because of the long half-life, short-term exceedences of the TDI are not expected to result in adverse effects. Nevertheless, it is not possible to identify a duration and degree of exceedence at which adverse effects might occur; and

[49] JECFA (2001). Joint FAO/WHO Expert Committee on Food Additives, 57th meeting, Rome, 5–14 June 2001. Summary and Conclusions. Available at http://www.who.int/pcs/jecfa/jecfa.htm.
[50] All parts available on the US EPA web-site at www.epa.gov/ncea/pdfs/dioxin/.
[51] COT Statement on the Tolerable Daily Intake for Dioxins and Dioxin-like Polychlorinated Biphenyls (19 November 2001).

- confirmed its previous advice that, although intakes of dioxins and dioxin-like PCBs by breast-fed babies are higher than is desirable, encouragement of breast-feeding should continue on the basis of convincing evidence of the benefits of human milk to the overall health and development of the infant.

95. The recommendation of COT to reduce the TDI from 10 to 2 pg WHO-TEQ/kg bw will now form the basis against which regulatory targets and risk assessments are set. The Committee's statement is in Annex E.

5.2 Environmental effects

96. In comparison to the considerable body of work on human health effects there is much less known about the effects of these pollutants on ecosystems. A range of adverse effects have been observed on animals in the laboratory but in the environment it is difficult to establish cause and effect when ecosystems may be exposed to a range of chemicals.

97. The Environment Agency is actively working on assessing and mitigating the potential for adverse effects of dioxins and dioxin-like PCBs on the environment. Much of the Environment Agency's work is focused on localised areas with known dioxin or PCB contamination with a view to minimising potential impacts. In addition sediment quality guidelines are being developed to help identify and manage areas of contaminated sediment[52].

98. The persistence of PCBs in the environment and their high solubility in fat has led to a process of accumulation in food chains – particularly in the marine environment – and adverse effects on sea mammal reproduction have been reported in some populations exposed to PCBs[53].

[52] Grimwood MJ, Mascarenhas R & Sutton A, Proposed environment quality guidelines for dioxins and furans in water and sediment. Environment Agency R&D technical report 48.

[53] Environmental Health Criteria 140, Polychlorinated Biphenyls and Terphenyls (Second Edition), IPCS, Geneva, 1993.

6. International Context

99. It is difficult to assess the UK's position in relation to other countries in terms of sources of dioxins, the levels in the environment, and human exposure because very few countries have made an assessment of their own situation. For those countries where data are available, they are reported in a variety of ways and are not readily comparable. In addition, the position in many countries is changing rapidly as control measures are put in place, as knowledge changes and improves, and as new data become available. However, increased efforts are being made to gather comparable datasets on dioxins and PCBs.

100. Some of the more detailed assessments of dioxins and dioxin-like PCBs have been carried out in Europe and work is underway to compile available information on sources, environmental concentrations and exposure across Europe. Other countries with good national information include the USA, Canada, Australia, Japan and New Zealand. There is much less information on sources and exposure in developing countries and countries in economic transition so more attention is being focused on assessing the releases to the environment and levels of exposure in these countries.

6.1 Sources

101. Two compilations of national inventories have recently been carried out. In 1997, the North Rhine Westphalia State Environment Agency (LUA) published an inventory of dioxin emissions in Europe on behalf of the European Commission[17]. More recently UNEP Chemicals produced a compilation of available national and regional dioxin emissions inventories, which contained datasets for just 15 countries, highlighting how little information has been produced internationally. Both reports focus only on emissions to air and both highlight a major problem due to differences in reporting conventions, analytical procedures and differences in the depth of coverage and the dates of inventory compilation. Figure 5 shows graphically estimates of emissions to air from the UNEP study (note that these values are not definitive and are included for illustration only).

102. The UK has studied releases of dioxins to all environmental media and information on releases of dioxin-like PCBs is now being generated. Until more of this type of information is available from other countries reliable comparisons cannot be made.

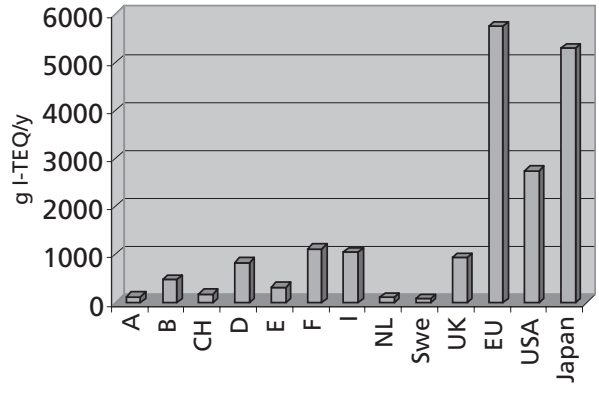


Figure 5: Illustrative estimates of dioxin emissions to air from national inventories (UNEP, 1999).

6.2 Levels in the environment

103. A study by AEA Technology on behalf of the European Commission compiled data on environmental concentrations of dioxins in European countries and found there was insufficient information available to make a satisfactory, detailed comparison of UK dioxins levels with other countries in Europe[25]. An initial review of this study suggests that the UK has broadly similar levels of dioxins in the environment to comparable industrialised countries.

104. Outside Europe information on environmental concentrations is scarce. Levels in the UK environment and in food are much higher than in New Zealand[54] where industrial activity is at a much lower level, but appear comparable to those in the USA[50].

6.3 Human exposure

105. Under the framework for co-operation in the scientific examination of questions relating to food, the European Commission set a Scientific Co-operation (EU SCOOP) task to collate data from nine participating member states and Norway on the levels of dioxins and dioxin-like PCBs in food and estimate dietary exposure. The results of this work were used by the European Scientific Committee on Food to inform its assessment of the potential health risks posed by these compounds, which was published in November 2000[55].

106. Estimates of consumer exposure to dioxins via food vary considerably from country to country- a selection of exposure estimates are shown in Table 6. The methods used to calculate exposure are not consistent and comparisons should be made with care. UK estimates of average consumer exposure are at the low end of the range and are approximately one third of those for Spain and half those of France. Dietary exposure in the UK appears comparable to Germany and the Netherland. Exposure in New Zealand is very low compared with more industrialised countries.

107. Less information is available on exposure to ''dioxin-like'' PCBs, although the UK has comparatively good information on levels of these compounds in food (Table 2, Section 3.3).

108. The United States Environmental Protection Agency in its draft reassessment of the health effects of dioxin and dioxin-like PCB[41] has suggested a risk specific dose of 0.01 pg TEQ per kilogram of body weight per day for cancer risks (one additional cancer in a million exposed individuals, this represents a plausible upper bound of risk based on animal and human data, true risks are not likely to exceed this, may be less and may even be zero for some members of the population). Their assessment assumes that there is no threshold level of exposure below which adverse effects are not seen and this is in contrast to the approach taken by WHO and many other authorities in setting a TDI designed to ensure that daily ingestion does not result in appreciable risk.

6.4 International regulatory action

109. Current information indicates that the populations of all developed countries are exposed to trace levels of dioxins and dioxin-like PCBs. An international focus on these compounds is

[54] New Zealand Ministry for the Environment (2000) New Zealand inventory of dioxin emissions to air, land and water and reservoir sources.

[55] Opinion of the Scientific Committee on Food on the risk assessment of dioxins and dioxin-like PCBs in Food, European Commission, November 2000.

Table 6: Estimates of dietary exposure to dioxins in various countries I-TEQ per day

	Denmark 1995	Finland 1991	France unspecified	Germany 1995	Netherlands 1991	Spain 1996	New Zealand 1997[56]	USA (assumed 1994)[57]	Sweden 1990	UK 1992
Average total diet exposure pg I-TEQ/day	171	95	Nd	69.6	65	210	14.5	19	126.5	69
Average exposure pg I-TEQ/kg bw/d	2.44	1.36	2.21*	0.99	0.93	3.0	0.18*	1.7	1.81	0.99
High level consumer pg I-TEQ/kg d			5.66*		2.3		0.44*			1.7-2.6
TDI pg TEQ/kg bw/d	5	5	1	1-10	10	Nd	Nd	N/A	5	10

Note: Comparisons of average adult dietary exposure should be taken with care as data are derived from different sources and for different reference years using a variety of methods and the figures may not be directly comparable. *Average bodyweight 70kg except for France where it is unspecified and New Zealand 80kg. nd = no data, N/A = not applicable.

[56] Reporting on Persistent Organochlorines in New Zealand, New Zealand Ministry for the Environment, 1998.

[57] Estimating Exposure to Dioxin-like Compounds, Volume I, Executive Summary, Review Draft, US EPA 1994.

particularly important as they may undergo long range environmental transport, migrating from warm regions to colder climates, where they may accumulate. Releases in one country can therefore have a direct impact on human exposure in another. The UK is actively involved in a number of international activities to address these issues and these are briefly outlined below:

110. In 1993 the European Union Council of Ministers set a target of a 90% reduction in emissions of dioxins from known sources between 1985 and 2005[58] and aimed for a 90% reduction in air emissions from municipal waste incineration over the same time period. The progress of the UK against these targets has been described above.

111. The United Nations Economic Commission for Europe (UNECE) adopted a Persistent Organic Pollutant (POP) protocol under the Convention on Long-Range Transboundary Air Pollution (LRTAP) in 1998. This protocol covers 16 POPs and includes measures to reduce releases of dioxins and PCBs based on the use of best available technology. This protocol differs from the UNEP treaty (below) as it is regional in nature, covering western Europe, North America and the Russian Federation. There are currently 43 Parties to the LRTAP Convention.

112. The UK is a signatory to the declarations of the North Sea Conferences which include an agreement to reduce total inputs from all sources (including atmospheric sources) of dioxins to 70% of 1985 levels - provided that such reductions are attainable by using the best available technology.

113. The UK is also a signatory to the Convention for the Prevention of Marine Pollution from Land-Based Sources (the Paris Convention) which has been merged with the Oslo Convention to form the Convention for the Protection of the Marine Environment of the North East Atlantic (the OSPAR Convention). This has now been ratified by all signatories and entered into force in March 1998. In July 1998 the UK signed the Sintra Statement under the auspices of the OSPAR Commission. Signatories to this have agreed to continually reduce emissions of certain hazardous substances with the ultimate aim of achieving near background concentrations for naturally occurring substances and close to zero concentrations for synthetic substances. PCBs and dioxins are on a list of 27 substances which have already been identified for priority action by OSPAR, and programmes for the control of their emissions with respect to the marine environment have to be established by 2003.

114. In December 2000, representatives of 122 countries met to finalise negotiations to develop an international legally binding instrument to phase out the use and release of twelve persistent organic pollutants. The treaty which was developed under the aegis of the United Nations Environment Programme (UNEP) is global in scope and contains an obligation for Parties to ban the use of PCBs by 2025 and to reduce total releases of dioxins derived from anthropogenic sources with the goal of continued minimisation and, where feasible, ultimate elimination. The Convention was signed in Stockholm in May 2001 and is anticipated to come into force by 2004. Under the Convention Parties will have to develop an action plan to identify, characterise and address the release of dioxins and dioxin-like PCBs and develop a schedule to implement that plan.

115. In 2001, the European Commission's proposals for setting maximum permitted levels (MPLs) for dioxins in certain foodstuffs were adopted as Council Regulation (EC) 2375/2001.

[58] Towards Sustainability: A European Community Programme of Policy and Action in Relation to the Environment and Sustainable Development, CEC, Luxembourg, 1993.

This and a proposed EC Directive laying down the sampling methods and methods of analysis in support of the regulation are due to apply from 1 July 2002. The Commission's proposals setting MPLs for dioxins in animal feedingstuffs were adopted as Directive 2001/102. These maximum limits shall be reviewed for the first time before 31 December 2004 in the light of new data on the presence of dioxins and dioxin-like PCBs, in particular with a view to the inclusion of dioxin-like PCBs in the levels to be set.

116. In October 2001, the European Commission published a Community Strategy for Dioxins, Furans and PCBs which sets out a series of short, medium and long-term actions to address these substances in the environment, food and feed[59]. Environment Council conclusions on the Commission communication were adopted in December 2001. The main objectives of the Strategy are:

- to assess the current state of the environment and ecosystems;
- to reduce human exposure to dioxins and PCBs in the short-term and to maintain human exposure at safe levels in the medium to long-term;
- to reduce environmental effects from dioxins and PCBs; and
- to reduce human intake levels below 14 pg WHO-TEQ per kg bodyweight per week.

117. European Community member states have been amongst the most active in addressing the issue of dioxins and dioxin-like PCBs . Outside of Europe major activities have also been underway for a long time in the US and Canada and more recently in Japan. However, with the Stockholm Convention other countries are now acting to assess and control their own problems. A concerted effort under this Convention should also ensure that approaches taken are consistent and that national datasets will be comparable.

118. Future UK dioxins policy will need to consider the impact of overseas emissions on domestic exposure (and vice versa) as the significance of these emissions may increase as domestic sources are more tightly controlled. This may include a consideration of how UK expertise may be used to help other countries address their own emissions.

[59] Communication from the Commission to the Council, the European Parliament and the Economic and Social Committee. Community Strategy for Dioxins, Furans and Polychlorinated Biphenyls. COM (2001) 593 final.

7. Conclusions

119. Since the last UK review of dioxins in 1989 our knowledge of their sources, environmental concentrations, exposure and effects has advanced considerably. We now have a far more detailed database on emissions, particularly from industrial sources, more information on concentrations in food, and can estimate human exposure with a degree of confidence. We know that activities such as domestic burning eg of garden refuse, not previously identified as important sources of dioxins, may in fact contribute significantly to total national emissions. There may be also be natural sources but the significance of these is not known. Advancing knowledge about the impacts of dioxin-like PCBs has led to these being considered alongside dioxins, and there are now concerns about possible endocrine disrupting effects which may occur at exposures lower than those associated with other end-points.

120. While our knowledge base has increased significantly, it has been clear in the production of this report that there remain significant gaps in our understanding, particularly on the contribution of non-industrial or domestic sources to overall emissions, on the contribution of overseas sources to the UK burden, and the relative significance of dioxin-like PCBs. These are gaps that will need to be filled.

121. In the last ten years we have taken steps to identify and quantify the major sources in the UK and have implemented a number of measures to substantially reduce emissions, and subsequently, exposure to dioxins and PCBs. The impact of these measures is described in Sections 2, 3 and 4 of this report. Between 1990 and 1998 emissions of dioxins to air fell by an estimated 70% while those of total PCBs fell by around 60%. Due to the lack of congener-specific data it has not been possible to calculate reductions in emissions of dioxin-like PCBs alone. Recent data from the Environment Agency's Pollution Inventory suggest that emissions from IPC regulated processes continue to decrease. Measures taken so far have focussed on those processes identified as having the greatest impacts, but it is clear that any further controls will have to address the wide range of more diffuse, and therefore harder to control, sources. In an international context we will need to consider the impact of overseas emissions on the UK and vice versa.

122. Surveys by MAFF and now FSA show that between 1982 and 1997, human dietary exposure to both dioxins and dioxin-like PCBs fell by around 70%. As levels in food have come down, the relative contribution of the dioxin-like PCBs to overall exposure has increased and they now contribute roughly 50% to the total TEQ intake.

123. As part of the development of this report, the University of Lancaster explored the feasibility of modelling dioxin exposures and body burdens so that future trends in these parameters could be predicted. The study indicated that, although this was possible, a number of assumptions with varying degrees of uncertainty had to be made. The Interdepartmental Group overseeing the development of the report felt that these uncertainties were so great that the results should not be used for further policy development at present. The Group however recommended that the model should be further developed to a stage where the level of uncertainty is reduced and it could usefully feed into policy development.

124. A number of international organisations have recently assessed the risks associated with exposure to dioxins. In 1998, a WHO group recommended a Tolerable Daily Intake range of 1-4 pg WHO-TEQ per kilogram of body weight. In 2001, the European Scientific Committee for Food (SCF) recommended a temporary Tolerable Weekly Intake (TWI) of 14 pg

WHO-TEQ per kilogram of body weight. Also in 2001 the JECFA recommended a provisional tolerable monthly intake of 70 pg WHO-TEQ per kg of body weight. The UK Committee on the Toxicity of Chemicals in Food, Consumer Products and the Environment has examined these recommendations and conducted its own review of the scientific data and recommended a TDI of 2 pg WHO-TEQ per kg bw (Annex E).

125. Average adult exposure to dioxins and dioxin-like PCBs in the UK was estimated to be 1.8 pg WHO-TEQ per kilogram of body weight per day from 1997 food samples, which falls within the range of recommended TDIs. However some consumers, in particular small children and babies, have dietary intakes which exceed TDIs as they have lower body weights and eat different diets to adults.

126. The exposure of breastfed babies is considerably greater than recommended TDIs based on the 1993 human milk samples. Exposure received is determined by the body burden and exposure of their mothers. There are indications that body burden levels peaked around the early/mid 1960s (following the trend of ambient air levels which peaked in the late 50s/early 60s) and have decreased since. This trend is expected to continue but we are unable to confidently predict when body burdens will be sufficiently reduced such that exposure of breastfed infants will be below the TDI. In its 2001 Statement COT confirmed its previous advice that breast-feeding should be encouraged on the basis of convincing evidence of the benefits of human milk to the overall health and development of the infant.

127. Although there have been significant reduction in releases of dioxins and dioxin-like PCBs, the extreme persistence of this class of compounds means that it will be some time before the resulting reductions in human exposure will be fully realised. Therefore we need to continue to reduce emissions wherever possible. The UK also has a number of international obligations to reduce emissions of these substances.

128. It is clear that any future actions will need to consider a larger number of sources, including much smaller processes or currently unregulated sources such as domestic burning. However the range of options for achieving a large reduction from any individual process might be limited and an assessment of likely costs and demonstration of benefits will be required. Development of UK dioxin policy will impact on a number of cross-Government initiatives and require consideration and consultation with a wide range of experts and stakeholders. We see this paper as a first step in such a consultation exercise.

129. The UK Government continues to support a substantial amount of monitoring and scientific research to underpin policy development on dioxins and dioxin-like PCBs. This will continue as an invaluable tool for identifying areas for future action and it is important that future research activities are carried out in a co-ordinated manner.

8. Future Action

130. Although there remain many uncertainties and data gaps in our estimates of dioxin and dioxin-like PCBs exposure and of the exposure levels that may give rise to health effects, the best evidence we have at present suggests that some sections of the UK population, breast-fed babies and small children in particular, are exposed to levels in excess of maximum recommended levels. Significant measures have already been put in place to correct this situation but more must be done to reduce exposures further. It is proposed that a **Dioxins Action Plan** be developed to reduce overall exposure to these chemicals and that the success of this strategy be reviewed every two years.

We request comments on the proposal for such an action plan, the areas on which it should focus to bring about reductions in emissions and exposure, and on the indicators that could be used in reviewing progress.

131. Action taken so far to reduce emissions to the environment has focussed on those processes identified as making significant contributions to total UK emissions. The focus of attention must now shift to numerous diverse activities which, although individually are small dioxins sources, when considered collectively can now be considered to be major contributors to the UK inventory. Controlling such a diverse range of sources will not be straightforward and will require input from a wide range of stakeholders. Action will need to be cost-effective and targeted at achieving reductions in exposure in an acceptable timeframe. With this in mind the following actions are proposed:

- **Formation of a Dioxins Strategy Group**

132. It is proposed that a UK Dioxins Strategy Group be established to include regulators, industry, public interest groups and national experts with a wide knowledge base on dioxins to develop an action plan. In doing this the Group should consider the results of this consultation exercise, the conclusions of the COT review, and other information, and identify further priorities for action taking into account the costs and benefits of these. The membership of the group should be such that it will be in a position to take forward measures to reduce emissions.

We request comments on the proposal to establish a Dioxins Strategy Group, on how it will function, and the stakeholder involvement.

- **Industrial Sources**

133. It is proposed that the environment Agencies will secure further reductions in emissions from industrial processes under their control. The environment Agencies have already required major industrial sources to reduce emissions commensurate with best available technique (BAT). The Agencies will keep BAT for dioxin and PCB-emitting industries under continual review and require further reductions as technological development permits. In the short-term the Agencies will review emissions data for processes they regulate and identify where further reductions may be achieved through the exercise of their regulatory powers in the medium and long-term.

134. It is proposed that DEFRA will similarly secure reductions in emissions from processes and activities not regulated by the environment Agencies and identified in this report as becoming relatively more significant. In the short-term DEFRA will review such emissions and identify where reductions may be made in the medium and long-term.

135. A massive reduction has already been secured in the amount of dioxins emitted by municipal waste incinerators, and they are now a relatively minor source. It is probably not realistic to secure further reductions in the short term from individual plants. However, we will continue to press for the tightest feasible emission standards.

136. Chemicals that have the potential to be contaminated with dioxins or PCBs have been withdrawn from the market or their composition tightly controlled. Similar controls will be placed on any further chemicals found to have the potential for significant contamination.

137. The UK phase-out and destruction of PCBs will be completed in line with EC Directive 96/59. Guidance will be produced on the disposal of equipment of less than 5 litres which is not covered by the registration requirement.

138. Dioxin-like PCBs may be formed in a similar manner to dioxins from industrial processes, although the contribution may be insignificant in comparison to historical PCBs already in the environment. The Environment Agency and SEPA, in collaboration with DEFRA, will make an assessment of the contribution of these sources, review levels released, and if necessary review how processes report their dioxin-like PCB emissions in the Pollution Inventory.

We request comments on the proposals to further reduce emissions of dioxins from industrial processes. In particular we would welcome comments on measures which would bring about reduced emissions in the most cost-effective manner.

- **Transport**

139. Transport emissions have already fallen with the withdrawal of lead from petrol and the corresponding removal of chlorinated scavengers required in leaded petrol and it is considered that future gains from any further action directed solely at dioxin emissions will be small.

- **Open burning and other diffuse sources**

140. Major reductions in dioxin emissions from open burning have already been achieved in the agricultural sector as a result of the ban on stubble burning. However, open burning, accidental fires and the household use of coal and wood have been estimated to account for approximately a quarter of current dioxin emissions and further reductions are needed. It is proposed that DEFRA investigates releases from this sector to produce more reliable emissions estimates for the National Air Emissions Inventory. This information will be used to focus future action which might, for example, include the production of guidance on domestic burning and an investigation into whether changes in construction and/or furnishing materials could cut emissions from accidental fires.

141. Pressure against open burning at commercial operations (eg building sites) will be maintained and the scope for further action will be reviewed and reported.

We request comments on the proposals to reduce dioxins emissions from open burning. What actions should be taken to reduce emissions from these and other diffuse sources in a cost-effective manner?

- **Exposure**

142. The Food Standards Agency will continue to monitor the UK food supply for dioxins and dioxin-like PCBs. As a priority the 2003 Total Diet Survey samples will be analysed to provide an update of human exposure.

143. The UK will continue to work to establish standards for levels of dioxins and dioxin-like PCBs in particular foods and feedstuffs. It will ensure that analytical and reporting methodologies are consistent and that monitoring programmes are practical and within the analytical capabilities available.

144. We would like to explore with the food industry the potential for taking measures during the production of food which will minimise the levels of dioxins and dioxin-like PCBs in food .

We request comments on what action could be taken to reduce the levels of dioxins and dioxin-like PCBs in food in the short to medium term. What factors need to be considered in determining the cost-effectiveness of any measures.

- **Measurement methodologies**

145. Investigation and development of analytical methods for an agreed suite of PCB congeners.

146. The development of faster, less costly, but effective analytical methods to improve the effectiveness of monitoring programmes.

- **Better information**

147. While continuing to act to secure reductions in human exposure to dioxins, we need also to refine our information base, including our inventory of sources, concentrations in the environment, human exposure and effects. We also need further information to refine the assumptions used in the preliminary work carried out by Lancaster University linking emissions to exposure and body burden. The following investigative programmes and research have been put in hand:

    - monitoring for dioxins in air has been extended to include the dioxin-like PCBs which are reported as WHO-TEF in the NAEI;

    - a survey of UK soils funded by EA, DEFRA, FSA, NIDOE and the Scottish Executive has been initiated. This will provide information on current concentrations of dioxins and dioxin-like PCBs in the UK and will be reported in 2003;

    - Surveys of dioxins in food will continue.

We request comments on current and proposed future arrangements for the collection and reporting of data on emissions of, and exposure to, dioxins and dioxin-like PCBs.

148. Other proposals for obtaining better information might include:

    - continuation of the future exposures modelling work, focussing on reducing the uncertainties in any assumptions so that modelling results can be used in policy development;

    - examining the importance of overseas sources and the impact of UK emissions overseas;

    - commissioning of an investigation into the location of historical deposits of PCBs in the UK and an assessment of any contribution they might be making to PCBs in the environment;

- commissioning of an investigation into the levels of emissions of dioxins to soil and water in order to assess the importance of these in terms of environmental and human exposure.

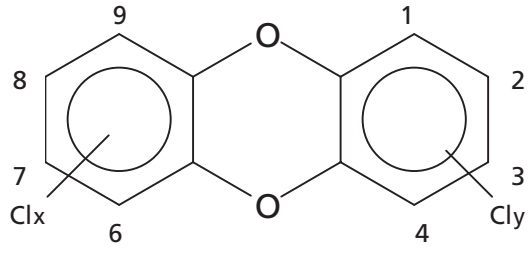
We request comments on these proposals and invite further suggestions for obtaining better information.

Acknowledgements

The Interdepartmental Group thanks Patrick Dyke of PD Consulting, Professor Kevin Jones, Dr Ruth Alcock and Dr Andy Sweetman of Lancaster University, Debbie Buckley-Golder and Mike Woodfield of AEA Technology and Andy Sewart formerly of FSA, for the valuable advice and contributions made in the preparation of this report.

Annex A – Structures and Nomenclature

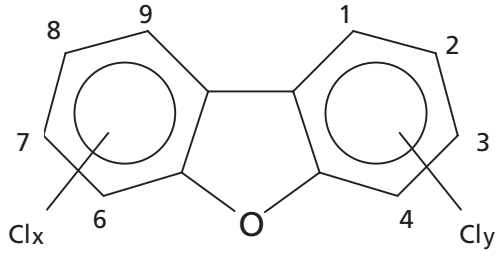
Polychlorinated dibenzo-*p*-dioxins (PCDDs)



x + y = 1 - 8

There are 75 distinct PCDDs with each congener being referred to by the position of its chlorine substituents. The congeners that have proven to be toxic are those with the four lateral positions (2,3,7 and 8) all chlorinated. There are seven PCDD congeners that fulfil this requirement, the most toxic of all being 2,3,7,8-tetrachloro dibenzo-*p*-dioxin (TCDD, or sometimes referred to as 'Dioxin' in the popular press).

Polychlorinated dibenzofurans (PCDFs)

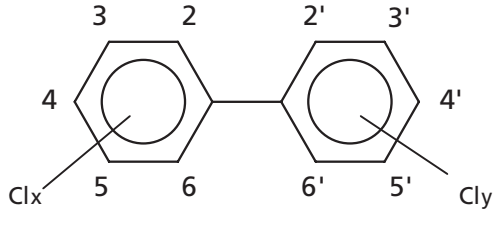


x + y = 1 - 8

There are 135 PCDF congeners. Although they are a separate family of chemicals, they are generally grouped together with PCDDs and the combined family referred to as 'dioxins' or as PCDD/Fs. As with PCDDs, it is the 2,3,7,8-substituted PCDFs that have proven to be toxic, of which there are 10.

Standard reporting format is to quote the individual concentrations of the seventeen toxic PCDD/Fs and to sum the non-2,3,7,8-substituted isomers of each homologue group.

Polychlorinated biphenyls (PCBs)



x + y = 1 - 10

There are 209 different chlorinated biphenyls dependent on the number of chlorine substituents, and the position of these substituents around the biphenyl template. All structural isomers, having the same number of chlorine substituents, are classified as a homologue group. For ease of notation an internationally recognised numbering system has been developed. For example 2,2′5,5′-tetrachlorobiphenyl is numbered PCB 52. The numbering system is described in detail by Ballschmiter and Zell (1980).

Annex B – Toxic Equivalency Factor (TEF) Schemes

Tables A1 and A2 show the toxic equivalency factor (TEFs) schemes that are in most common use for reporting concentrations of mixtures of dioxins and dioxin-like PCBs. Until very recently the majority of data on dioxins have been expressed using International Toxic Equivalency Factors (I-TEF). These factors have been in common use worldwide for the past 10 years or so. In 1997, the World Health Organisation reviewed the TEF scheme and recommended new factors which recognised the different effects seen in humans/mammals, fish and birds. The revised WHO-TEF scheme for humans and mammals has already gained acceptance by a number of international fora, and in the UK the COT has recommended their use in place of the I-TEF scheme.

Table A1: TEF Schemes for dioxins and furans

Congener	I-TEF(1990)	WHO-TEF (1997/8)[1]		
		Human/Mammals	*Fish*	*Birds*
Dioxins				
2,3,7,8-TCDD	1	1	1	1
1,2,3,7,8-PeCDD	0.5	1	1	1
1,2,3,4,7,8-HxCDD	0.1	0.1	0.5	0.05
1,2,3,6,7,8-HxCDD	0.1	0.1	0.01	0.01
1,2,3,7,8,9-HxCDD	0.1	0.1	0.01	0.1
1,2,3,4,6,7,8-HpCDD	0.01	0.01	0.001	$<$0.001
OCDD	0.001	0.0001	-	-
Furans				
2,3,7,8-TCDF	0.1	0.1	0.05	1
1,2,3,7,8-PeCDF	0.05	0.05	0.05	0.1
2,3,4,7,8-PeCDF	0.5	0.5	0.5	1
1,2,3,4,7,8-HxCDF	0.1	0.1	0.1	0.1
1,2,3,7,8,9-HxCDF	0.1	0.1	0.1	0.1
1,2,3,6,7,8-HxCDF	0.1	0.1	0.1	0.1
2,3,4,6,7,8-HxCDF	0.1	0.1	0.1	0.1
1,2,3,4,6,7,8-1HpCDF	0.01	0.01	0.01	0.01
1,2,3,4,7,8,9-HpCDF	0.01	0.01	0.01	0.01
OCDF	0.001	0.0001	0.0001	0.0001

1 Van den Berg *et al.* (1998). Toxic Equivalency Factors for PCBs, PCDDs and PCDFs for Humans and Wildlife. *Environmental Health Perspectives,* **106**, 12.

Until recently dioxin-like PCBs were reported using TEF-factors recommended by Ahlborg et al in 1993, however the UK now uses the revised TEFs for human and mammals as recommended by WHO in 1997.

Table A2: TEF factors used for dioxin-like PCBs

Congener	Ahlborg et al (1993)[1]	WHO-TEF (1997/8)[4]		
		Human/mammals	*Fish*	*Birds*
Non-ortho PCBs				
3,4,4′,5-TCB (81)	-	0.0001	0.0005	0.1
3,3′,4,4′-TCB (77)	0.0005	0.0001	0.0001	0.05
3,3′,4,4′,5PeCB (126)	0.1	0.1	0.005	0.1
3,3′,4,4′,5,5′-HxCB(169)	0.01	0.01	0.00005	0.001
Mono-ortho				
2,3,3′,4,4′-PeCB (105)	0.0001	0.0001	<0.000005	0.0001
2,3,4,4′,5-PeCB (114)	0.0005	0.0005	<0.000005	0.0001
2,3′,4,4′,5-PeCB (118)	0.0001	0.0001	<0.000005	0.00001
2′,3,4,4′,5-PeCB (123)	0.0001	0.0001	<0.000005	0.00001
2,3,3′,4,4′,5-HxCB (156)	0.0005	0.0005	<0.000005	0.0001
2,3,3′,4,4′,5′-HxCB (157)	0.0005	0.0005	<0.000005	0.0001
2,3′,4,4′,5,5′-HxCB (167)	0.00001	0.00001	<0.000005	0.00001
2,3,3′,4,4′,5,5′-HpCB (189)	0.0001	0.0001	<0.000005	0.00001
Di-ortho				
2,2′,3,3′,4,4′,5-HpCB (170)	0.0001	0		
2,2′,3,4,4′,5,5′-HpCB (180)	0.00001	0		

1 From Ahlborg UG *et al* TEFs for dioxin-like PCB – Report on a WHO-ECEH and IPCS Consultation December 1993.

For both tables the shaded elements indicate values that have differences between the old schemes and new scheme used in the UK.

Annex C – Glossary of Terms and Units Used

BAT – best available technique
COC – Committee on Carcinogenicity of Chemicals in Food, Consumer Products and the Environment
COMA – Committee on Medical Aspects of Food Policy
COMAH – Control of Major Accident Hazard Regulations 1999
COSHH – Control of Substances Hazardous to Health Regulations 1999
COT – Committee on the Toxicity of Chemicals in Food, Consumer Products and the Environment
DEFRA – Department for Environment, Food and Rural Affairs
DETR – Department of the Environment, Transport and the Regions
Dioxin-like PCB – PCB congener which has toxicity similar to the most toxic dioxin congener (2,3,7,8-tetrachlorodibenzo-*p*-dioxin) and which is assigned a TEF value (see Annex B)
EPA – Environmental Protection Act 1990
Exposure is expressed in pg TEQ/kg bw/d – picograms toxic equivalent per kilogram of body weight per day
fg – femtogram (10^{-15} g)
FSA – Food Standards Agency
HMIP – Her Majesty's Inspectorate of Pollution
HSE – Health and Safety Executive
IDG – Interdepartmental Group on Dioxins
IPC – Integrated Pollution Control (Regulations)
IPCS – International Programme on Chemical Safety
IPPC – Integrated Pollution Prevention and Control (Directive 96/61/EC)
LAPC – Local Air Pollution Control
MAFF – Ministry of Agriculture, Fisheries and Food
MEL – Maximum Exposure Limit
NAEI – National Atmospheric Emissions Inventory
ng – nanogram (10^{-9} g)
OSPAR – Oslo and Paris Commission
PCB – polychlorinated biphenyl
PCDD – polychlorinated dibenzo-*p*-dioxins (also known as 'dioxins')
PCDD/F – mixture of congeners of PCDD and PCDF (referred to collectively as 'dioxins' in this consultation paper)
PCDF – polychlorinated dibenzofurans (also known as 'furans')
pg – picogram (10^{-12} g)
PPC – Pollution Prevention and Control (Regulations)
SAB – US EPA's Scientific Advisory Board
SCF – European Commission's advisory Scientific Committee for Food
SEPA – Scottish Environment Protection Agency
TDI – tolerable daily intake
TDS – Total Diet Surveys
TEF – toxic equivalency factor (see Annex B)
TEQ – toxic equivalent concentration
TWI – tolerable weekly intake
UNECE – United Nations Economic Commission for Europe
UNEP – United Nations Environment Programme
WHO – World Health Organisation
WHO-ECEH – World Health Organisation European Centre for Environment and Health

Annex D – Recent and Current Government Funded Research and Monitoring

Area of Research/ Project title	Funding Dept.	Start/End date	Contractor	References
Environmental exposure				
Polychlorinated biphenyls, dioxins and furans in the Pontypool environment	Welsh Office	1990/94	University of East Anglia	PCBs, dioxins and furans in the Pontypool Environment – the Panteg monitoring project: 4th report (April 93) 5th report (Jan 94) 6th Report (April 94)
Study of PCBs and dioxins in human adipose tissue from inhabitants of 5 areas of Wales	Welsh Office	1990/94	Lancaster University	Duarte-Davidson *et al* (1994) PCBs and other organochlorines in human tissue samples from the welsh population: – adipose Env Poll 84 p69-77
Examination of sewage sludges for dioxins and furans	DETR	1993	Lab of the Govt Chemist	
A review of dioxin emissions in the UK	HMIP	1994 /95	Environmental Resources management	Research report no: DOE/ HMIP/RR/95/004
Risk assessment of dioxin releases from municipal waste incineration processes	HMIP	1995/96	Environmental Resources management	DOE Reference: HMIP/ CPR2/41/1/181
Dioxin inputs to the environment: a review of temporal trend data	DETR	1995/96	Lancaster University	DoE Reference: EPG/1/5/53
Monitoring of dioxins and furans in the environmental media	HMIP	1995	AEA Technology	Report No: AEAT/18380031/REMA-152
Regulation of dioxin releases from the Runcorn operations of ICI and EVC	Env. Agency	1996/97	Environment Agency	Environment Agency Information report (Jan 97)
Dioxins and furans in sewage sludge: A review	DETR; UKWIR		Lancaster University	

Area of Research/ Project title	Funding Dept.	Start/End date	Contractor	References
Measurement of dioxins in sewage sludge and milk	DTI	1996/98	Laboratory of the Government Chemist (LGC)	Project in the Government Chemist Programme 1996/01
Monitoring of hazardous air pollutants	DETR; NAW; SE; DOE-NI	1996/99	AEA Technology and Lancaster University	Toxic Organic Micro-pollutant Monitoring 1996 to 1999 (Sept 99) AEAT-4970
A review of dioxin releases to land and water in the UK	EA	1997	AEA Technology	ISBN I 873160 40 2
A study of dioxins and trace metals in soil around 4 municipal waste incinerators in Hampshire	EA	1997	AEA Technology	Environment Agency Report HO-7/97-160-C-AZLM
PCBs in building sealants	DETR	1997	Building Research Establishment	PCBs in building sealants: CR 168/97
Polychlorinated biphenyls in building sealants: A review of health effects and exposure to	DETR	1997/99	Institute of Environment and Health, Leicester	IEH Report, Feb 99
Releases of PCBs to the UK environment	DETR	1997/99	ETSU	Report no AEAT-2731
Compilation of EU dioxin exposure and health data	EU DGXI; DETR	1998/99	AEA Technology	Published on EC website at: http://europa.eu.int/comm/environment/dioxin/index.htm
Dioxins and PCB releases from Industrial sources	EA	1998/2000	PD Consulting	
Organics in sewage sludge	DETR; EA; UKWIR		Lancaster University	
Dioxins in the UK: Preparation of UK position paper on dioxins	DETR	1998/2000	PD Consulting	
Dioxins in the UK: projection of future exposure	DETR		Lancaster University	

Area of Research/ Project title	Funding Dept.	Start/End date	Contractor	References
Chemical contaminants in human milk: A pilot study towards establishing an archive of samples from the UK	MAFF; DH; HSE; DETR	Start 2000	University of Leeds	
UK soil survey Monitoring of hazardous air pollutants	EA DETR, EA, SE, NAW, DOENI	2000 2000		
1.4 Dietary exposure				
Survey of dioxins and PCBs in background foods	MAFF	1994/98	Central Science Laboratory, Norwich	FSIS 71 (July 95) Dioxins in food - UK dietary intakes; FSIS 105 (June 97) Dioxins and PCBs in food and human milk; FSIS 89 (May 96) PCB in food- UK dietary intakes; FSIS 88 (May96) Dioxins in human milk; FSIS 106 (June 97) Dioxins and PCBs in fish oil dietary supplements and licensed medicines
Survey of dioxins and PCBs in hen and duck eggs.	MAFF	1994/98	Central Science Laboratory, Norwich	Summary report (June 2001). Dioxins and dioxin-like PCBs in eggs.
Dioxins in PVC food packaging	MAFF	1994/95	AEA Technology	FSIS 59 (April 95) dioxins in PVC food packaging
Dietary uptake, distribution and depletion of dioxins in cattle	MAFF	1994/95	Institute for Animal Health, Crompton	Thorpe *et al* (1999) Residue depletion study of PCDDs and PCDFs in dosed beef cattle. Organohalogen Compounds 43 405-408.
Mass balance and distribution studies of PCBs in grazing animals.	MAFF	1994/98	University of Lancaster	• Sweetman, A J *et al* (1999) Modelling the fate and behaviour of lipophilic organic contaminants in lactating dairy cows. Environ. Pollut. 104: pp261-270 • Thomas, G O *et al* (1998) Development and validation of methods for the trace determination of PCBs in biological matrices. Chemosphere 36: pp2447-2459

Area of Research/ Project title	Funding Dept.	Start/End date	Contractor	References
				• Thomas, G O *et al* (1998) Air-pasture transfer of PCBs. Environ. Sci. Technol. 32: pp936-942 Thomas, G O *et al* (1998) Further studies of the air-pasture transfer of PCBs. Environ. Pollut. 102: pp119-128 • Thomas, G O *et al* (1999) Derivation and field testing of air-milk and feed-milk transfer factors for PCBs. Environ. Sci. Technol. 32: pp3522-3528 • Thomas, G O *et al* (1999) Metabolism and body-burden of polychlorinated biphenyls in lactating dairy cows. Chemosphere 39: pp1533-1544. • Thomas, G O *et al* (1999) Input-output balance of PCBs in a long-term study of lactating dairy cows. Environ Sci Technol 33: pp104-112
Survey of dioxins and PCBs in retail cows' milk.	MAFF	1995/97	Central Science Laboratory, Norwich	FSIS 136 (Dec 97) Dioxins and PCBs in retail cows milk in England
Survey of dioxins, furans and PCBs in edible marine fish and fish products.	MAFF	1995/97	Central Science Laboratory, Norwich	FSIS 184 (Aug 99) Dioxins and PCBs in UK and imported marine fish;
Survey of dioxins and PCBs in farmed trout in England and Wales	MAFF	1995/97	Central Science Laboratory, Norwich	FSIS 145 (March 98) Dioxins and PCBs in farmed trout in England and Wales
Survey of PCBs in paper and board packaging	MAFF	1996/98	Central Science Laboratory, Norwich	FSIS 174 (April 99) Survey of Retail Paper and Board Food Packaging Materials for PCBs
Investigation of effects of cooking and other processing on the nature and levels of dioxin residues in beef tissues	MAFF	1996/97	Central Science Laboratory, Norwich	Thorpe *et al* (1999) The effects of cooking by various methods on concentrations of PCDDs and PCDFs in bovine meat. Organhalogen compounds 44 p 237-240

Area of Research/ Project title	Funding Dept.	Start/End date	Contractor	References
Generic model of human terrestrial food chain exposure to persistent organics: application to dioxins, furans and PCBs.	MAFF	1996/97	University of Lancaster	
Survey of dioxins and PCBs in shellfish.	MAFF	1997/99	Central Science Laboratory, Norwich	Not yet published. Follow up work in progress
Survey of dioxins and PCBs in fats and oils for food production.	MAFF	1997/99	Central Science Laboratory, Norwich	Not yet published
Survey of dioxins and PCBs in infant formulae.	MAFF	1997/99	Central Science Laboratory, Norwich	Not yet published. Follow up work in progress
Dioxins and PCBs in 1997 Total Diet Study samples	MAFF	1998/99	Central Science Laboratory, Norwich	
Study of the effect of dioxins and PCBs in river sediment, deposited on pasture by flooding, on concentrations in cows' milk	MAFF	1998/2000	Central Science Laboratory, Norwich	
Measuring the bioavailability of human dietary intake of dioxin-like compounds	MAFF	1998/2000	Birmingham University	
Survey of dioxins and PCBs in cows' milk from farms in the Bolsover area.	MAFF	Rolling programme	Central Science Laboratory, Norwich	FSIS 75 (Nov 95) Dioxins and PCBs in cows milk from the Bolsover area; FSIS 124 (Aug 97) same title; FSIS 134 (Nov 97) Oct 97; FSIS 143 (March 98) collected in Oct and Nov 1997
Survey of Dioxins and PCBs in marine fish and dietary supplement fish oils –1996	MAFF	1995/99 (fish oil supplement data reported in 1999)	Central Science Laboratory, Norwich	FS2649

Area of Research/ Project title	Funding Dept.	Start/End date	Contractor	References
Survey of dioxins and PCBs in foods and human milk	MAFF	1994/97	Central Science Laboratory	(ED/29)
Survey of background levels of dioxins and furans in cows milk from Northern Ireland	MAFF	1995/97	Central Science Laboratory	FS2651
Survey of dioxins and PCBs in farmed freshwater fish.	MAFF	1995/97	Central Science Laboratory, Norwich	
Survey of dioxins and PCBs in cows' milk from the vicinity of industrial sites.	MAFF	rolling programme	Central Science Laboratory, Norwich	FSIS 100 (Jan 97) Dioxins and PCBs in cows milk from farms close to industrial sites; FSIS 107 (June 97) same title; FSIS 123 (Aug 97) 1996 survey results; FSIS 133 (Nov 97) Rotherham 1997; FSIS 135 (Nov 97) Huddersfield 1997;
1.5 Test Methods				
Pilot assessment of the feasibility of using a commercially available immunoassay for the screening of dioxins in food.	MAFF	1995/98	Central Science Laboratory, Norwich	MAFF R&D and Surveillance Reports No 453: Pilot assessment of applicability of commercial immunoassay kits to screening for dioxins in food extracts
Inter-laboratory method performance of assessment of measurement of PCDDs and PCDFs in sewage sludge	DETR; MAFF	1996	Central Science Laboratory	FD 94/207: Inter-laboratory Method Performance Assessment of Measurement of PCDDs and PCDFs in Sewage Sludge. Part 1. Study Conduct and Results (+ appendices)
Evaluation for immunochemical methods for PCBs in fish oil.	MAFF	1996/97	Laboratory of the Government Chemist	
Development and evaluation of methodology based on digestion and solid phase extraction for the isolation of dioxins and PCBs from liquid milk.	MAFF	1996/97	Central Science Laboratory, Norwich	FD 96/116: Development and evaluation of methodology based on digestion and solid phase extraction for the isolation of PCDDs, PCDFs and PCBs from liquid milk

Area of Research/ Project title	Funding Dept.	Start/End date	Contractor	References
Selective extraction of PCBs from both aqueous and oleaginous foodstuffs using recycling perfluorocarbon fluids	MAFF	1996/97	Chimaeron	CSL Report FD 00/38: Rapid single step PCB extraction from liquid milk using perfluorocarbon fluids*
A simple robust assay for dioxins in foods using a fluorescent liposome enhanced immunostrip	MAFF	1997/98	IFR, Norwich	
Rapid single step PCB extraction from liquid milk using perfluorocarbon fluids	MAFF	1998/99	Chimaeron Ltd, Central Science Laboratory, Norwich	CSL Report FD 00/38: Rapid single step PCB extraction from liquid milk using perfluorocarbon fluids* * joint projects with a combined report

Annex E

COMMITTEE ON TOXICITY OF CHEMICALS IN FOOD, CONSUMER PRODUCTS AND THE ENVIRONMENT

STATEMENT ON THE TOLERABLE DAILY INTAKE FOR DIOXINS AND DIOXIN-LIKE POLYCHLORINATED BIPHENYLS

Introduction

Dioxins and polychlorinated biphenyls (PCBs)

1. Dioxins are persistent organochlorine compounds that are widely dispersed environmental contaminants and which accumulate in fatty foods. The term ''dioxins'' is commonly used to refer to a group of 75 polychlorinated dibenzo-*p*-dioxin (PCDD) and 135 polychlorinated dibenzofuran (PCDF) congeners, of which less than 20 are considered to be biologically active. Dioxins are produced in a number of thermal reactions, including incineration of municipal waste, domestic fires and bonfires, forest fires and internal combustion in automobile engines. They are also generated as trace contaminants during the synthesis of many organochlorine compounds (e.g. chlorophenoxy herbicides such as hexachlorophene, chlorodiphenyl ether herbicides) and during some industrial processes (e.g. bleaching of pulp and paper with chlorine gas).

2. Polychlorinated biphenyls (PCBs) are environmentally stable, lipophilic chemicals that were widely manufactured for a range of industrial applications between the 1930s and 1970s. Use of PCBs for industrial purposes has been discontinued but these substances may still be released to the environment during disposal of materials and obsolete equipment. There are 209 theoretically possible PCB congeners, of which 12 non-*ortho* or mono-*ortho* compounds exhibit similar biological activity to PCDDs and PCDFs, and are therefore referred to as ''dioxin-like PCBs''.

3. There is continuing public concern about the health hazards of dioxins and related compounds. These compounds are persistent in the environment and tend to accumulate in biological systems. One of the most extensively studied PCDD congeners, 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), exhibits a broad range of toxic effects in laboratory animals, some at very low doses.

4. Exposure of the general population to dioxins and dioxin-like PCBs is primarily from food. The estimated exposures from the UK Total Diet Study samples for all age groups have declined substantially. In 1982, average intakes for dioxins and dioxin-like PCBs were 7.2 and 18 pg TEQ/kg bw/day for adults and toddlers, respectively. In 1997 the averages had fallen to 1.8 and 4.6 pg TEQ/kg bw/day for adults and toddlers, respectively.[1] Over the same period, the intake estimates for high level (97.5th percentile) consumers have fallen from 13 and 28 pg TEQ/kg bw/day to 3.1 and 7.2 TEQ/kg bw/day, for adults and toddlers, respectively. Dioxins and PCBs are detectable in almost all types of food. Highest concentrations are found in meat, fish, eggs and dairy products. However, cereals, fats and oils contribute significant proportions of the total dioxin and PCB intake because they are major components of the diet. The decline has been attributed in part to controls on emissions to the environment and the discontinuation of production and use of dioxin-like PCBs. It

is anticipated that exposures will continue to decline with present and planned environmental controls.

5. The highest dioxin exposures in humans have generally been associated with occupational exposure or accidental contamination of the environment or edible oils. Occupational exposure studies have been undertaken at plants in the USA, Germany, the Netherlands and the UK that manufacture chlorophenols and/or chlorophenoxy herbicides. Application of chlorophenoxy herbicides has been associated with much lower levels of exposure. Exposures to more highly chlorinated PCDDs have been estimated for workers exposed to pentachlorophenol and/or other chlorophenates at saw mills or manufacturing plants. In addition, an explosion in a chemical plant at Seveso in 1976, resulted in widespread release of TCDD to the environment and exposure of the local population. The ingestion of edible oils contaminated with high levels of polychlorinated compounds including PCBs and PCDFs was associated with toxicity in food poisoning incidents in Yusho and Yu-Cheng, which we reviewed in 1997.[2]

Previous COT evaluations

6. The COT and our sister Committees on Carcinogenicity (COC) and Mutagenicity (COM) have considered dioxins and dioxin-like PCBs on several occasions in the past.[1-8] In 1989 we made a comprehensive statement about the health hazards of PCDDs and PCDFs.[3] We made a second statement in 1991 when UK exposure data on these compounds from food became available.[4] On that occasion, we endorsed the Tolerable Daily Intake (TDI) of 10 pg/kg bw/day 2,3,7,8-TCDD recommended by an expert group convened by the WHO Regional Office for Europe[9] and we recommended that, when considering mixtures of PCDDs and PCDFs, the TDI can be regarded as 10 pg/kg bw/day 2,3,7,8-TCDD Equivalents (TEQ). We further stated that, in view of the estimated long elimination half-lives of this class of compounds, it would be more appropriate to regard the TDI as a time-weighted average tolerable intake. We reviewed PCDD and PCDFs again in 1995, when we concluded that the new information available at that time did not necessitate the alteration of the previously agreed TDI.[6]

7. The Toxic Equivalency Factor (TEF) approach was initially used to facilitate risk assessment of PCDDs and PCDFs (i.e. dioxins). In 1997, we tentatively accepted that the TEF approach could be extended to include the dioxin-like PCB congeners[2] and in 1998 we endorsed the revised WHO-TEFs for dioxins and dioxin-like PCBs.[7]

Recent International evaluations

World Health Organisation

8. In 1998 the WHO European Centre for Environment and Health (WHO-ECEH) and the International Programme on Chemical Safety (IPCS) conducted a re-evaluation of the TDI for dioxins and dioxin-like PCBs. The Executive Summary of this report was published in a special issue of Food Additives and Contaminants[10], devoted to the 1998 WHO-ECEH/IPCS Consultation on Dioxins, allowing an evaluation of the basis on which the WHO consultation reached its conclusions.

9. The WHO consultation recommended a TDI for dioxins and dioxin-like PCBs of 1-4 pg WHO-TEQ/kg based on the NOAEL/LOAELs of those effects considered

to be the most sensitive in experimental animals, namely endometriosis, developmental neurobehavioural effects, developmental reproductive effects and immunotoxicity.

Scientific Committee on Food

10. The Scientific Committee on Food (SCF) undertook a reassessment of the TDI for dioxins and dioxin-like PCBs for the European Union, adopting a temporary opinion in November 2000. This was revised in June 2001, in the light of newly published data allowing calculation of the total amount of dioxin in the fetus (the fetal body burden) associated with maternal exposure at steady state.[11] The SCF concluded that, because TCDD and related compounds have very long half-lives in the human body, the tolerable intake should be expressed on a weekly rather than a daily basis. Based on the LOAEL from a study showing developmental effects in male rat offspring following repeated subcutaneous administration of TCDD[12], the SCF established a tolerable weekly intake (TWI) of 14 pg WHO-TEQ/kg bw.[13]

Joint FAO/WHO Expert Committee on Food Additives

11. The Joint FAO/WHO Expert Committee on Food Additives (JECFA) also considered dioxins and dioxin-like PCBs in June 2001. The JECFA used a similar body burden approach to that used by the SCF and also took into account exposure from background contamination considered to be present in feed provided to laboratory animals. It proposed a provisional tolerable monthly intake (PTMI) of 70 pg WHO-TEQ/kg bw[14], based upon the lowest LOAEL and a NOAEL for developmental effects in male rat offspring.[12,15]

Environmental Protection Agency

12. The U.S. Environmental Protection Agency (EPA) commenced a reassessment of dioxin exposure and human health effects entitled, ''Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds'' in April 1991. In 1994, it released its initial external review draft describing health effects and exposures. In our 1995 statement[6], we welcomed the US EPA initiative to investigate further the health hazards of 2,3,7,8-TCDD and related compounds. The document provided a thorough review of the literature on the effects of these compounds on various biological systems. However, we did not consider it provided any new information or analysis that necessitated the alteration of the previously agreed TDI of 10pg TEQ/kg bw/day or of our previous advice.

13. Following public comment and advice from its Science Advisory Board, the EPA undertook an extensive revision of its review, particularly two key sections on Dose-Response Modelling and Integrated Summary and Risk Characterization.[16] These chapters were subject to public comment and further Science Advisory Board review during late 2000 and Spring 2001. The EPA's draft assessment considered that cancer was the most appropriate end-point for risk assessment and undertook an evaluation based on their risk assessment guidelines for carcinogens. The results of this evaluation are not yet available.

Evidence considered in the current evaluation

14. In 2000, we were asked to review the risk assessments of dioxins carried out by the WHO, the SCF, and the US-EPA. We concluded that it was appropriate

to conduct our own evaluation of the data, informed by these international assessments and other relevant information, before reconsidering the TDI for dioxins and dioxin-like PCBs. As part of this evaluation it was essential that the evidence concerning human cancer risks for dioxins be evaluated to determine whether or not it is appropriate to assume the existence of a threshold and hence whether a TDI could be established. We are grateful for the assistance provided by the COC and we have taken account of its conclusions[17] in completing our evaluation.

15. In undertaking our evaluation we have had access to the published assessments of all three international evaluations. The EPA documents provided the most detailed and comprehensive review of the published literature. We have supplemented this by evaluation of the original publications identifying critical end-points and recently published data.

Mechanism(s) of action of TCDD

16. Most of the actions of TCDD and related compounds can be ascribed to the consequences of an initial binding to what has become known as the Ah or aryl hydrocarbon receptor (AHR), although this binding protein is now more properly termed a ligand activated transcription factor. This binding results in multiple changes in gene transcription leading to increases in biotransformation enzymes, modulation of cell cycling proteins and other responses. Inappropriate gene expression resulting from the high affinity binding and long term occupancy of the receptor may be the basis of the toxicity of TCDD. However, although the mechanisms of early molecular changes are well understood, the relationship between changes in gene regulation and observed toxicity is still unresolved.

17. It has become apparent that the sequence of events from TCDD binding to gene transcription involves other transcription factors, chaperones (such as HSP90) and regulatory proteins. The net result is the association of TCDD-AHR with another factor, the Ah receptor nuclear translocator (ARNT), in the nucleus followed by binding of the complex to 'dioxin' responsive regulatory elements (DREs) in enhancer regions upstream of particular genes. Downstream activation of promoter regions then occurs with production of mRNA from the genes. Most of the molecular events for transcription of the CYP1A1 gene have been elucidated. For other genes the sequence of events is far less clear but probably occurs in a similar manner[18] and the number of known AHR-regulated genes is still increasing.

18. Mechanistic studies on the role of the AHR in the toxicity of TCDD have shown that proteins similar to the AHR have been found in many organisms suggesting that this receptor has an essential biological function[19]. Sequencing studies on the AHR have shown that it is a member of a family of gene regulating proteins known as PAS (PER-ARNT-SIM)[20]. In mammals, these proteins (which include hypoxia inducible factor 1-α [HIF1α] and ARNT) regulate the transcription of specific genes. Heterodimerisation of the AHR with ARNT is apparently essential for the TCDD activated AHR to induce specific DNA binding and transactivation *in vitro*. However, heterodimerisation of ARNT can also occur with HIF1α and with a newly discovered factor AHR repressor (AHRR).[21] TCDD/AHR might act by competing against these, or even competing against the binding of a hypothetical normal endogenous ligand of the AHR that has yet to be found. Other studies have shown that levels of the AHR, AHRR, ARNT and HIF1α may be regulated by cell type and activation and by stages of growth and differentiation.[22]

19. A number of lines of evidence *in vivo* support the role of AHR in TCDD toxicity. For instance, polymorphism of the AHR, with varying affinities for TCDD, in mice correlates with variable susceptibility to toxic effects.[23] Different strains of mice that do not possess the functioning gene for the AHR (referred to as *Ahr* null or 'AHR knockout' mice) have been shown to be extremely resistant to very high doses of TCDD for a variety of toxic endpoints. Binding capabilities of dioxins and dioxin-like PCBs to the AHR, as shown by structure activity relationships, generally show similar ranked order to their elicitation of biochemical responses.

20. However, in seeking to understand the mechanisms of action in order to inform risk assessment, it might be inappropriate to place exclusive emphasis on the AHR. At very high doses of TCDD (in the *Ahr* null mouse) the chemical may have toxic actions which are not mediated by the receptor. Similarly, in some *in vitro* experiments, various effects of TCDD have been interpreted as non-AHR dependent.

21. In terms of binding to the AHR, some ligands may be competitors of TCDD-induced gene regulation. Conditional disruption of the *Arnt* gene has recently shown that ARNT is required for AHR-stimulated gene activation by TCDD in liver, but this association has yet to be extended to toxicity.[24] Other, as yet unidentified, AHR ligands may be present, or TCDD-AHR complex may participate in cell dysfunction by unknown routes not involving the regulation of gene expression via DREs and ARNT. Although no endogenous ligand of AHR has been proven, a number of naturally derived chemicals are ligands.

22. Some data suggest that the binding affinity, and the effect of binding, of TCDD to the AHR, are much lower in humans than in rodents, even the resistant DBA/2 mouse.[25] This could contribute an extra safety margin but the difference in response may vary with endpoint. Some polymorphisms of the human AHR gene have been reported but the functional significance of these polymorphisms is still under investigation.[26] We note that, in view of this uncertainty, it is not possible to exclude the possibility that the most sensitive humans are as responsive as the most sensitive rodents. Overall, we agree that the evidence that toxicity is mediated via the AHR, and the limited evidence that dioxin/receptor interaction does not inevitably lead to a toxic response, are sufficient to consider a threshold approach to the risk assessment.

Toxicokinetics of dioxins

Absorption

23. The extent of gastrointestinal absorption of dioxins is reported to vary with the medium or vehicle of administration, and the lipophilicity of the individual congeners. The percentage absorption of TCDD is approximately 60% in rodents.[27] Similar absorption has been reported for other chlorinated dibenzodioxins and dibenzofurans, although the absorption of octachlorodibenzodioxin (OCDD) is less than 20%. PCDDs and PCDFs are incompletely absorbed because they are not in solution within the gut lumen, and absorption is dependent on the digestion and emulsification of the food matrix.

Distribution

24. Once absorbed, probably via chylomicrons, TCDD rapidly leaves the blood compartment with a distribution half-life of approximately 30 minutes in rats, after

which time it is primarily found in adipose tissue, the liver, skin, muscle and other tissues. TCDD present within the blood is largely associated with lipoproteins. Studies in rats have shown that after initial rapid distribution there is a slower redistribution from muscle and other organs, primarily to the liver and adipose tissue, skin and thyroid gland; the concentrations in these organs show a slow increase over a period of about 4 days following a single intraperitoneal dose.[28] This pattern of distribution is probably representative of distribution in humans and there is a high correlation between adipose tissue concentrations and the levels in serum.

25. The duration of the distribution phase is very short compared with the elimination phase. After tissue distribution, which takes about 4 days, *in vivo* elimination is adequately represented by a single mono-exponential decrease and half-life. The distribution phase is important in the interpretation of effects produced *in utero* in rats after a single oral dose given late in pregnancy, which are the basis for determining the tolerable intake.

Metabolism and elimination

26. Although early studies suggested that TCDD is not metabolised, it is now recognised that it is slowly converted to polar metabolites that are eliminated as glucuronides. The main metabolites of TCDD formed with rat hepatocytes *in vitro* are 1-hydroxy-2,3,7,8-TCDD and 8-hydroxy-2,3,7-TCDD. Other metabolites have been identified in dog, including tri- and dichloro-hydroxy and dihydroxy- compounds. Oxidative metabolism does not appear to give rise to significant bioactivation or formation of DNA adducts and the limited available data indicate that the metabolites are less toxic than the parent compound.[29] A major route of elimination of the hydroxy-metabolites is as glucuronic acid conjugates in the bile. Unmetabolised PCDDs and PCDFs are not detected in bile but are excreted in the faeces and faecal fat by direct intestinal elimination.

27. The half-life of TCDD has been reported to be about 20 days in the rat, 12 days in mice, 90 days in the guinea pig and between 6 and 11 years in humans.[28,30-32] The elimination half-life in humans correlates positively with the percentage body fat, indicating slower elimination in individuals with higher fat composition. Consistent with this is evidence suggesting an age-related decrease in half-life in the elderly, as the fat stores are mobilised during redistribution from the subcutaneous to abdominal areas[33]. Mobilisation of fat stores during lactation contributes to the presence of dioxins in breast milk[34], and this is associated with a decrease in the maternal body burden during breast-feeding.

Human data

Introduction

28. The human effects observed in one or more studies are summarised in Table 1. In assessing the effects of dioxins and dioxin-like PCBs in humans, we have selected those studies that provide the most information on the relationship between outcomes and exposure to TCDD-contaminated materials. Case reports were not reviewed and only cohort studies with calculated standardised mortality ratios (SMRs) or equivalent, were discussed in assessing mortality. Many of the studies reviewed are cross-sectional in design and there are inherent limitations of this type of study. We noted that the lack of adequate exposure data was a frequent limitation

Table 1. Effects associated with human exposure to dioxins.

Effect	Epidemiological evidence
Chloracne	Proven association No clear dose relationship
Gastrointestinal effects and liver enzymes	Transient increases in some liver enzymes
Cardiovascular diseases	Positive association in occupational studies, but not in airforce veterans exposed to herbicides in Vietnam (Operation Ranch Hand). Dose-response in some studies
Changes in lipid levels	Results not consistent
Diabetes	Overall results not consistent Increased risks of morbidity in Seveso and Ranch Hand study
Reproductive hormones	Inconsistent results
Reproductive outcomes	Change in sex ratio of offspring with highly exposed fathers in Seveso No data yet on possible effects such as endometriosis and fertility in women – Seveso endometriosis study on-going
Thyroid function	Results not entirely consistent. Some small differences reported in thyroid hormone uptake levels.
Neurological / psychological effects	Inconsistent findings. Some effects reported in Ranch Hand study and Seveso (polyneuropathies, abnormal co-ordination) No association with depression
Respiratory system	Inconsistent evidence Irritative effects and reduced lung function in some studies
Urinary system	No major renal or bladder dysfunctions observed.
Immunological effects	Inconsistent findings.
Neurobehavioural developmental effects	Some observed differences in on-going Dutch studies
Cancer	Regarded as a probable human carcinogen (based on human, animal and mechanistic data)

of the available epidemiology. Exposure is measured in different media and expressed in different units across the studies, which makes comparison difficult. Some studies were only able to use indirect estimates of exposure, which cannot be directly related to dioxin levels. Development of a tolerable intake requires studies with quantitative assessment of exposure.

29. We focused our evaluation on studies in which exposure was assessed by measurement of dioxin concentrations in serum or body fat, which could be correlated with body burden and intake. The body burdens in human studies have been estimated in two ways. Firstly, the body burden may be calculated from the concentrations of dioxins in lipid and the percentage body composition as fat. This does not allow adequately for sequestration of dioxins within the liver, but this should produce only a minor error in the calculation of body burden. The second method is calculation of the body burden based on estimates of intake and half-life. In humans the intakes of dioxins will have varied historically and there is uncertainty about past exposures. In addition, little is known about the half-life of dioxins and dioxin-like PCBs at different life stages. Calculation of body burden based on daily intake has to allow for the bioavailability from the food matrix and the half-life or clearance from the body. A limitation to this method for considering mixtures of dioxins and dioxin-like PCBs is that reliable estimates of the half-life of TCDD and also its congeners are necessary.

30. We also focused on the relationship between exposure and response, particularly (although not exclusively, if other important health end points were investigated) for the health end points that are relevant/comparable to the results of animal studies. We noted that the EPA report identified six studies or series of studies in humans, which measured serum levels of TCDD and compared them with possible health effects.[35-43] We were also informed of an additional study in Dutch chemical workers, which provided exposure data[44] and a series of Dutch studies on cognitive development.[45-53]

31. With the exception of the series of Dutch studies on cognitive development, the studies reported the effects of high level occupational exposure or the results of accidental release. Occupational or accidental exposure would be associated with higher peak body burdens, followed by gradual elimination and were therefore difficult to compare with steady state conditions associated with background human exposure via the diet or with repeated exposure in animal studies. Also, the occupational studies have not addressed the reproductive effects that represent the most sensitive endpoints in the animal studies.

Studies of cognitive development

32. A series of Dutch studies involved cohorts in Rotterdam and Groningen, representing a highly industrialised region and a less industrialised, more rural area, respectively. The cohorts were sub-divided between breast-feeding for a minimum of six weeks and formula fed using a single batch of one commercial formula. Plasma from maternal and cord blood samples and milk samples were analysed for dioxins and PCBs, including some PCB congeners considered not to have dioxin-like properties. The infants were monitored at ages from 3 to 42 months, with assessments of motor and cognitive development, as well as indicators of thyroid function.[46-52] Similar studies were conducted on a smaller cohort in Amsterdam.[53] We invited additional expertise to ensure that these studies were reviewed adequately, particularly the relevance of the methodology, and we gratefully acknowledge the assistance provided.

33. We noted that the measures used were standard for the age of children assessed, and the best available in the absence of an *a priori* hypothesis of specific effects. However, we were informed that in very young children it is only possible to perform crude tests which do not provide a clear distinction between motor and

cognitive development. Such tests therefore serve more as screening tests than definitive measures and thus the interpretation of any observed change may be hard to assess. Tests of motor function had been conducted from shortly after birth until about 30 months of age. Tests of cognitive function were conducted from 3 months to about 42 months. Different patterns had been observed in the studies conducted at different ages and very little change was observed in the middle of the age range. We noted that Prechtl's neurological examination (as conducted on the Rotterdam and Groningen cohort[47,48]) was considered the most stringent, but with the disadvantage of generating a large number of false positives. For infants, the Bayley Scales, based on a very large sample and well standardised, is probably the best instrument. This scale is divided into a mental development index (MDI) that measures how motor tasks (e.g. control of hands) are applied and a psychomotor index (PSI) that measures gross movements (e.g. walking). However, the Bayley Scales provide a measure of timing of appearance of certain skills and not the quality with which they are carried out. We noted that the study used a 1969 version of the test whereas a more advanced version was published in 1993.

34. The paper of Patandin *et al*.[52] reported changes at 42 months using the Kaufman Assessment Battery. This was considered to be critical to our assessment, since cognitive function is stabilising at this age and becomes predictive of function in later life. In contrast, Bayley scales are used for younger age groups (3 months to 3 years) and have low predictivity. The Kaufman scores at 42 months suggested an effect of pre-natal dioxin exposure leading to an effect on cognitive development.

35. It was difficult to determine whether the effects were due to dioxin exposure or to confounding factors. Complex correlations were found between dioxin and PCB levels and confounding factors, such as breast-feeding, smoking and maternal education. Linear regression analysis had been used to assess the influence of confounding factors. It was not clear whether this was appropriate, and the data were insufficient to determine whether the statistical approach might result in over- or under-correction. Overall, if the effects were real, they were most likely to be due to pre-natal exposure. Breast-feeding ameliorated the effects. However concerns over the known and potential confounders made it impossible to reach firm conclusions.

36. We noted that distinction between pre-natal and post-natal exposure to dioxins and PCBs was an issue of concern relating to the Dutch studies. Prenatal exposure was based on analyses at 8 months gestation, and it was not clear whether these were fully representative of exposure throughout pregnancy. However, when considering effects on thyroid function it should be noted that these effects may be confounded by changes in maternal thyroid hormone production prior to thyroid development in the fetus. None of the populations examined in the Dutch studies were considered to have exposures greater than the normal background range, differences were found between industrial and rural locations and there was a very large natural variation. In addition breast-feeding appeared to be a major confounder, with the highest proportion of breast fed infants having the highest dioxin concentration. Similarly level of maternal education appeared to correlate best with high exposure as did smoking. The paucity of information on the mathematical models used in the study made it impossible to determine whether effects were ''real'' or due to confounders.

37. We concluded that it was not possible to determine whether any cognitive changes represented temporarily delayed milestones of development or a persistent

decrement and that follow-up studies were needed. These should be carried out two to three years after the original study or during the teenage years, as increasingly sensitive measures can be used in older children. Decreased variability in older children also tends to make the tests more sensitive. In the absence of such studies we do not consider it possible to come to clearer conclusions about the outcome of dioxin exposure.

Sex ratio

38. A recent study has reported on the sex distribution of children born between 1 April 1977 and 31 December 1996, with one or both parents exposed to TCDD in the Seveso incident, for whom TCDD serum concentrations were available relating to the time of the incident[54]. The exposed individuals were between 3 and 45 years old in 1976. Compared with an unexposed population, there was a dose-related decrease in the proportion of male children born to TCDD-exposed fathers. We note that this difference was statistically significant at paternal serum TCDD concentrations of 118 pg/kg or more. This could be estimated to correspond to a body burden of 24 ng/kg bw, which is equivalent to a daily intake of 12 pg/kg bw/day. However, the high exposure resulting from the Seveso incident is not comparable to steady state exposure, and the body burden derived from the peak serum concentrations in 1976 may not be the most appropriate dose surrogate for reproductive effects occurring in subsequent years.

Endometriosis

39. Eskenazi and co-workers published initial details of the Seveso Women's Health Study[55]. The primary objectives of this study are to investigate whether there is a relationship between TCDD exposure and the following end-points; endometriosis, menstrual cycle characteristics, age at menarche, birth outcomes of pregnancies conceived after 1976, time to conception, clinical infertility and age at menopause. Insufficient results are currently published to assess the effects of TCDD exposure in the Seveso incident on endometriosis and other reproductive end-points in women. We considered that further consideration of female reproductive outcomes should be deferred until further papers on the Seveso Women's Health Study become available.

Immunotoxicity

40. We noted that, compared with studies in experimental animals, there is much less information regarding immunotoxicity in humans. Nevertheless, there are suggestions that human immune function may be less susceptible to TCDD and dioxin-like PCBs than of rodents.

41. Evidence for immunotoxicity in humans resulting from occupational or accidental exposure to TCDD or related PCBs is inconsistent. However, a common feature of some investigations has been a modest exposure-related reduction in the frequency of peripheral CD4 T lymphocytes. The extent to which these effects represent an early indication of immunosuppression is unclear.

42. A recent paper has examined infectious and atopic diseases and immunological parameters in children with background levels of exposure to PCBs.[56] These are the cohorts from Rotterdam discussed in paragraphs 32 to 37, above. A large number of analyses are reported, many of which are simply correlation coefficients

and some of the statistically significant results are likely to have occurred by chance. The authors concluded that exposure to PCBs and dioxins might be associated with a greater susceptibility to infectious diseases and a lower prevalence of allergic diseases. However, we noted a number of contradictions in the reported results, in addition to the uncertainty over control for confounders as noted in paragraph 35. We concluded that the study did not provide convincing evidence of a causal relationship between pre-natal exposure or total body burden to PCBs and increased susceptibility to infectious diseases or decreased incidence of allergic disease.

Cardiovascular disease

43. Some studies have reported a positive association between exposure to TCDD, or to PCDDs and PCDFs, and the incidence of ischaemic heart disease[39,40,42,44]. These studies have indicated that a significant increase in ischaemic heart disease is associated with a body burden at or above 25 ng TCDD/kg bw, or 55 ng TEQ/kg bw for PCDDs and PCDFs. However, they did not adequately allow for confounding by other risk factors, such as smoking and diet. No studies included measurement of dioxin-like PCBs exposure or its contribution to the body burden.

Cancer

44. The Committee on Mutagenicity (COM) and the Committee on Carcinogenicity (COC) considered 2,3,7,8-TCDD in 1988/9 and concluded that this compound was carcinogenic in rodents but that this was unlikely to be due to a mutagenic mechanism. The COC gave further consideration to the carcinogenicity of 2,3,7,8-TCDD in 1993, when more epidemiological data were available. The Committee concluded that the new data strengthened the possibility of an epidemiological link between occupational exposure to 2,3,7,8-TCDD and an increase in total cancers in humans, although there was no consistent association with cancer at any specific anatomical site(s). It was considered that there was insufficient evidence for a clear causal link but it would be prudent at present to regard 2,3,7,8-TCDD as a possible human carcinogen[5].

45. The COC reviewed TCDD in 1998, following the publication of the IARC monograph which concluded that TCDD should be considered as a definite human carcinogen[57]. The COC agreed that TCDD is a potent carcinogen in laboratory animals, but that the information from the most heavily occupationally exposed cohorts suggested that there was, at most, only a weak carcinogenic effect in these individuals. It therefore concluded that there were insufficient epidemiological and toxicological data on TCDD to conclude a causal link with cancer in humans, but it would be prudent to consider TCDD as a ''probable weak human carcinogen''.[58]

46. The COC has reconsidered its 1998 statement in the light of recently published data on cancer epidemiology, including the twenty-year follow-up of the Seveso incident[59], and mechanisms of carcinogenicity. It agreed that TCDD should be regarded as a ''probable human carcinogen'' on the basis of all the available data. The COC agreed that although a precise mechanism for carcinogenesis in laboratory animals or humans could not be elucidated from the available information, the data (i.e. negative genotoxicity in standard assays, and evidence from studies of mechanisms) suggested that a threshold approach to risk assessment was likely to be appropriate. The COC did not consider it possible to quantify the margin-of-safety risk assessment in view of the difficulties in selecting the appropriate metric of exposures. However, it noted that the excess cancer mortality reported in the

heavily exposed industrial cohorts was small and commented that any increased risk of cancer at background levels of exposure is likely to be extremely small and not detectable by current epidemiological methods.[17]

Animal data

47. There are few regulatory rodent toxicity studies and no regulatory non-rodent studies on the dioxins, and most of the available data relate to TCDD. Most of the regulatory toxicity studies were performed at least 20 years ago and cannot be considered adequate for the determination of NOAELs. The recent studies were conducted to non-standard protocols and many of the studies examining the most sensitive end-points also failed to identify NOAELs. We have reviewed the experimental toxicology of TCDD, with particular consideration to those showing effects at the lowest doses.

Immunotoxicity

48. We noted that the available data presented a complicated picture, with diverse protocols, including the use of different species and strains; various routes and durations of exposure and a wide range of doses. Nevertheless, some general points could be made:

49. In rodent studies the most consistent effect is a reduction in antibody responses to sheep red blood cells (SRBC). The SRBC assay is primarily a measure of the integrity of humoral immunity. However, as initiation and maintenance of antibody responses to SRBC requires not only B lymphocytes, but also functional T lymphocytes and antigen processing/presenting cells, this assay provides something of an overall view of adaptive immunity.

50. The most sensitive adverse effect level resulting from exposure to TCDD in which an immune alteration has been implicated was reported by Burleson *et al*[60]. An increased mortality of mice following challenge with influenza A virus was found following a single exposure to 0.1, 0.05 or 0.01 μg/kg TCDD. However, there is no evidence that the observed increase in susceptibility to virus challenge was necessarily attributable to impaired immune function and mortality was not associated with increased titres of virus in the lungs of mice exposed to TCDD. Therefore it could not be concluded that the lowest dose in this study represents the LOAEL for TCDD-induced immunotoxicity in mice.

51. We concur with the conclusion of the WHO, EPA and SCF reviews in considering the studies of Gehrs and colleagues to be important in assessing the immune effects of dioxins.[61, 62] Pregnant rats (Fischer 344 strain) received a single oral dose (on gestational day 14) of 0.1, 0.3, 1.0 or 3.0 μg/kg TCDD. Exposure at all doses was associated with a persistent (up to 14 months) reduction in males of delayed-type hypersensitivity (DTH) responses to bovine serum albumin. Maternal doses of 0.3 μg/kg TCDD and above were required for persistent suppression of DTH reactions in female offspring. On the basis of these investigations it is likely that 0.1 μg/kg TCDD should be regarded as the LOAEL for immune effects in young rats.

52. A second conclusion drawn from these studies was that maximal inhibition of immune function required both lactational and *in utero* exposure. This was more effective than lactational exposure alone, which was in turn more effective that *in*

utero exposure only. It was noted that these differences in potency related to rats and might differ in humans.

Developmental and reproductive toxicity

53. The studies on developmental and reproductive effects in experimental animals mainly involved administration of TCDD alone, but there were comparative data for other congeners on teratogenicity and ovarian function. TCDD was able to elicit a number of different developmental effects although the sensitivity differed. The most sensitive and robust end-point was the effect on epididymal sperm count.

54. The EPA provided an excellent comprehensive review of the literature on developmental and reproductive toxicity, and although some new studies had emerged since it was written these did not have a major impact. The human sensitivity (based on *in vitro* data on embryonic AHR concentrations in different species) appeared to be in the middle of the range shown by experimental animals. Whilst the AHR was clearly implicated in the teratogenicity of TCDD, its role in other developmental effects was less clearly established. The reproductive effects were correlated with body burden at the critical stage of sexual differentiation (GD 15-16, as noted by SCF and JECFA[13,14]) and it appeared that equivalent fetal body burdens on day 16 of gestation were achieved by administration of different bolus doses on day 8 and day 15 of gestation.

55. We noted that the most sensitive end-points were observed following bolus administration and paid careful consideration to the relevance in deriving a tolerable intake. These studies are considered in detail in paragraphs 64-70. We noted that there was evidence to support an extrapolation from a bolus dose to a chronic exposure, as considered in paragraphs 71-74. The only multigeneration study was old[63] and was subjected to detailed evaluation in previous considerations by the Committee.[4] We considered that the results from this multigeneration study supported the body burden estimates but that there were questions about the statistics which required further evaluation.

56. We were informed that data from animal developmental studies did not show differences in the sex ratio of offspring, as had been reported for humans in the Seveso region. However, we accepted the animal studies were not designed specifically to address this issue.

Endometriosis

57. In our 1995 statement we noted a study reporting an increased incidence of endometriosis in rhesus monkeys 10 years after completion of a study in which TCDD was administered in the diet for a period of about 4 years.[64] A recently published paper follows up the same group of monkeys 13 years after completion of the dietary study, reporting that the incidence of endometriosis correlated with serum levels of certain PCB congeners, but not TCDD,.[65] Monkeys involved in a study in which lead was administered were also found to show an association between serum PCB levels and endometriosis. The authors could not account for the source of PCB exposure to these animals.

58. We noted that a number of aspects of this observational study undermined confidence in the results and in the earlier findings and concluded that it was not possible to draw reliable conclusions.

Acute, subchronic and chronic toxicity

59. TCDD causes a wide range of toxic responses after short and long term exposure with large differences in sensitivity between species/strains of animals to particular responses. Most of the reported toxic responses could be produced in every species provided an appropriate dose was given. The wide variability in sensitivity and the particular toxic response produced within and between species, makes it difficult to identify an appropriate endpoint for risk assessment. Lethality (as determined by LD50) varies with species from the highly sensitive guinea pig to the relatively insensitive hamster. There is also considerable variation within species. The value of these studies for risk assessment is doubtful given the age of the various studies, and the use of different strains, dosing regimens, routes of administration and observation period. No single site of toxicity has been identified as the cause of lethality; each species has a different spectrum of organ toxicity with a wasting syndrome and hepatotoxicity as the most common features. The wasting effect occurs in several species, but no single explanation for this effect has been described. Hepatotoxicity includes a wide range of liver effects in many species with rats and mice at the sensitive end and guinea pigs and hamsters as the least sensitive species. There is considerable variation in response within different strains of rat. The chronic dietary administration studies of Kociba *et al.*[66] reported that the lowest dose of 0.001 μg/kg bw/day was a NOAEL for hepatocellular nodules, although low body weights were recorded at various times during the study and only animals surviving to the end of the study were necropsied. In this study, the tumour incidences were significantly increased at a number of sites at the 0.1 μg/kg bw/day dose level.

60. We noted that there was no adequate basis for decisions on acceptable risk levels in humans based on the standard toxicity studies. Two of the most sensitive endpoints across the species seemed to be induction of CYP 1A1 and oxidative stress. Although CYP 1A1 induction is not considered to be a toxic response, it could underlie toxicity resulting from disruption of various endogenous processes. However, we noted that induction of CYP isozymes does not always show a good correlation with responsiveness in different mouse strains, indicating that it cannot be directly linked to toxicity. Oxidative stress had been detected in mouse brain[67], although it was not clear whether this was related to CYP induction.

Overall assessment

Use of body burden as a dose surrogate

61. We considered that the most appropriate measure of exposure for assessing the sensitive endpoints of TCDD toxicity were the associated tissue concentrations, rather than the administered dose. Ideally the concentration in the target tissue would be the most appropriate measure of dose for comparing effects in different species, but this is impracticable for humans. The tissue concentration is directly related to the body burden at steady-state so that calculated body burdens are a valid surrogate. We therefore consider that the exposure/dose-response relationship for TCDD and related compounds should be based on body burden not external dose. The body burden approach allows for the massive interspecies differences in the half-life, and the potential for accumulation. An additional advantage of using body burdens, compared with previous dose-response assessments based on external dose, is that the body burdens can be estimated for occupational and accidental

exposures, and body burden-response relationships assessed. We concur with the recent evaluations that, despite some limitations, the body burden provides the appropriate dose metric, and that there is sufficient scientific evidence to support the use of body burden.

Human daily intakes and body burden

62. Following dietary exposure to dioxins and dioxin-like PCBs, the body burden will be accumulated over a period of 15-30 years in humans, during which time the environmental concentrations of these substances have decreased. In consequence, the body is not truly at steady-state, and hence there will be errors in the daily intake when calculated from current concentrations in body lipids. A pharmacokinetic model that allows for decreasing environmental concentrations with time indicates that the simple steady-state assumption over-estimates daily intake by approximately 20%. Some equations relating daily intake to body burden (based on adipose levels) do not include a specific term for bioavailability, and this would need to be considered for each route/protocol for exposure. This analysis is particularly important in relation to interpretation of human epidemiology studies where the body burden and daily intake is based on analysis of adipose tissue concentrations.

63. Overall, the data indicate that dioxins and dioxin-like PCBs may be associated with a number of effects, including cancer and cardiovascular disease, but generally at body burdens at least 10-fold higher than those occurring in the general population. Most of the studies involve groups that have been exposed to very high levels of dioxins resulting from occupational or accidental exposure and the pattern of exposure does not reflect long-term dietary exposure.

Evaluation

Key studies

64. We conducted a detailed review of the human data linking health effects to dioxin exposure, and a summary of these data is available on the COT website (http://www.foodstandards.gov.uk/committees/cot/summary.htm). We concluded that the available human data did not provide a sufficiently rigorous basis for establishment of a tolerable intake. This was because:

- the epidemiological studies do not reflect the most sensitive population identified by animal studies,
- there are considerable uncertainties in the exposure assessments and inadequate allowance for confounding factors;
- the patterns of exposure did not reflect exposures experienced in the general UK population, which are mainly from diet.

We therefore found it necessary to base our evaluation on the data from studies conducted in experimental animals.

65. In accordance with the advice of the COC[17], we considered it appropriate to take a threshold approach to establishing a tolerable intake. This is based upon the negative genotoxicity in standard assays and evidence from studies of mechanisms.

66. Because a threshold-based approach was considered appropriate, we examined all of the toxicological effects, in addition to cancer, in order to identify the

most sensitive end-points. We concluded that the most sensitive indicators of TCDD toxicity were the effects on the developing reproductive systems of male rat fetuses exposed *in utero*. These data were used despite inconsistencies in the findings reported, and the fact that none of the recent observations were made following sub-chronic or chronic dietary administration that would give constant (steady-state) maternal body burdens. We note that tolerable intakes were also derived from these endpoints in the recent SCF and JECFA evaluations. The key studies used different strains of rats and tended to give contradictory findings. A change in urogenital distance was found after single oral doses given on day 15 of gestation (GD15) of 50ng/kg bw[15], 200ng/kg bw[68] and 1000ng/kg bw[69]. We considered that the data on ano-genital distance were not robust because of lack of correction for body weight or other means of normalisation, and should be regarded as an intermediate marker with no functional significance. Decreases in sperm numbers, production, reserve or morphology were found after single oral doses of 50ng/kg bw and above (GD15)[68-70] and subcutaneous dosage to give a body burden of 25ng/kg bw[12], but not, in one study, at 800ng/kg bw (oral dose on GD15)[15]. Changes in the weight of the urogenital complex, including the ventral prostate were reported after an oral dose of 200ng/kg bw on GD15[15] but not at 300ng/kg bw subcutaneously[12].

67. Despite some inconsistencies, we considered that the effects on sperm production and morphology represented the most sensitive effects. These were indicative of the functional adverse reproductive effects in the rat that were produced by long-term administration in the multigeneration study of Murray *et al* at doses resulting in a 10-fold higher body burden than those in the studies of sperm production[63]. We also note that the sperm reserve in the human male is much less than that in the rat, and therefore these changes are considered relevant. No NOAEL was available for these effects, but the study of Faqi[12] provided the lowest LOAEL. We noted limitations in this study but considered that the results could not be discounted and therefore, that this should be used as the basis for deriving the tolerable intake.

68. We considered that a tolerable intake based on these effects would also protect against any risk of carcinogenicity from dioxins and dioxin-like PCBs. This conclusion is based on the mode of action of dioxins and difference between the body burdens at background levels of exposure and those associated with increased cancer risk as observed by the COC[17].

69. Three of the studies[15,68,70] reported adverse effects in male rat offspring following a single oral dose of TCDD given on GD15, and one[12] following repeated weekly subcutaneous injections. In all cases the effects were observed postnatally and the pattern of both *in utero* and post-natal exposure would be different. Because of the long half-life of TCDD (21 days in rats), and its presence in milk, the male offspring would be exposed to decreasing concentrations until the time of measurements. The recent SCF and JECFA evaluations[13,14] used recently published toxicokinetic studies[11,27] that allow the fetal body burdens to be calculated on GD16, on the assumption that this is the appropriate site of action, and period of sensitivity.

70. We have adopted a similar approach to the SCF and the JECFA. However, in view of the numerous assumptions in this approach (described below), we have used a simplified calculation of fetal and maternal body burdens associated with these different dosage regimens and their conversion to the steady-state dietary intakes that would result in the same fetal body burdens. Calculation of a tolerable intake for humans is complex and requires a number of steps: calculation of the fetal body burden of rats under the experimental conditions; correction of the

corresponding maternal body burden in rats to represent chronic daily intake *via* the diet; the use of uncertainty factors to give an equivalent tolerable human maternal body burden; and finally, derivation of a daily intake by humans that would result in the tolerable human maternal body burden.

Calculation of body burden

71. On the assumption that the critical period of exposure is GD16, the adverse effects following a single oral dose on GD15 would have been initiated at a time when the dose was undergoing tissue distribution. At this time, more of the maternal body burden would have been associated with well-perfused tissues, such as the liver, and the reproductive system and less with adipose tissue. It is possible to estimate the fetal exposure on GD16 by allowing for differences in the maternal dosage protocol using the toxicokinetic data of Hurst *et al*, following a single oral bolus dose on GD15[27] and following dietary administration of 1, 10 and 30ng/kg bw per day for 5 days per week from 13 weeks before mating[11].

72. A problem with the interpretation of the Hurst *et al* papers[11,27], which measured radioactivity after dosage with radioactive TCDD, is that the ratios of maternal to fetal body burdens on GD16 were not independent of dose, as would be predicted for such low doses. This non-linearity is difficult to explain on biological grounds and may have arisen as an artefact of the low levels of radioactivity measured. The SCF evaluation used regression analysis with a power model forced through the origin to correct maternal dosage and derive a correction factor of 2.6 for the higher fetal body burdens when dosed on GD15 compared with daily treatment.[13] These regressions used the ratios of maternal:fetal body burdens in ng/kg bw after single doses of 50 and 200ng/kg bw on GD15[27] (30:5.3 and 97.4:13.2, respectively) and after daily oral doses equivalent to 0.71, 7.1 and 21.3ng/kg bw/day[11] (20:1.4, 120:7.5 and 300:15.2 respectively). The JECFA evaluation confirmed the results of the power model but also used a linear model that gave a correction factor of 1.7, and the JECFA concluded that both models fitted equally well to the available data.[14] Although the power and linear models fitted equally well, they gave different correction factors, especially at very low body burdens. This resulted in a discrepancy (see JECFA, 2001)[14] when applied to the correction of the 5ng/kg bw subcutaneous maintenance dose used in the study of Faqi *et al*[12] (see below).

73. Because the correct mathematical model cannot be determined based on goodness of fit, and because the regressions are determined largely by body burdens higher than those relevant for derivation of a tolerable intake, we decided to adopt a simpler method of correction using the ratios calculated directly from the lowest doses in each of the studies by Hurst *et al.*[11,27] After a single oral dose of 50ng/kg bw on GD15, the fetal body burden on GD16 was 5.8-fold lower than the maternal body burden (5.3ng/kg bw compared with 30.6ng/kg bw).[27] After sub-chronic oral treatment with 1ng/kg bw/day for 5 days a week, which gave a maternal body burden of 19ng/kg bw, the fetal body burden on GD16 was 14.6-fold lower than the maternal body burden (1.3ng/kg bw compared with 19ng/kg bw).[11] Thus a bolus dose given on GD15 results in 2.5-fold higher fetal body burdens (14.6/5.8) on GD16, than would occur if the same maternal body burden had arisen as a result of sub-chronic treatment.

Derivation of the TDI

74. In order to derive a tolerable intake for humans, it was necessary to convert the subcutaneous dosage regimen used in the Faqi study[12] into a steady-state

maternal body burden on GD16. The study involved a bolus dose of 25ng/kg bw, 14 days before mating, and subsequent weekly maintenance doses of 5ng/kg bw. Assuming that the first day of mating corresponds to GD0, these weekly maintenance doses would have been given on GD-7, GD0, GD7, etc. By GD16, the doses given up to GD7 would have distributed to all tissues, representing steady-state distribution and resulting in a maternal body burden of 18.3ng/kg bw. This value is comprised of 9.3 + 2.3 + 3.0 + 3.7ng/kg bw remaining in the body from the doses given on GD-14, GD-7, GD0 and GD7, respectively, assuming a half-life of 21 days. The maternal body burden from the 5ng/kg bw maintenance dose given on GD14 would give a 'non-equilibrium' maternal body burden of 4.5ng/kg bw on GD16. Using the correction factor described in paragraph 73, it can be estimated that a steady state maternal body burden of 2.5-fold higher (i.e. 11.3ng/kg bw) would be needed to produce the same fetal body burden as this ''non-equilibrium'' dose. Therefore the calculated total steady-state maternal body burden on GD16 arising from the sub-cutaneous dosing protocol at the LOAEL is approximately 30ng/kg bw, which would be about 33ng/kg bw after allowing for the TCDD intake from food.

75. Conversion of the calculated equivalent steady-state maternal body burdens from these studies in rats into an equivalent human body burden requires the use of uncertainty factors to allow for the use of a LOAEL and to allow for species differences and human variability. Both the SCF and the JECFA evaluations used a default factor of 3 to allow for the use of LOAEL, and an overall factor of 3.2 ($10^{0.5}$) to allow for species differences and inter-individual variability.[71,72] The latter factor is lower than the default of 100 normally used because it incorporates the following chemical-specific adjustment factors:

- inter-species differences in toxicokinetics: uncertainty factor of 1.0 because the body burden approach allows for toxicokinetic differences;
- inter-species differences and human variability in toxicodynamics: uncertainty factor of 1 to cover both of these aspects based on the assumption that in general, rats are more sensitive than humans, but the most susceptible humans might be as sensitive to TCDD as rats;
- human variability in toxicokinetics: uncertainty factor of 3.2 to allow for potential increased accumulation, and hence body burden, of dioxins in the most susceptible individuals. This is only relevant for congeners with shorter half-lives than TCDD, because an individual with a 3.2-fold longer TCDD half-life would not reach steady-state body burden.

Applying the uncertainty factor of 9.6 (3 x 3.2) to the calculated maternal steady-state body burden from the study of Faqi *et al* (LOAEL = 33ng/kg bw) gives a tolerable human equivalent maternal body burden of 3.4ng/kg bw.

76. Estimation of the daily intake of TCDD that would result in this body burden has to take into account the fraction absorbed (bioavailability) from the diet by humans (both the SCF and JECFA evaluations concluded that the bioavailability of TCDD in humans is 50%), and the very long half-life in humans (which the JECFA concluded was an average of 7.6 years, while the SCF used a figure of 7.5 years). The human equivalent body burdens can be converted into daily intakes by the equation:-

$$\text{daily intake (pg/kg/day)} = \frac{\text{body burden (pg/kg bw) x ln2}}{\text{bioavailability x half-life in days}}$$

77. Using a bioavailability of 0.5 and a half-life of 2740 days (7.5 years), the tolerable human equivalent steady-state body burden from the study of Faqi *et al*[12]

would be produced in humans by a daily intake of 1.7pg/kg bw/day. Given the imprecision and assumptions inherent in these calculations we concluded that the tolerable daily intake for dioxins and dioxin-like PCBs should be based on this value rounded to a single figure, i.e. 2pg WHO TEQ/kg bw per day. We note that SCF and JECFA have used longer averaging periods, but because intakes are usually expressed on a daily basis, we considered that establishment of a tolerable daily intake was more appropriate and transparent. This value is consistent with tolerable intakes derived recently using similar data (WHO: 1-4pg WHO TEQ /kg bw/day[10]; SCF: 14pg WHO TEQ /kg bw/week[13]; JECFA: 70pg WHO TEQ /kg bw/month[14]).

78. We note that the body burden is the most appropriate dose metric for establishment of a tolerable intake and, because of its long half-life, the body burden of TCDD at steady state is about 2000 fold higher than the average daily intake. For example, an intake of 10 times the TDI on a single day would result in a 0.5% increase in the body burden. Therefore short term variation in intake does not significantly alter the body burden, and occasional exceedance of the TDI would not be expected to result in harmful effects, provided that intake averaged over a prolonged period is within the TDI.

Conclusions

79. We *conclude* that dioxins and dioxin-like PCBs have the potential to cause a wide range of adverse health effects. The health effects most likely to be associated with low levels of exposures relate to the developing embryo/fetus.

80. We *recommend* that a tolerable daily intake of 2 pg WHO-TEQ/kg bw per day is established, based upon effects on the developing male reproductive system mediated via the maternal body burden.

81. We *consider* that this TDI is adequate to protect against other possible effects, such as cancer and cardiovascular effects.

82. We *note* that the most recent intake estimates for the UK population are 1.8 pg/kg bw/day for the average consumer and 3.1 pg/kg bw/day for the 97.5 percentile consumer and that dietary intakes are decreasing.

83. There are no short-term measures that can be used to decrease the body burden of dioxins and dioxin-like PCBs in humans because of their long half-lives and widespread presence at low levels in food.

84. Similarly, because of the long half-life, short-term exceedances of the tolerable intake are not expected to result in adverse effects. Nevertheless, it is not possible to identify a duration and degree of exceedance at which adverse effects might occur.

85. Finally, we *confirm* our previous advice that, although intakes of dioxins and dioxin-like PCBs by breast-fed babies are higher than is desirable, encouragement of breast-feeding should continue on the basis of convincing evidence of the benefits of human milk to the overall health and development of the infant.

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COT/2001/07

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Annex F

PCDD/Fs AND PCBs IN THE UK: QUANTIFYING THE LINK BETWEEN EMISSIONS AND HUMAN EXPOSURE IN THE PAST, THE PRESENT AND THE FUTURE

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Executive Summary

of a report on Contract EPG 1/5/121

Department of the Environment, Transport and the Regions (DETR)
Chemicals and Biotechnology

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We are grateful to the Chemicals and Biotechnology Division of the Department of the Environment, Transport and the Regions (DETR) for funding this contract and the opportunity to address this extremely interesting topic. However, the exercise would not have been possible without the support of other funding bodies, namely:

- The Food Contaminants Division of the Ministry of Agriculture, Fisheries and Food (MAFF)
- The Environment Agency
- The Air and Environmental Quality Division of the DETR
- The Natural Environment Research Council

Their financial support has enabled us to obtain much of the information to make the approach used here possible.

Brief comments on the context of this report

In 1989 the (then) Department of the Environment (DoE) published a report which established a framework for policy on PCDD/Fs, consisting of the following three elements:

- to identify and control sources of PCDD/Fs;
- to monitor levels in the environment and establish human exposure;
- to continue to review information on the adverse health effects.

Since 1989 these policies have been implemented and a number of specific measures have been enacted to reduce releases of PCDD/Fs to the environment and – in turn – reduce human and ecosystem exposure. In addition, much more data is available as a result of monitoring and research programmes undertaken in the UK and elsewhere. This includes information on sources to air, land and water, monitoring of foods and human exposure and a number of specific studies drawn on for this report.

The bulk of exposure to PCDD/Fs and PCBs received by the general population comes from the ingestion of food. The approach to quantify and assess exposure to TEF-rated PCDD/Fs and PCBs is relative to a Tolerable Daily Intake (TDI) value suggested by the World Health Organisation and endorsed in the UK by the Department of Health and the COT. This has undergone a number of changes in recent years. It was originally set at 10 pg 2,3,7,8-TCDD/kg body weight (B.W.)/day, then taken as 10 pg ΣTEQ/kg B.W./day for the TEF-rated PCDD/Fs, then modified again to include the TEF-rated PCBs. In a further move that effectively lowers the recommended exposure, the WHO recently recommended a reduction in the TDI from 10 pg ΣTEQ/kg B.W./day to 1-4 pg ΣTEQ/kg B.W./day.

Although human exposure to PCDD/Fs and PCBs has generally declined in the UK over recent years, the general reductions in the TDI limit value mean that a proportion of the UK population is exceeding the current TDI. Breast-fed infants are the sub-group of the population where exceedance of the limit is greatest, because lipophilic compounds accumulate in milk and their low body weights. Indeed, the most recent data from a study by MAFF followed the consumption of human milk by 48 infants over an eight month period to give estimates of the mean consumption of human milk by nursing infants between 2 and 10 months of age. Multiplication of milk consumption figures by the average levels of PCDD/Fs and PCBs in human milk samples collected in 1993-94 gave estimated intakes from human milk of 170 pg TEQ/kg B.W./day at age 2 months. This fell to 39 pg TEQ/kg/day at 10 months of age, due to an increased bodyweight and the move to a mixed diet. Clearly these values are considerably in excess of both the current and proposed TDIs. In addition, whilst the average estimated contemporary exposures of toddlers, school children and adults fall below the current endorsed TDI, they are at or exceed the promulgated WHO TDI values.

The background in this section therefore gives some context to the Government's decision to review:

- the current state of knowledge;
- the effect of regulatory actions;
- the toxicology of these compounds;
- the success of existing policy measures, and
- to consider the need for additional measures.

It's aim is to produce a Position Paper and this report has been prepared to help the Chemicals and Biotechnology Division of the Department of the Environment Transport and the Regions place the document on a sound scientific footing. We were asked to address certain specific objectives by DETR, namely to:

1. examine effects of measures already taken to reduce PCDD/F emissions on levels in the environment and human exposure;
2. make projections of future human exposure to PCDD/Fs in the UK for 'average' adults and breast fed infants;
3. consider the timescale over which the results of emission control strategies would be expected to occur;
4. estimate how much PCDD/F emissions would need to reduce to achieve a human tolerable daily intake below the lower end of the World Health Organisation (WHO) recommended range.

We have developed a novel model framework which links emissions to atmosphere, via the foodchain, to human exposure and tissue concentrations. The modelling approach can be envisaged as a series of step-wise modules that can be modified and updated to deal with new information and different scenarios, as appropriate.

An introduction to the modelling approach

It is appropriate to explain the general approach we have used.

- PCBs and PCDD/Fs accumulate in the human body through life. Hence, contemporary tissue concentrations and body burdens in the UK population reflect a complex integral of past and present exposures, compound-specific differences in transfer efficiencies, metabolism and clearance from the body and differences between individuals.

- The principle source of exposure/intake is the diet. Information is available on which components of the diet contribute most to exposure for 'typical consumers', namely lipid-rich foods such as milk, dairy products, meat and fish. Concentrations of PCBs and PCDD/Fs in these products are themselves a complex function of many variables. Ultimately, however, they are controlled by concentrations in the diet of the animal (i.e. vegetation, feed *etc*), which itself will be controlled by levels in the surrounding environment (i.e. the air, water, soil).

- The critical factor, ultimately 'controlling' or 'driving' concentrations in vegetation, water or soil is the concentration in air. The air concentration is itself controlled by emissions from primary sources and by complex exchanges/re-cycling of these persistent, semi-volatile compounds with the surface compartments of water/soil/vegetation. Hence, in the past, when emissions were high the air concentration was presumably largely controlled by direct or primary emissions. As primary emissions have been reduced, contemporary air concentrations (and, of course, future air concentrations) will be influenced – to a greater or lesser extent—by secondary sources. Importantly, different compounds have different residence times in different environmental compartments, so it should be noted that the 'response times' for different environmental compartments to source reduction measures will differ.

- In summary, re-constructing past trends in human exposure/tissue concentrations and making projections about future exposure is highly complex. It requires knowledge of:

- The array of sources of PCDD/Fs and PCBs to the environment, particularly the atmosphere, over time;
- The likely past, present and possible future emission factors from different source types into the atmosphere;
- The compound-specific persistence and partitioning processes which control the environmental distribution and exchange of these compounds;
- The compound-specific foodchain transfer, metabolism and clearance processes of these compounds;
- The patterns of dietary exposure through the lifetime of individuals in the population.

Assessing and predicting the size and timing of past and future declines in concentrations, arising from reduced atmospheric emissions is a critical requirement of this report. Quite clearly, this requirement presents a considerable challenge and major uncertainties will be introduced into the modelling exercise because of data gaps and lack of knowledge. It is important that these are acknowledged and we have highlighted and addressed these in the relevant sections of the detailed report. They are also summarised below. However, the general framework to be adopted is clear, namely:

1. Quantify past and present atmospheric concentrations of PCDD/Fs and PCBs;
2. Quantitatively link air concentrations to the key foodchain compartments which control the PCDD/F and PCB composition of the human diet;
3. Estimate past and present human dietary intake of PCDD/Fs and PCBs;
4. Relate cumulative dietary intake to tissue concentrations/body burdens;
5. Derive and evaluate scenarios for future emissions/air concentrations and – hence – human dietary intake and tissue concentrations;
6. Compare these projections of past, present and future human exposure to the TDI.

Some general comments on physico-chemical property-based environmental fate modelling

Certain key properties are needed for the environmental fate and foodchain transfer modelling of PCDD/Fs and PCBs, namely:

a. *partition coefficient data*. Compound environmental partitioning (e.g. between air-soil, air-vegetation, soil/sediment-water, aqueous phases and lipids) can be 'mimiced' and modelled using defined and measurable properties that can be determined in the laboratory. The octanol:water partition coefficient (Kow) and the octanol:air (Koa) partition coefficient are most commonly used for this purpose, or direct measurements of an environmental partition coefficient of relevance.

   At the present time there are some deficiencies in the data that are available for PCBs and PCDD/Fs. For example, Koa is temperature dependent and a correction term is needed to relate the Koa measured in the laboratory under defined conditions to the relevant field condition.

b. *persistence or half-life data.* PCBs and PCDD/Fs are persistent in the environment. They commonly have half-lives in soils and sediments of the order of years/decades and are only slowly metabolised by higher organisms. Often reliable half life data are difficult to acquire, and variable between compounds, environmental systems/species etc. Another difficulty is that half-life data is often 'generic', not specifying the

mechanism of loss. For example, disappearance from soil could be due to microbially mediated degradation (i.e. genuine loss) or volatilisation to air (i.e. an apparent loss, but actually just a transfer from one environmental compartment to another). Similar examples apply to losses from the tissues of higher organisms.

c. *vapour pressures, solubilities etc.* Experimentally measured data on these properties are also important for modelling and—as with the partition coefficient data—there is often a lack of good quality data, agreement between data sets and temperature correction information.

d. *quantities.* Given information on the properties above, a chemical can be introduced into a hypothetical environment of air, soil, vegetation, water, sediment etc. and allowed to partition/distribute itself through it. The quantity of chemical released or discharged into the environment is obviously of key importance, together with information on the way it is introduced into the environment. The persistence and environmental behaviour of a discharge to air will be different from a discharge to land or water. It is also important to consider whether the chemical has been discharged as a 'pulse' or more continuously - perhaps as a diffuse, secondary source.

e. *the environment itself.* The most well known and widely accepted environmental fate modelling approach for persistent organic compounds is that developed by Mackay and often described as 'fugacity modelling'. This considers a 'unit world' or 'evaluative environment', with a defined mass/volume of soil, air, water etc. and with defined constituents (e.g. typical mass of aerosol per unit volume of air; average organic carbon content of soil) and environmental conditions (e.g. temperature). These can obviously be left general, perhaps to define a country or region, or adapted to smaller and more specific scenarios. We have developed CHEMUK, a model of the UK based on this approach and used in some of the supporting documentation to evaluate and predict the behaviour of PCDD/Fs and PCBs in the UK.

The dynamic nature of organic compounds in the environment means that consideration needs to be given to whether a given compound attains an equilibrium distribution in a given multi-media environment (i.e. thermodynamics) or whether kinetic constraints (i.e. rates) apply. Often the environmental distribution of a given compound is not at equilibrium and it is controlled by a whole range of factors and processes (such as changing emissions, fluctuating temperatures, 'flows' of water, air etc, changes in biomass and degradation mechanisms/rates). These factors and processes can vary spatially and temporally, so the appropriateness of kinetic versus equilibrium partitioning modelling depends on the spatial and temporal scales that the models need to simulate.

The focus of the work presented in this report considers the transfer of PCDD/Fs and PCBs to humans, primarily from the terrestrial environment. We systematically consider each of a series of steps that 'moves' the chemicals to humans, along the 'chain' from sources, to air and atmospheric deposition, to soils and vegetation, to grazing animals, to the human diet, to human tissues. As we do so, we need to consider transfer processes that can take very different time frames to approach equilibrium; consequently we need to consider both kinetically constrained and equilibrium partitioning conditions. Similar concerns relate to the pathways involved in air-water exchange and the water-phytoplankton-zooplankton-fish/shellfish transfer processes which supply the human diet from the aquatic foodchain. Indeed, these are perhaps rather better studied and characterised than terrestrial foodchain transfers, so that aquatic foodchain modelling can reach a high level of sophistication.

Key uncertainties

There are several areas of uncertainty in our current state of knowledge, which are relevant to the approach presented here. These include:

Compound properties

- Key physico-chemical properties of the PCDD/Fs and PCBs used as input for the models. These can be addressed, however, by prescribing ranges to be used in uncertainty analyses in the modelling.

Sources and environmental trends

- Difficulties in accurately quantifying the importance of various sources of PCDD/Fs to the air (i.e. diffusive emissions from domestic burning of coal/wood; secondary re-cycling sources; accidental fires; natural formation mechanisms);

- Uncertainties over the primary and secondary emission fluxes of PCBs;

- Uncertainties over the major sources of co-planar PCBs to the atmosphere (i.e. the relative importance of combustion-derived and Aroclor-derived sources);

- Uncertainties over the relative contribution of UK emissions versus regional emissions and advected air to the PCDD/F and PCB burden of the UK atmosphere;

- Projections over future sources of PCBs and PCDD/Fs to the atmosphere;

- A general lack of detailed, high resolution time trend data with which to model the 'input pulse' of PCDD/Fs and PCBs to the UK environment.

Environmental and foodchain processes

- Uncertainties over the relative importance of key loss mechanisms (e.g. atmospheric reaction; biodegradation; physical occlusion) in controlling the depletion of PCBs and PCDD/Fs from the UK environment;

- Uncertainties over possible biotransformations of the TEF-rated PCDD/Fs in soils and sediments;

- Uncertainties over certain food chain transfers (notably for marine and freshwater fish and other livestock types – pork, lamb, chickens etc);

- Possible future changes in the patterns of dietary intake (i.e. the balance between domestically produced and imported foods; terrestrially-derived and aquatically-derived food products).

Human exposure

- The assumption that absorption is constant throughout lifetime in the human model, which likely leads to an overestimate of the body burden;

- The variability inherent in the UK population, due to differences in dietary habits, intakes, exposure histories, metabolism *etc*.

As new data and knowledge becomes available, however, the modelling and evaluative framework presented here can be updated and improved.

Summary and conclusions of the work

- Past and present human exposure to PCBs and PCDD/Fs results primarily from their transfer along the pathway: atmospheric emissions – air – deposition – terrestrial/aquatic food chains – human diet. This report presents the first detailed attempt to model these transfers on a congener-specific and time-resolved basis, to re-construct past and present trends, and to allow projections of future trends to be made.

- Emissions to atmosphere of both classes of compounds have been higher in the past than at the present time. Evidence points to ambient concentrations of PCBs peaking in the late 1960s/early 1970s; they have been decreasing over the last decade or so with congener-specific half-lives of the order of ca. 2-10 years. From rather less conclusive evidence, it appears that PCDD/F concentrations peaked in the early 1970s and have declined considerably since that time and with congener-specific half-lives somewhat longer than those of PCBs.

- Past exposure to PCBs resulted from their widespread and diverse uses, controlling the primary emissions to atmosphere. These have been re-constructed in this report, with the timing and magnitude of emissions being used to drive a multi-media environmental compartment model. Current ambient concentrations (and hence human exposure) of PCBs are controlled by a mixture of primary and secondary (re-cycling sources).

- There have been and are numerous, diverse sources of PCDD/Fs to the atmosphere which have released a changing mixture of congeners to the environment. It is still difficult to re-construct the emission 'pulse' or trend of PCDD/Fs over time from our existing knowledge of sources and how they have changed over time. Different approaches are used in this report and give reasonable agreement with measured data and observations. It is probable that ambient concentrations are currently still controlled by primary (as opposed to secondary) emissions. However, these are increasingly being controlled by diffusive sources (rather than large point sources), and hence it may be difficult to cost-effectively reduce emissions much further.

- Ambient concentrations in the UK are only partly controlled by emissions within the UK itself. We estimate that advective inputs currently supply of the order of 30-70% of the inputs to the UK atmosphere, implying that substantial further reductions in UK air concentrations and human exposure will only be achieved through:
  - Further global/regional reductions in emissions;
  - Declining ambient levels, controlled by various loss mechanisms (i.e. atmospheric reactions, degradation and physical removal etc.), acting on the environmental burden of PCDD/Fs and PCBs.

- We have modelled changing human exposure to PCBs and PCDD/Fs in the UK population using congener-specific transfer data. The model transfers are driven by air concentrations. Certain key pathways can be modelled well from our current knowledge, namely the important air-vegetation – meat/milk terrestrial foodchain route. The model currently handles statistically generated 'typical individuals' in the population, and simulates lifetime exposure through typical UK dietary composition. A separate component of the model simulates the important mother – breast-fed infant transfer pathway.

- Model simulations of human tissue PCB concentrations compare well with the limited available measurements. Model simulations for selected PCDD/Fs have also been made, but these should be regarded as preliminary. In some cases, there is good agreement with measured data which is available for other European countries (no appropriate UK data was available for the simulation). For other congeners, the agreement is weaker.

- Human exposure to PCBs and PCDD/Fs has declined, with similar half-lives to those noted above for air. Measurement programmes in various European countries have shown declines in adipose, blood and breast milk concentrations. Using various half-life simulations, scenarios of dietary exposure have been estimated for different sub-groups of the population and can be compared against the current TDI.

- The starting point for these simulations was the MAFF Total Diet Study information for the early 1990s. These simulations have been performed for PCDD/Fs only. They suggest that, for average adults, dietary intake will approach the lower limit of the WHO TDI within the next 5 years. However, for young toddlers this may not occur for the next 20 years, at least. It should be stressed that, at the present time, these calculations do not include the TEF-rated PCBs (or other TEF-rated compounds) and do not consider high consumer sub-groups. This is an important omission because the co-planar PCBs contribute about 50% of our current exposure to the TEF-rated PCDD/F and PCB total. Similar calculations for the breast-fed infant suggest that the lower limit of the TDI will not be achieved for the forseeable future.

Recommendations for further measurements and research-based programmes

- Further data are required on the long-term (i.e. decades/centuries) and short-term (years) trends in atmospheric concentrations and environmental burdens of PCDD/Fs. This should be achieved by further analysis of sediment and peat core records and of archived samples of air, vegetation etc. These are necessary to distinguish local from regional sources and to improve the resolution and confidence we have in the historical trends.

- Clarification is required of the significance and role of:
  - Possible natural sources of PCDD/Fs;
  - Possible biotransformations of PCDD/Fs in soils and sediments, which could perhaps convert higher chlorinated (low TEF-rated) PCDD/Fs to lower chlorinated (high TEF-rated) PCDD/Fs over time;
  - The relative importance of primary diffusive and secondary sources in controlling current ambient concentrations.

- Experimental studies and field measurements are required to assess the likely future contribution of environmental re-cycling to ambient levels (i.e. re-mobilisation of soil-/sediment-borne PCDD/Fs and PCBs to the atmosphere).

Recommendations for further model developments and improvements

- The human exposure modelling approach can usefully be improved and made more sophisticated. Most importantly, we should:

  - move away from the current approach which just considers 'typical individuals' to one in which a range of consumers with a wide variety of diet types and intake rates can be studied (i.e. probabilistic modelling). This will allow estimates of the *proportion* of individuals in a given population or sub-group who exceed the TDI to be made;
  - adapt the modelling approach to consider total (integrated) lifetime exposure scenarios, because these allow the total body burden/tissue concentration to be derived and related directly to appropriate toxicological data;
  - include pathways via livestock other than beef/dairy products.

- In the absence of information to suggest the contrary, we have modelled future trends based on recent rates of decline. However, other future emission scenarios can be envisaged and their potential to influence human exposure explored.

- It is considered that the bioconcentration or bioaccumulation factor (BCF/BAF) approach currently being used to quantify the aquatic foodchain transfers can be improved.

List of the accompanying papers, comprising the main report

1. Duarte-Davidson, R, Sewart, A. P., Alcock, R. E., Cousins, I. and Jones, K. C. (1997). Exploring the balance between sources, deposition and the environmental burden of PCDD/Fs in the UK terrestrial environment: an aid to identifying uncertainties and research needs. Environ. Sci. Technol. 31: 1-11.

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5. Sweetman, A. J. and Jones, K. C. (submitted). Modelling historical emissions and environmental fate of PCBs in the UK. *Environ. Toxicol. Chem.*

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8. Alcock, R. E., Sweetman, A. J. and Jones, K. C. (submitted). A congener-specific PCDD/F emissions inventory for the UK: do current estimates account for the measured atmospheric burden? *Chemosphere*

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15. Lohmann, R., Green, N. J. L. and Jones, K. C. (1999). Atmospheric transport of PCDD/Fs in air masses across the UK and Ireland: evidence of emissions and depletion. *Environ. Sci. Technol.* 33: 2872-2878.

16. Lohmann, R., Green, N. J. L. and Jones, K. C. (1999). Detailed studies of the factors controlling atmospheric PCDD/f concentrations. *Environ. Sci. Technol.* 33: 4440-4447.

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18. Lohmann, R., Harner, T., Thomas, G. O. and Jones, K. C. (submitted). A comparative study of the gas-particle partitioning of PCDD/Fs, PCBs and PAHs. *Environ. Sci. Technol.*

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30. Sweetman, A. J., Alcock, R. E., Wittsiepe, J. and Jones, K. C. (submitted). Human exposure to PCDD/Fs in the UK: the development of a modelling approach to give historical and future perspectives. *Environ. International.*