

**Technical Note 6/2001**

**June 2001**

**INVESTIGATION OF DIOXIN/FURAN COMPOSITION  
IN EMISSIONS AND IN ENVIRONMENTAL MEDIA.**

**Selection of congeners for modelling**

N. Vulykh, V. Shatalov

**Meteorological Synthesizing Centre - East**  
Ul.ArHITEKTOR Vlasov, 51, 117393 Moscow Russia  
tel.: 007 095 128 90 98  
fax: 007 095 125 24 09  
e-mail: [msce@msceast.org](mailto:msce@msceast.org)  
[www.emep.int](http://www.emep.int)



## CONTENTS

EXECUTIVE SUMMARY	5
INTRODUCTION	7
1. BRIEF DESCRIPTION OF POLYCHLORINATED DIOXIN AND FURAN STRUCTURE AND PROPERTIES	8
2. ANALYSIS OF PCDD/F EMISSION COMPOSITION IN THE MAIN TYPES OF SOURCES	11
2.1. Main sources of the input to the environment and chemistry of PCDD/F formation	11
2.2. Methodology of selection of PCDD/F congeners characterizing the toxicity of some kinds of sources	12
2.3. Distribution of inputs to toxicity of PCDD/F homologous groups in emissions from three main types of sources	12
2.4. Toxicity distribution with congeners in selected homologous groups	21
2.5. Conclusions	25
3. THE ANALYSIS PCDD/F MIXTURE COMPOSITION IN THE ENVIRONMENTAL MEDIA ON THE BASE OF MEASUREMENTS	26
3.1. Peculiarities of measurement data presentation	26
3.2. The selection of PCDD congeners for calculations of their long-range transport on the base of measurement data analysis	27
3.3. The analysis of the contribution of PCDD/F homologous groups and congeners to sample toxicity for different environmental media	28
3.4. Conclusion	32
4. COMPUTATION EXPERIMENTS	33
4.1. Model parameterization	33
4.2. Balance values	34
4.3. Long-term pollution dynamics	36
4.4. Spatial distribution	38
4.5. Seasonal variations	40
4.6. Structure of deposition and gas/particle partitioning	41
5. CONCLUSIONS	44
REFERENCES	45
ANNEX A	51
ANNEX B	65



## Executive summary

### Problem formulation and ways of its solution

This report describes investigations, which are a preparatory study of model evaluation of polychlorinated dibenzo-p-dioxins and furans (PCDD/F) airborne transport. This study is aimed at:

- selection of priority homologous groups and congeners for modelling and
- determination of an individual compound or congener characterizing the behaviour of the whole group of species with acceptable (permissible) accuracy.

The key criterion for the selection was the contribution of this or that congener to total equivalent toxicity of the mixture (here we use NATO Toxic Equivalents System).

All the data used for the analysis and calculations of contributions of different homologous groups and congeners to PCDD/F mixture total toxicity in emissions and environmental media are taken from works of different authors. The references are given in the end of the Note.

The procedure of priority homologous group selection is one and the same both for emissions and pollution levels in media. At first we specify the contribution of a homologous group to PCDD/F mixture total toxicity. The priority groups are selected in such a way that the sum of their contributions constitutes more than 50% of overall mixture toxicity.

Then we investigated the toxicity distribution with congeners inside a homologous group. In doing so only toxic 2,3,7,8-substituted congeners were taken into account.

The first section of the Note gives a short description of PCDD/F structure and properties.

The second section is aimed at the analysis of PCDD/F mixture composition in view of individual congener contributions to total toxicity of emissions from the main three types of sources – organic fuel combustion, waste incineration and secondary processing of non-ferrous metals.

The third section provides the results of investigations of homologous groups and congeners contributions to the total toxicity of samples taken from air, soil, vegetation and sea water.

**PeCDF** group makes the maximum contribution to the toxicity and it is most important for all the environmental compartments. **HxCDF** and **PeCDD** groups are also very important for air.

The list of priority groups specified as a result of analysis of emissions from different types of sources basically coincide with the list of priority groups defined by the analysis of measurement data.

The distribution of contributions of individual congeners to the total toxicity of air samples shows that **2,3,4,7,8-PeCDF** is the most hazardous compound since its fraction in the total toxicity of air samples is maximum.

**1,2,3,7,8-PeCDD** is contained in air in less quantities and having equal toxicity coefficient in the NATO system with **2,3,4,7,8-PeCDF** it takes the second place. When using WHO toxicity coefficient system they can interchange places. It seems quite natural that “light” congeners — **2,3,7,8-TCDD** and **2,3,7,8-TCDF** make great contributions to air samples. Their airborne transport by mathematical simulation is planned in future.

\* \* \*

Then the results of model investigations aimed at selection of “indicator congener” which properties will be used in further calculations

of PCDD/F mixture long-range transport are considered. Namely, the fourth section is aimed at the comparison of calculation results for the transport of four congeners with the use of their individual physico-chemical properties (multi-congener run) and four calculation runs when physico-chemical properties of each congener are prescribed to the whole mixture (mono-congener runs).

The necessity of these computational experiments is conditioned by the fact that it is impossible to predict the effect of differences in physical-chemical properties of particular PCDD/F congeners on their long-range transport by simple analysis of these properties.

These experiments involved the analysis of PCDD/F content in environmental media by the final calculation year and values of uptake by media for the whole modelling period (so-called budget values)

The lowest deviation from the multi-congener run demonstrates the run with the use of **2,3,4,7,8-PeCDF** properties. It means that this congener best of all describes the mixture long-range transport both from the viewpoint of budget values and of spatial distribution. The deviation (over the entire EMEP grid) of the calculation results with **2,3,4,7,8-PeCDF** properties from mixture transport calculation is not more than 50% for the content in vegetation and do not exceed 30% in other media.

For calculation of long-term trends and seasonal variations of PCDD/F content **2,3,4,7,8-PeCDF** properties were used. The following results were obtained:

- The substance fraction accumulated in natural media is maximum in soil (about 60%) and forest litter (about 30%), the marine environment and the atmosphere contain less than 10%;

- PCDD/F partitioning in the atmosphere between gaseous and particulate phases is subject to seasonal variations with elevation of the gas phase in summer months and decline in winter;
- PCDD/F content decrease is most slow in soil. **2,3,4,7,8-PeCDF** half-life used in the model is about 2 years;
- the gas-phase fraction calculated is basically consistent with measurement data;
- dry deposition flux makes the main contribution to the process of PCDD/F scavenging from the atmosphere.

Deposition fractions of the gaseous and particulate phases over land appear to be comparable and vary in agreement with fractions of these phases contained in the atmosphere. However, over sea dry deposition of the gas phase dominates.

Since dry depositions of the gas phase (gas exchange with the underlying surface) turned out to be rather essential we investigated its temperature dependence.

\* \* \*

Annex A to the Note provides measurement data on PCDD/F content in different natural media in Germany and the Russian Federation (in measurement units of total equivalent toxicity) collected and systematized for this study. Annex B contains the list of EMEP countries for which measurement data on PCDD/F content in different natural media have been collected for 17 toxic congeners.

## Introduction

Nowadays the environmental pollution by persistent organic pollutants is of a global character.

In 1998 thirty six Parties to the UN/ECE Convention on Long-Range Transboundary Air Pollution signed the Protocol on persistent organic pollutants (POPs) taking the obligation on the emission inventory, elimination, restriction on use and reduction of selected POPs envisaged by the Protocol. The list of POPs contains both individual species – lindane, hexachlorobenzene, DDT etc. and groups of species – polychlorinated biphenyls (PCB) and polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans (PCDD/F) often called “dioxins”.

The literature dedicated to dioxin problems contains results of PCDD/F content determination represented by mass concentration of all PCDD/F, concentrations of individual homologous groups and compounds (congeners). However, taking into account peculiar toxic properties of dioxins, authors present their results by value of Toxic Equivalents (TEQ). This way of presentation of PCDD/F content does not reflect the real weighted quantity of the determined species and says nothing about PCDD/F mixture composition, masking homologous groups (or individual compounds) responsible for this toxicity.

An estimation of contributions of different homologous groups and congeners to PCDD/F total toxicity in emissions and environmental media as well as the selection and investigation of congener properties for further model calculations are considered in this report. The priority task of this work is the selection of a congener which is capable to characterize the behaviour of the entire group in view of physical-chemical properties and the

contribution to the overall toxicity. The analysis dioxins/furans mixture composition can be fulfilled both in view of contributions made by individual congeners and on the base of emission and measurement data analysis. In our study we used both approaches. By these means homologous groups and individual congeners for priority simulation have been specified. On the base of provisional calculations the congener has been selected which properties are used for modelling the transboundary transport of PCDD/F mixture within the EMEP domain.

The report describes in brief the structure and properties of PCDD and calculation experiments investigations of PCDD/F mixture composition in emissions and environmental media made with the aim at selecting a congener for the long-range transport and calculation experiments. Annex A gives the collected and systematized measurement data of PCDD/F content in different environmental media in Germany and the Russian Federation (TEQ).

Annex B contains the list of EMEP countries for which measurement data on PCDD/F content in different media for 17 toxic congeners have been collected.

## 1. Brief description of polychlorinated dioxin and furan structure and properties

Polychlorinated dibenzo-p-dioxins and polychlorinated furans refer to polyhalogenated heterocyclic hydrocarbons. PCDD/F family is characterized by a structural diversity and it combines more than 200 compounds. Depending on the quantity of added chlorine both dioxins and furans are distributed over 8 groups which names and short designations are presented in Table 1.1.

Inside a homologous group congeners are distinguished by the position of chlorine atoms indicated by figures, for example, 1,2,3,7,8-pentachlorodibenzofurans. The number of possible congeners in each homologous group is also indicated in Table 1.1.

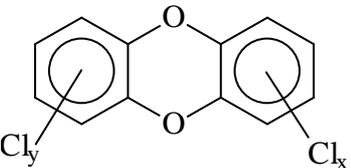
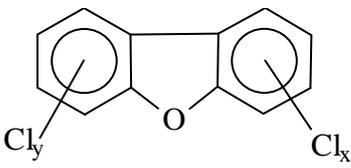
The bulk of PCDD/Fs is crystal species which melting temperature increases with the increase of the number of chlorine atoms in the molecule. On the contrary solubility in water decreases with the increase of a substitute mass. PCDD/F are sufficiently easy soluble in organic solvents - acetone,

benzene, octanol etc. but practically insoluble in water. In spite of extremely low saturated vapour pressures PCDD/F can be determined by modern analytical methods both on atmospheric aerosols and in the vapour phase and the concentration ratio directly depends on the congener molecular mass. PCDD/F are very stable to any chemical impact thereby determining their stability and peculiar behavior in the environment.

Toxic properties of PCDD/F are well known at present, however, among 75 polychlorodibenzo-p-dioxins only 7 compounds are toxic and among 135 polychlorodibenzofurans - 10. In all these compounds chlorine atoms occupy in molecule positions - 2,3,7,8. Congeners with such a position of substitutes are available only in homologous groups with not less than 4 chlorine atoms.

Congeners with chlorine atoms in positions - 2,3,7,8 are of a different degree of toxicity. Among all the compounds of PCDD/F family 2,3,7,8 - tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) is most toxic and often when speaking about "dioxins" this very compound is meant.

**Table 1.1.** Homologous groups and the number of PCDD/F congeners

PCDD		PCDF	
			
Homologous groups of polychlorodibenzo-p-dioxins	Number of congeners	Homologous groups of polychlorodibenzofurans	Number of congeners
Monochlorine - Cl <sub>1</sub> - PCDD	2	Monochlorine - Cl <sub>1</sub> - PCDF	4
Dichlorine - Cl <sub>2</sub> - PCDD	10	Dichlorine - Cl <sub>2</sub> - PCDF	16
Trichlorine - Cl <sub>3</sub> - PCDD	14	Trichlorine - Cl <sub>3</sub> - PCDF	28
Tetrachlorine - Cl <sub>4</sub> - PCDD or TCDD	22	Tetrachlorine - Cl <sub>4</sub> - PCDF or TCDF	38
Pentachlorine - Cl <sub>5</sub> - PCDD or PeCDD	14	Pentachlorine - Cl <sub>5</sub> - PCDF or PeCDF	28
Hexachlorine - Cl <sub>6</sub> - PCDD or HxCDD	10	Hexachlorine - Cl <sub>6</sub> - PCDF or HxCDF	16
Heptachlorine - Cl <sub>7</sub> - PCDD or HpCDD	2	Heptachlorine - Cl <sub>7</sub> - PCDF or HpCDF	4
Octachlorine - Cl <sub>8</sub> - PCDD or OCDD	1	Octachlorine - Cl <sub>8</sub> - PCDF or OCDF	1
Total number of congeners	75	Total number of congeners	135

For the evaluation of the hazard of compound mixtures various toxicity systems of conversion of individual compound toxicity to units of the reference substance so-called “systems of Toxic Equivalent Factors (TEF)” or “systems of toxicity factors” have been developed [NATO-CCMS, 1988]. 2,3,7,8-TCDD which toxicity is maximum was taken as a reference and the Toxic Equivalent Factor (I-TEF) is equal to 1. To determine the TEQ of PCDD/F mixture simple calculations are performed: concentrations of individual 2,3,7,8-substituted congeners are multiplied by their (I-TEF) and the obtained results are summed. Hence total concentration of PCDD/F is characterized by the value of Toxic Equivalents (TEQ).

The application of this system allows us to reduce to dioxin toxicity equivalent toxic characteristics of any mixture. Nowadays

national and international systems of TEF have been developed and used.

Table 1.2 gives TEF in the International Systems of NATO and World Health Organization (WHO). In this study we used TEF of NATO system for the determination of mixture toxicity [NATO-CCMS, 1988].

PCDD/F congeners are different not only in their toxicity but in their physical-chemical properties. Table 1.3 gives the main physical-chemical properties of PCDD/F congeners influencing their long-range transport. It contains data of different authors which were obtained in experiments and/or calculations by special models specifying these or those physical-chemical properties (parameters) of substances reasoning from their structure and different correlation dependencies between physical-chemical properties.

**Table 1.2.** Toxic Equivalent Factors

Homologous group	Congener	TEF of NATO International System	TEF of WHO System
Polychlorodibenzo-p-dioxins			
TCDD	2,3,7,8	1.0	1.0
PeCDD	1,2,3,7,8	0.5	1.0
HxCDD	1,2,3,4,7,8	0.1	0.1
	1,2,3,6,7,8	0.1	0.1
	1,2,3,7,8,9	0.1	0.1
HpCDD	1,2,3,4,6,7,8	0.01	0.01
OCDD	1,2,3,4,6,7,8,9	0.001	0.0001
Polychlorodibenzofurans			
TCDF	2,3,7,8	0.1	0.1
PeCDF	1,2,3,7,8	0.05	0.05
	2,3,4,7,8	0.5	0.5
HxCDF	1,2,3,4,7,8	0.1	0.1
	1,2,3,6,7,8	0.1	0.1
	1,2,3,7,8,9	0.1	0.1
	2,3,4,6,7,8	0.1	0.1
HpCDF	1,2,3,4,7,8,9	0.01	0.01
	1,2,3,4,6,7,8	0.01	0.01
OCDF	1,2,3,4,6,7,8,9	0.001	0.0001

**Table 1.3.** Physical-chemical properties of PCDD/F toxic congeners

		$H_i$ Pa/m <sup>3</sup> /mol	$P_{0L}$ , Pa	W	$T_{1/2}$		
					Air, days	Soil, years	Sea water, days
Polychlorodibenzo-p-dioxins (dioxins)							
TCDD	2,3,7,8	1.6 – 5.1	$5.8 \times 10^{-5} - 6.17 \times 10^{-4}$	18000	0.4 - 12.5	2-103	12.5 – 167
PeCDD	1,2,3,7,8	0.26 – 1.5	$1.74 \times 10^{-5} - 1.25 \times 10^{-3}$	18000	0.7 - 17.9	114	? – 300
HxCDD	1,2,3,4,7,8	0.20 – 6.3	$1.45 \times 10^{-6} - 5.2 \times 10^{-5}$	9000	1.0 - 41.7	6-274	41.7 – 617
	1,2,3,6,7,8	0.20 – 1.4	$3.3 \times 10^{-6} - 2.0 \times 10^{-5}$	9000	- “ -	- “ -	- “ -
	1,2,3,7,8,9	0.20 – 0.8	$1.4 \times 10^{-6} - 2.4 \times 10^{-5}$	9000	- “ -	- “ -	- “ -
HpCDD	1,2,3,4,6,7,8	0.12 – 1.27 17.7!	$1.77 \times 10^{-7} - 1.2 \times 10^{-5}$	64000	2.9 – 77.1	6 - 103	41.7 – 1250
OCDD	1,2,3,4,6,7,8,9	0.5 – 1.3	$1.3 \times 10^{-7} - 3.29 \times 10^{-5}$	91000	0.5 – 200.6	6 – 148	41.7 – 3292
Polychlorodibenzofurans (furans)							
TCDF	2,3,7,8	1.2 – 2.7	$1.13 \times 10^{-4} - 7.51 \times 10^{-4}$	19000	1.2 – 60.8	2 – 63	12.5 – 267
PeCDF	1,2,3,7,8	0.24 – 1.9	$3.1 \times 10^{-5} - 2.71 \times 10^{-4}$	13000	2.3 – 134.4	2 – 63	12.5 – 550
	2,3,4,7,8	0.51 – 2.6	$1.72 \times 10^{-5} - 1.91 \times 10^{-4}$	14000	- “ -	- “ -	- “ -
HxCDF	1,2,3,4,7,8	1.39 – 2.6	$3.08 \times 10^{-6} - 8.45 \times 10^{-5}$	10000	3.9 – 71.6	51.4 – 80	? – 1167
	1,2,3,6,7,8	0.57 – 1.9	$3.61 \times 10^{-6} - 8.14 \times 10^{-5}$	10000	- “ -	- “ -	- “ -
	1,2,3,7,8,9	0.7 – 1.16	$2.2 \times 10^{-6} - 8.66 \times 10^{-5}$	10000	- “ -	- “ -	- “ -
	2,3,4,6,7,8	0.67 – 2.0	$4.97 \times 10^{-6} - 9.21 \times 10^{-5}$	10000	- “ -	- “ -	- “ -
HpCDF	1,2,3,4,7,8,9	0.11 – 1.0	$5.39 \times 10^{-7} - 2.56 \times 10^{-5}$	32000	11.1 – 655.4	2 – 40	41.7 – 2667
	1,2,3,4,6,7,8	0.088–3.5	$5.74 \times 10^{-7} - 5.54 \times 10^{-5}$	32000	- “ -	- “ -	- “ -
OCDF	1,2,3,4,6,7,8,9	0.19 – 1.3	$1.01 \times 10^{-7} - 1.33 \times 10^{-5}$	22000	12.5 – 1445	6 – 28.5	124 – 8000

$H$  – Henry's law coefficient at 25<sup>o</sup>C, the range includes data of *D.Mackay et al.* [1992]; *A.J.Beck et al.* [1996]; *H.A.J.Govers and H.B.Krop* [1998], *Handbook of physical properties of organic chemicals* [1997];

$P_{0L}$  – saturated vapour pressure of subcooled liquid at 25<sup>o</sup>C, the range includes data of *D.Mackay et al.* [1992]; *H.A.J.Govers and H.B.Krop* [1998]; *J.Paasivirta et al.*, [1999]; *A.Delle Site* [1997]; *B.D.Eitzer and R.A.Hites* [1991, 1998];

$W$  – washout ratio for the particle phase, *C.J.Koester and R.A.Hites* [1992]; *P.Chrostovski and S.A.Foster* [1996]; *A.A.Bulgakov and D.A.Ioannisian* [1998], *B.D.Eitzer and R.A.Hites* [1989];

$T_{1/2}$  – half-life, the range includes data of *D.Mackay et al.* [1992]; *Handbook of physical properties of organic chemicals* [1997]; *R.Atkinson* [1996]; *W.W.Brubaker and R.A.Hites* [1997]; *E.Kwok et al.* [1995]; *T.F.Bidleman* [1999]; *S.Sinkkonen and J.Paasivirta* [2000].

Table 1.3 demonstrates existing considerable differences in physical-chemical constants of PCDD/F available in the literature. For example, the scattering of Henry's law constants is within 3 to 40 times. Henry's law constant makes an impact on model calculations of concentrations in soil, sea water and precipitation. The difference in values of saturated vapour pressure over subcooled liquid exceeds two orders of magnitude. This parameter is used for model description of the pollutant partitioning between gaseous and particle phase.

The dramatic difference concerns degradation constants in environmental compartments and especially in soil. In future we plan to study physical-chemical properties of PCDD/Fs and refine these properties by more detailed investigation of PCDD/Fs behaviour in the environment, in particular, in soil.

## 2. Analysis of PCDD/F emission composition in the main types of sources

### 2.1. Main sources of the input to the environment and chemistry of PCDD/F formation

Dioxins are formed in the process of organic matter combustion at the presence of chlorine containing compounds, chlorine and oxygen as well as in combustion and pyrolysis of polymeric materials especially of those based on polyvinylchloride (PVC). They may occur as by-products of technological processes in the production of light chlorinated saturated and unsaturated hydrocarbons (dichloroethane, tetrachloroethane, epichlorohydrin). PCDD/F are always present in chlorophenol and chlorobenzene used for plant protection and especially in herbicides containing trichlorophenol and its derivatives and other commercial products of chlorine chemistry. Natural sources of dioxins are forest and steppe fires, volcanic activity, however, according to estimates of specialists their input is low therefore the pollution by dioxins can be considered to be purely anthropogenic.

The list of sources of dioxin and furan emissions to the environment is rather wide and includes:

1. installations for heat and power generation;
2. industrial plants of different sectors of economy;
3. plant for destruction of various wastes (municipal-domestic, industrial and medical);
4. transport;
5. remedies for plant protection and disinfection, containing dioxins and furans as admixtures;
6. polymeric materials and synthetic washing means;
7. industrial accidents;
8. forest and steppe fires;
9. water chlorination for disinfection;
10. secondary input from soil, water and vegetation surface.

According to expert estimates [*Berdowski et al.*, 1997] basic sources of dioxin input to the environment are:

- organic fuel combustion - 38%;
- destruction (incineration) of production and consumption wastes - 24%;
- industrial production in chemical, metallurgical, and pulp and paper sectors, in particular ferrous metallurgy gives 17% of PCDD/F emissions and non-ferrous - 14%.

The mechanism PCDD/F formation in combustion (thermal processes) has been the object of investigations of many groups of specialists. The basis of these processes is homogeneous reactions taking place in the combustion zone and heterogeneous reaction in post-combustion zone. [*Addink and Olie*, 1995] indicate the following factors affecting the processes of PCDD/F formation:

- original products or reactants;
- possible chlorine sources;
- temperature;
- reaction time;
- ambient air composition in the combustion and post-combustion zones;
- catalyst availability;
- nature and composition of surfaces on which reactions of PCDD/F formation take place.

Ash collected and fly ash produced in the organic matter combustion is a reactive surface and at the same time it can be a catalyst. Under these conditions PCDD/F synthesis *de novo* is possible from macromolecules of hydrocarbon structures as well as a stepped process with the formation

at first precursors containing many substituted aromatic compounds and then PCDD/F themselves.

## 2.2. Methodology of selection of PCDD/F congeners characterizing the toxicity of some kinds of sources

Mathematical simulation is widely used for investigations of PCDD/F transport from emission sources, their redistribution between different phases within environmental compartments, for the determination of basic directions in migration and transformation processes and for the assessment and prediction of the input and accumulation in natural media.

This study was aimed at selecting a few individual compounds of PCDD/F family for model calculations of their transboundary transport within the EMEP domain.

Since the hazard of PCDD/F is defined by their toxic properties, the criterion for the selection was the contribution of this or that congener to the TEQ. Only main types of sources were considered.

At first priority homologous groups were determined. For this purpose of their percentage contribution to TEQ were compared.

Since dioxins and furans family is numerous the composition of PCDD/F mixture most often was represented as a profile visually demonstrating the input of homologous groups with different content of chlorine atoms to the total concentration or TEQ.

Our investigations showed once more that the calculated homologous profile of PCDD/F mixture relative to toxicity differs considerably from that relative to mass.

Then we estimated the distribution of inputs of 2,3,7,8-substituted congeners of the priority

homologous groups which behavior is to be simulated.

## 2.3. Distribution of inputs to toxicity of PCDD/F homologous groups in emissions from three main types of sources

In this study averaged profiles of homologous groups in emissions from three main type of sources have been analysed. Averaging was based of literature data on emission composition.

### 2.3.1. Organic fuel combustion

Organic fuel combustion is the most essential source of polychlorinated dioxins and furans input to the environment.

The most interesting papers deal with the input of dioxin and furan compounds from heat installations and systems with soot particles and fly ash. PCDD/F mixture composition emitted to the air with flue gases either was not analysed at all or only TEQ was estimated. Therefore we had to restrict ourselves to the analysis of toxicity of PCDD/F mixture sorbed on soot produced in the combustion of wood, coal and oil products. In doing so we used data of toxic congener concentration measurements published in [Thoma, 1988].

Before estimating PCDD/F mixture toxicity we evaluated the toxicity of homologous groups. For this purpose mass congener concentration was multiplied by TEF, the obtained values were summed inside their homologous group. Toxicity values of all the groups were summed and the contribution of each group to the TEQ was determined. Then the homologous groups were listed in the order of the contribution decrease, see Table 2.1.

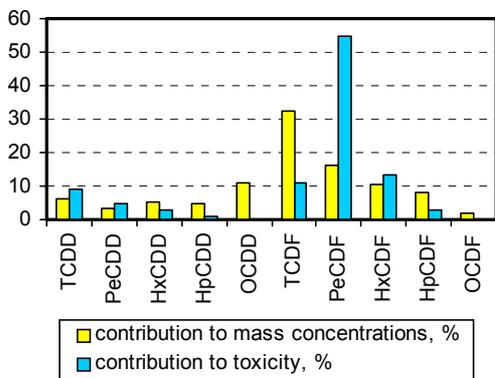
Toxicity of furan groups exceeds toxicity of dioxin groups for all types of fuels considered (Table 2.1). Their fraction is responsible for

80% of toxicity from wood burning, about 70% coal.  
 from oil product combustion and about 90% -

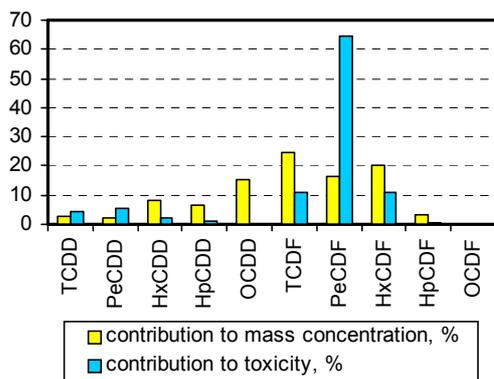
**Table 2.1.** Contributions of PCDD/F homologous groups to TEQ in the order of its decrease, %

Organic fuel types		
Wood	Coal	Oil products
1. PeCDF -54.9	1. PeCDF - 64.3	1. PeCDF – 41
2. HxCDF -13.2	2. TCDF - 11.2	2. HxCDF – 22
3. TCDF - 10.9	3. HxCDF - 10.8	3. PeCDD – 10
4. TCDD - 9.1	4. PeCDD - 5.6	4. TCDD - 8.3
5. PeCDD - 4.9	5. TCDD - 4.2	5. HpCDF – 8.0
6. HxCDD - 3.0	6. HxCDD - 2.2	6. HxCDD – 5.8
7. HpCDF - 2.9	7. HpCDD - 0.9	7. TCDF - 3.0
8. HpCDD - 0.8	8. HpCDF - 0.6	8. HpCDD – 1.8
9. OCDD - 0.1	9. OCDD - 0.2	9. OCDD - 0.1
10. OCDF - <0.1	10. OCDF - <0.1	10. OCDF - <0.1
Toxicity ratio of furan groups to dioxin groups		
4.6	6.6	2.8

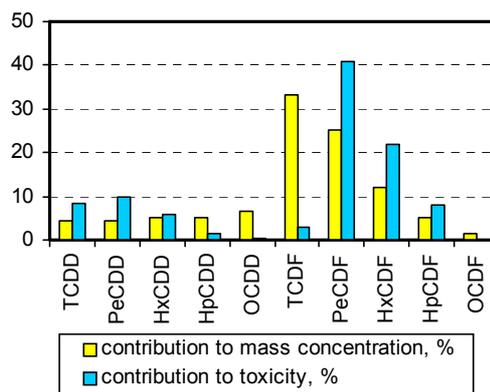
Differences in PCDD/F homologous profiles of contributions to mass concentrations found from the combustion of three organic fuels are illustrated in Figures 2.1-2.3.



**Figure 2.1.** Emission profiles of wood burning



**Figure 2.2** Emission profiles of coal combustion



**Figure 2.3.** Emission profiles of oil product combustion

In order to construct homologous profiles of PCDD/F mass concentrations in soot particles originated in the combustion of different kinds of fuels, we used averaging of data provided in:

**for wood** [Parma et al., 1995; Kjeller & Rappe, 1995; Thoma, 1988; Bacher. et al., 1992; Tiernan et al. 1983; Oehme & Mueller., 1995; Pandopatom et al. 1997];

**for coal** [Parma et al., 1995; Kjeller & Rappe, 1995; Thoma, 1988; Nielsen & Blinksbjerg, 1989; Bonfanti et al., 1994];

**for oil products** [Thoma, 1988].

The selection of congeners for modelling unfortunately is not subject to formalization. As it is mentioned above the only criterion for the selection was the contribution of particular congeners to TEQ. The quantitative prerequisite was introduced - the sum of inputs of homologous groups should be not less than 70% of the TEQ of PCDD/F mixture.

When several homologous groups had close values of contributions to TEQ, preference is given to those, which had reliable estimates in environmental media, first of all in air, for further comparison with model results. Since the behavior of PCDD/F congeners in the environment is defined by their physical-chemical properties, although similar but still they have differences, in the selection of priority homologous groups we tried to involve both furan and dioxin ones.

To reduce the number of input parameters among homologous groups with similar inputs to TEQ the preference was given to groups with less number of toxic congeners.

As evident from Figures 2.1-2.3, **PeCDF** group defines the toxicity of PCDD/F mixture for all kinds of organic fuel. Its share in all the organic fuels considered is not lower than 40% as to coal it exceeds 60%. The second group in this respect is **HxCDF**. In view of the above considerations the third priority group is **PeCDD**. Hence, priority homologous groups for sources of organic fuel combustion are **PeCDF**, **HxCDF** and **PeCDD**.

The distribution of PCDD/F mixture toxicity with priority homologous groups for sources of

this type is demonstrated in Figure 2.4.

**Figure 2.4.** Organic fuel combustion

### 2.3.2. Waste incineration

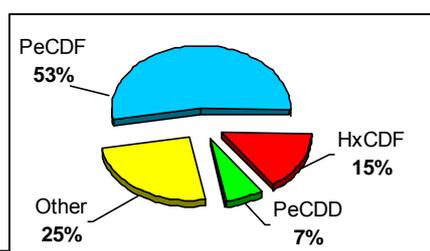
The destruction of wastes from production and consumption is one of the main sources of PCDD/F input to the environment in many countries. For a number of European countries this source category is the main one. To specify of priority homologous groups making the main contribution to PCDD/F mixture toxicity at the outlet of sources of "waste incineration" type, at first we studied separately the emission composition from incineration of:

- solid municipal wastes;
- medical wastes;
- industrial wastes.

The obtained results were averaged to obtain the homologous profile of source emission toxicity with a unified name "waste incineration" (see section 2.4.2) presenting priority homologous groups and congeners selected for this source group.

#### *Solid municipal wastes (SMW)*

As a rule solid municipal wastes are destructed in incinerators equipped with flue gas cleaners. Peculiarities of equipment, temperature regime and gas cleaner are key factors of dioxin emissions to the air. The hazard of PCDD/F emissions from waste incineration was the reason for introducing standards of dioxin emissions from incinerators in some European countries and the USA. Emission regulation was followed by systematic control of emitted compound mass and composition. During recent decade the reduction of incineration plant emissions receives much attention. It is confirmed by a great number of published papers dedicated to the investigation of emission composition of



this group of sources. These investigations are concerned with the determination of PCDD/F concentrations in the gas and aerosol phases.

The distribution of PCDD/F compounds between two phases, which are different in regard to their nature and behavior in the environment, complicates the analysis of emission composition and identification of the most toxic homologous groups and individual compounds as well.

In this review we analysed published data on gas and fly ash separately. For the assessment of the contribution of homologous groups to mass concentration or toxicity at the last stage the results were combined.

### Gas emissions

Calculated results of the averaged contribution of homologous groups to TEQ of gaseous emissions from incinerators taken from literature data are presented in Table 2.2.

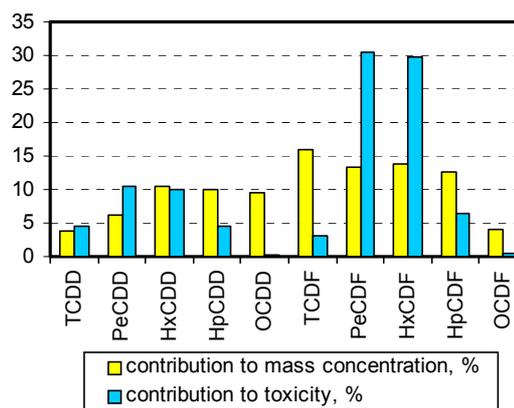
The comparison of averaged homologous profiles for gaseous emissions from waste incineration installation of SMW is demonstrated in Figure 2.5.

Contributions to mass concentration is determined here as arithmetic mean of data obtained in [Hagenmaier et al., 1994; Маїстренко и др., 1996; Tiernan et al., 1983; Lorber et al., 1998; Hutsinger et al., 1996; Abad et al., 1997; Pitea et al., 1989; Olie et al. 1983].

**Table 2.2.** Contributions of PCDD/F homologous groups to TEQ

Homologous group	Contribution of homologous group to TEQ, %;						Mean
	Hagenmaier et al., 1994	Abad et al., 1997	Sakai et al., 1994	Olie et al., 1983	Sakai et al., 1996	Miyata et al., 1994	
TCDD	10.4	2.1	5.0	1.9	0	7.7	4.5
PeCDD	14.2	6.8	16.2	9.1	9.7	7.3	10.5
HxCDD	5.3	9.0	5.5	23.8	6.1	10.2	10.0
HpCDD	1.2	4.6	3.8	13.9	1.9	2.0	4.6
OCDD	0.2	0.6	0.5	0	0.3	0.3	0.3
TCDF	5.2	1.6	2.7	2.8	3.3	2.5	3.0
PeCDF	41.4	24.5	39.3	9.9	40.0	27.6	30.5

Toxicity of gas emission mixture is determined mainly by the presence of furan group. According to data of different authors the ratio of toxicity of furans to that of dioxins varies from 1.05 to 4.55. Mean value obtained in this study is 2.3. The difference in contributions of different homologous groups to TEQ is very big and reaches tens of times. For example, **PeCDF** makes the greatest contribution - about 30%, group OCDD makes the least contribution - less than 1%. **HxCDF** makes the contribution almost equal to that of **PeCDF** and their sum is 60% of TEQ. Each fraction of the remained groups is accounted for 10%. More than 70% of all PCDD/F toxicity provides three groups - **PeCDF**, **HxCDF** and **PeCDD**, which are prioritized for gas emissions of solid waste incinerators.



**Figure 2.5.** Gas emission profiles

HxCDF	19.9	39.3	23.1	27.2	33.0	35.5	29.7
HpCDF	2.0	10.4	3.7	11.4	5.2	6.5	6.5
OCDF	0.05	1.0	0.2	0	0.4	0.4	0.4
Ratio of toxicity of furan group to dioxin group							
	2.2	3.3	2.2	1.0	4.5	2.6	2.3

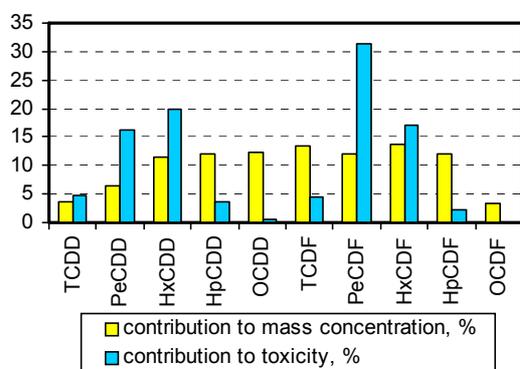
### Fly ash

Averaging the homologous profile of fly ash PCDD/F was made in a similar way, see Table 2.3.

**Table 2.3.** Contributions of PCDD/F homologous groups to TEQ

Homologous group	Contribution of homologous group to TEQ, %;			
	Hagenmaier et al., 1994	Sakai et al., 1994	Casanovas et al., 1994	Mean
TCDD	6.9	6.3	1.2	4.8
PeCDD	17.3	24.4	7.0	16.2
HxCDD	8.3	15.6	35.2	19.8
HpCDD	3.1	4.2	3.8	3.7
OCDD	0.73	0.4	0.5	0.6
TCDF	5.5	2.0	5.9	4.5
PeCDF	39.7	28.6	25.9	31.4
HxCDF	15.6	16.3	19.0	17.0
HpCDF	2.8	2.1	1.5	2.1
OCDF	<0.1	<0.1	<0.1	<0.1
Ratio of toxicity of furan to dioxin group				
	1.8	1.0	1.1	1.2

In this review contributions to mass concentrations are determined as mean arithmetic values of data presented in [Hagenmaier et al., 1994; Lorber et al., 1998; Sakai et al., 1994; Pitea et al., 1989; Czuczwa & Hites, 1986; Casanovas et al., 1994].



**Figure 2.6.** Fly ash profiles

PeCDF group is the priority homologous group accounted for one third of toxicity of all PCDD/F. Groups of dioxins and furans with 6 chlorine atoms are responsible for 35% of TEQ, they also should be defined as priority ones. Hence for fly ash more than 70% of toxicity of all PCDD/F is provided by four groups - PeCDF, HxCDF, HxCDD and PeCDD.

### “Combined emissions”

In reality fly ash and the gas-phase are emitted to the air simultaneously. Therefore it seems justified to combine the two phases for the evaluation of the hazard of this source types. The composition of total emission content which is conventionally called “combined emissions” is calculated as mean arithmetic value of their contributions to toxicity of gas emissions and to fly ash, see Table 2.4.

**Table 2.4.** Contributions of PCDD/F homologous groups to TEQ of “combined emissions”

Homologous group	Contribution to “combined emissions” toxicity, %		
	Contribution to gaseous emission toxicity, %	Contribution to fly ash toxicity, %	Contribution to “combined emissions”, %
TCDD	4.5	4.8	4.7
PeCDD	10.5	16.2	13.4
HxCDD	10.0	19.8	14.9
HpCDD	4.6	3.7	4.2
OCDD	0.3	0.6	0.5
TCDF	3.0	4.5	3.8
PeCDF	30.5	31.4	31.0
HxCDF	29.7	17.0	23.4
HpCDF	6.5	2.1	4.3
OCDF	0.4	<0.1	0.2
Ratio of toxicity of furan to dioxin group			
	2.3	1.2	1.7

The input of furans to the TEQ of “combined emissions” of PCDD/F exceeds 60%, maximum contributions result from **PeCDF** and **HxCDF** and their integral share is more than 50%. The third group with TEQ equal to 14.9% is **HxCDD**, a little bit less contribution, 13.4%, makes **PeCDD** group. The comparison of “combined emissions” homologous profiles relative to mass and toxicity is illustrated in Figure 2.7.

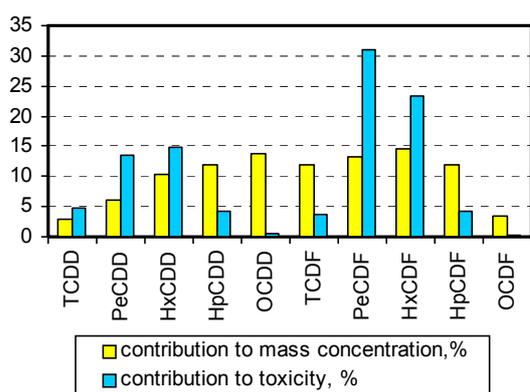


Figure 2.7. Combined emission profiles

Contributions to mass concentrations were determined here as mean arithmetic values of the data contained in papers: [Hagenmaier *et al.*, 1994; Lorber *et al.*, 1998; Sakai *et al.*, 1994; Pitea *et al.*, 1989; Czuczwa & Hites, 1986; Майстренко и др., 1996; Tiernan *et al.*, 1983; Hutsinger *et al.*, 1996; Abad *et al.*, 1997; Olie *et al.*, 1983; Brzuz & Hites, 1996; Brubaker & Hites, 1997].

The comparison of the discussed PCDD/F homologous groups demonstrate that **HxCDF** makes the maximum contribution to mass concentration and is the second one in regard to the input to TEQ. The main contribution to toxicity makes **PeCDF** group. If we take into consideration dioxin groups with five and six chlorine atoms, then their fraction in the mixture TEQ will be more than 80%. G.Schetter [1989] drew a similar conclusion using Eadon system of TEF.

### Medical wastes

Destruction of medical wastes, i.e. means of nursing, packing of medicine and instruments of single use and the likes are made by special installations (incinerators). Mainly these things are manufactured from various polymers, artificial and natural fibres. In this study only gaseous emissions from these incinerators are analysed. From a number of published investigations two papers were selected for the assessment of the contribution of homologous groups to total PCDD/F toxicity. These data and obtained by us mean values are demonstrated in Table 2.5.

Table 2.5. Contributions of PCDD/F homologous groups to TEQ

Homologous group	Contribution to TEQ, %		
	Hagenmaier <i>et al.</i> , 1994	Lindner <i>et al.</i> , 1990	Mean
TCDD	0	2.0	1.0
PeCDD	7.8	4.9	6.4
HxCDD	7.6	7.5	7.6
HpCDD	1.8	3.3	2.6
OCDD	0.4	0.5	0.5
TCDF	3.1	1.5	2.3
PeCDF	40.2	30.7	35.5
HxCDF	34.1	41.5	37.8
HpCDF	4.8	6.9	5.9
OCDF	0.2	1.2	0.7
Ratio of toxicity of furan to dioxin group			
	4.7	4.5	4.5

**HxCDF** group makes the maximum contribution to PCDD/F mixture toxicity released from the incineration of hospital wastes, the fraction of **PeCDF** is slightly less. The sum of **PeCDF** and **HxCDF** inputs exceeds 70%. Hence the list of priority homologous groups for these sources could be limited by the two groups. **PeCDD** group is selected as the third one. TEQ of the mentioned three groups is more than 75% thereby the main condition is fulfilled. **HxCDD** group could be selected as the third priority group, but it contains three toxic congeners

requiring further study of their distribution inside given homologous group.

The comparison of emission homologous profiles of these sources is shown in Figure 2.8. Homologous profiles of medical incinerator emissions are obtained on the basis of data given in [Hagenmaier *et al.*, 1994; Lindner *et al.*, 1990; Lorber *et al.*, 1998; Майстренко *и др.*, 1996; Pandopatom *et al.*, 1997].

Gaseous emission toxicity of these sources is basically formed by two furan groups and the difference between inputs of these groups is more than 30 times. The contributions of homologous groups to mass concentration differ greatly as well, for instance, **HpCDF** group makes the maximum contribution - 17.5%, TCDD group - minimum - 0.8%. The difference is more than 20 times.

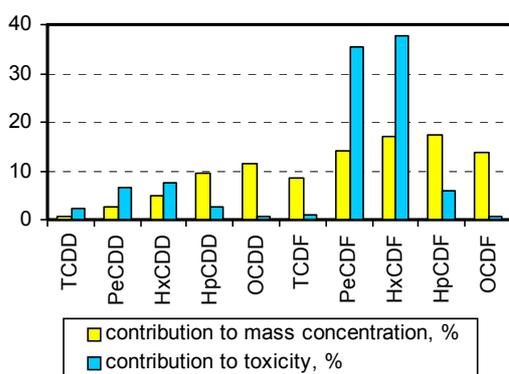


Figure 2.8. Profiles of medical incinerator emissions

### Industrial wastes

Industrial waste is the notion combining remnants of raw materials, semi-products and various used materials, spent details and constructions and the like. Their utilization and consequently pollution emissions to the

environments is considered in literature from different viewpoints. Analyses for PCDD/F composition of emissions from incinerators of industrial wastes have been made recently, they are not systematic and they are rather of an evaluation character. Obviously the composition of emissions from such installations directly depends on the kind of wastes and their mixture.

At present literature data available does not allow us to estimate PCDD/F content produced from the destruction of the whole scope of industrial wastes. Besides a number of authors present averaged PCDD/F homologous profiles of industrial waste emissions without identification of their origin or waste mixture. [Czuczwa and Hites, 1986, Майстренко *и др.*, 1996, Parma *et al.*, 1995].

In studying emissions from industrial waste incinerators the following kinds of wastes were considered: PVC, PCB, wood wastes and electrode wastes and wastes from chemical industry.

Industrial waste mixture and averaging to produce PCDD/F profiles of contributions to TEQ are demonstrated in Table 2.6.

Table 2.6. Contributions of PCDD/F homologous groups to TEQ

Homologous group	Contribution to emission TEQ, %;					
	Electrode wastes	PVC averaged	PCB	Wood wastes	Chemical industry wastes	Mean

	<i>Hagenmaier et al., 1994</i>	<i>Christman et al., 1989a; Theisen et al., 1989</i>	<i>Ke Jiang, et al., 1997</i>	<i>Oehme &amp; Muller, 1995</i>	<i>Майстренко и др., 1998</i>	
TCDD	0	0.7	0.8	22.7	2.1	5.2
PeCDD	0	4.5	1.3	15.8	1.0	4.5
HxCDD	0	3.7	2.6	5.2	0.3	2.4
HpCDD	0.02	1.7	2.3	1.1	0.09	1.0
OCDD	0.06	0.7	1.3	0.3	0.03	1.0
TCDF	10.3	1.4	5.7	9.5	11.4	7.6
PeCDF	35.6	37.5	19.0	34.1	27.1	30.6
HxCDF	52.8	42.3	49.3	10.8	36.5	38.3
HpCDF	1.1	7.1	10.3	0.7	19.9	7.8
OCDF	<0.1	0.4	7.3	<0.1	1.6	1.9
Ratio of toxicity of furan to dioxin group						
	1200	7.8	11	1.2	27.6	6.1

Averaging the composition of emissions from incineration of various materials is obviously not quite correct. However, it is dictated by the necessity to use in long-range transport modelling emission data from one category of sources “waste destruction” without separation of materials and types of wastes. Differences in waste mixture and ranging of contributions to mass concentration and TEQ of dioxin and furan homologous groups are shown in Figures 2.9 and 2.10 on the examples of wood and PVC wastes.

PCDD/F homologous profiles at wood waste burning are obtained on the basis of data presented in [Oehme and Mueller, 1995; Olie et al., 1983].

**PeCDF** group makes the maximum contribution, more than 30%, to the toxicity of wood waste burning emissions, the fraction of 2,3,4,7,8-PeCDF is 30%. Almost a fourth of toxicity (23%) is accounted for **TCDD** (2,3,7,8-TCDD). **PeCDD** is selected as the third group. The toxicity of wood waste burning is almost equally distributed between dioxin and furan groups. When products and wastes the bulk of which makes PVC are destroyed, furans predominate in mass concentration and toxicity of emissions (Fig.2.9). The main groups are **PeCDF** and **HxCDF**; their integral contribution to the toxicity is 80%. Almost a third (29%) of all PCDD/F is accounted for 2,3,4,7,8-PeCDF.

For the construction of PCDD/F homologous profiles at PVC waste combustion data of [Christman et al., 1989a; Theisen et al., 1989] are used.

Due to averaging of the homologous profile of emissions from industrial wastes considered, the following contributions of priority homologous groups to TEQ were obtained (Fig.2.11).

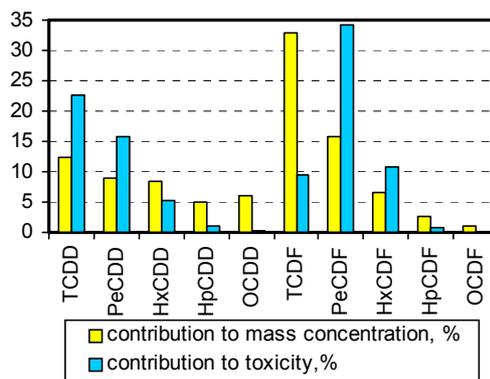


Figure 2.9. Profiles of emissions from wood waste burning

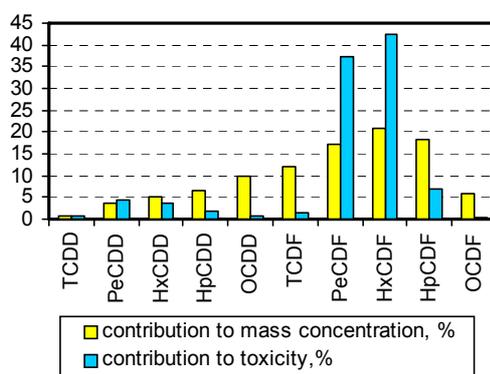


Figure 2.10. Profiles of emissions from PVC waste burning

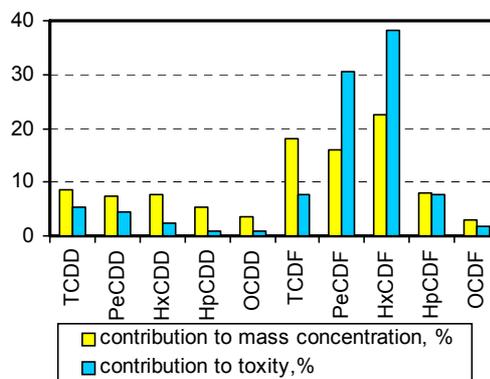


Figure 2.11. Profiles of industrial wastes

Furans predominate in mass concentration and emission toxicity. Their input to PCDD/F mixture toxicity is about 90%. The greatest contribution is accounted for **HxCDF** and **PeCDF** groups. Their total contribution, however, is less than 70%. Besides four homologous groups - two from furan family (**TCDF** and **HpCDF**) and two from dioxin family (**TCDD** and **PeCDD**) - are considered

as the third priority group. PeCDD group is favored. Thus **HxCDF**, **PeCDF** and **PeCDD** are prioritized in regard to the formation of PCDD/F mixture toxicity emitted in the course of combustion of industrial wastes.

### *Waste combustion sources as a whole*

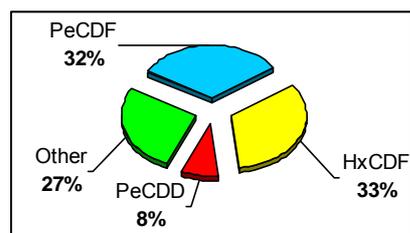
The formation of the averaged homologous profile of the considered emissions (municipal, medical and industrial) is based only on the results of averaging the homologous group contributions to total emission toxicity. The results are presented in Table 2.7.

**Table 2.7.** PCDD/F homologous group contributions to TEQ

Homologous group	Contributions to TEQ of different wastes, %			
	Solid municipal	Medical	Industrial	Mean
TCDD	4.7	1.0	5.2	3.6
PeCDD	13.4	6.4	4.5	8.1
HxCDD	14.9	7.6	2.4	8.3
HpCDD	4.2	2.6	1.0	2.6
OCDD	0.5	0.5	1.0	0.7
TCDF	3.8	2.3	7.6	4.6
PeCDF	31.0	35.5	30.6	32.4
HxCDF	23.4	37.8	38.3	33.2
HpCDF	4.3	5.9	7.8	6.0
OCDF	0.2	0.7	1.9	0.9
Ratio of toxicity of furan to dioxin group				
	1.7	4.5	6.1	3.3

**HxCDF** group is responsible for the maximum contribution (33.2%), next to it is the share of **PeCDF** (32.4%). Their total input, however, is less than 70%. While selecting priority homologous groups for "Waste combustion sources" the following groups are favored: **HxCDF**, **PeCDF** and **PeCDD** above all due to less number of toxic congeners in **PeCDD** compared to **HxCDD** group.

The distribution of different homologous group inputs to TEQ of emissions from these sources is illustrated in Figure 2.12.



**Figure 2.12.** Waste combustion

### *2.3.3. Production processes*

Modern industrial production involves a diversity of sectors, which for the reason of technologies used are considered hazardous in view of dioxins. Dioxin and furan compounds can be present in emissions, waste waters, production wastes and occur in certain quantities in products. The occurrence of chlorine and its compounds and organic substances, cycling hydrocarbons, in particular, most probably will result in dioxin formation. In this context chlorine industry and first of all chloro-organic synthesis is most dangerous. Literature provides very scarce information on these sources.

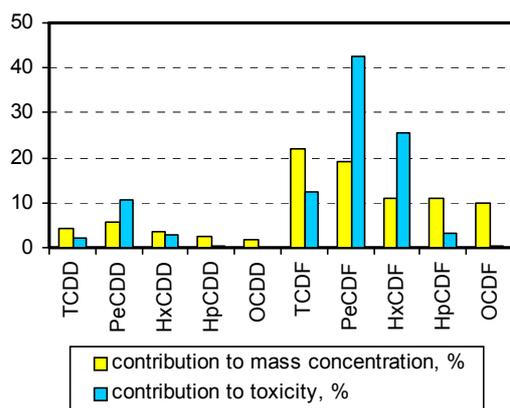
#### *Chemical industry*

Inspection of the Russian Federation chlorine industry carried out within the framework of special program "dioxins" showed that the distribution of inputs of homologous groups to PCDD/F mixture toxicity in flue gases of chemical production is very different from sources considered above [Майстренко и др., 1998]. **PeCDD** group is responsible for the bulk of emission toxicity, its contribution amounts to 50%. In production of herbicides an essential contribution (about 30%) make **TCDD** and **PeCDF**, in production of glycerin - **HxCDD** (more than 45%). The application of the obtained results to the estimation of emission composition of a similar production in Western Europe is not quite justified in view of

different technologies, equipment and cleaning installations used.

### Metallurgy

Metallurgy is recognized to be the main source of dioxins and furans input to the atmosphere. According to estimates of specialists this group of sources emits 30% of total dioxin emissions [Berdowski *et al.*, 1997]. We carried out the analysis of homologous profiles of the contribution to toxicity only for emission of secondary treatment of non-ferrous metals. On the basis of data [Harnly *et al.*, 1995; Aitolla *et al.*, 1996; Laue *et al.*, 1994] homologous group contributions to mass concentration and TEQ are averaged. The results are demonstrated in Figures 2.13 and Table 2.8.



**Figure 2.13.** Profiles of emissions from plants of secondary processing of non-ferrous metals (copper and aluminium)

**Table 2.8.** PCDD/F homologous group contributions to TEQ

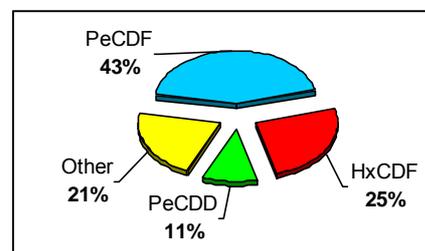
Homologous group	Contribution to TEQ, %		
	Copper and aluminium scrap processing <i>Harnly et al.</i> , 1995	Aluminium secondary processing <i>Aitolla et al.</i> , 1996	Mean
TCDD	0	4.3	2.1
PeCDD	3.5	17.7	10.6
HxCDD	3.0	2.7	2.9
HpCDD	0.7	0.1	0.4
OCDD	0.1	<0.01	<0.1
TCDF	8.6	16.1	12.4
PeCDF	38.9	46.5	42.7
HxCDF	39.2	11.6	25.4
HpCDF	5.5	0.6	3.1

OCDF	0.6	0.3	0.4
Ratio of toxicity of furan to dioxin group			
	12.7	3.0	5.3

The toxicity of furan groups is many times higher than that of dioxins. Furan content is appreciably higher compared to dioxin one in mass concentration as well. The distinguishing feature of this type of sources is an utter absence of **TCDD** group in emissions.

The major portion (more than 65%) of toxicity in emissions from plants of non-ferrous metal secondary processing makes two groups - **PeCDF** and **HxCDF**. Group **PeCDF** makes the maximum contribution both to mass concentration and TEQ. **TCDF** (12.4%) and **PeCDD** (10.6%) groups take the third and fourth places relative to the input to TEQ.

Priority homologous groups for these sources are **PeCDF**, **HxCDF** and **PeCDD** and their contributions to TEQ are illustrated in Figure 2.14.



**Figure 2.14.** Non-ferrous metal secondary processing

## 2.4. Toxicity distribution with congeners in selected homologous groups

As it was mentioned above the toxicity is formed only by congeners which have substitution in positions 2,3,7,8. If some homologous groups have one compound with 2,3,7,8 - substitution, its contribution to the homologous group toxicity is always 100%. In homologous groups with several toxic congeners the fraction of each may differ depending on a source type.

### 2.4.1. Organic fuel combustion

Distribution of toxic congener contributions to priority group toxicity of organic fuels considered is shown in Table 2.9.

For emission sources with combined name “**Organic fuel combustion**” mean contributions of toxic congeners are calculated. These values are used for the selection of individual substances characterizing emission toxicity of these sources.

**2,3,7,8-PeCDF** on the average is responsible for 89% of its group toxicity for all kinds of fuels in question and its input to PCDD/F mixture toxicity amounts to 50%. Congeners from **HxCDF** group with substitution in positions 1,2,3,4,7,8 - and 1,2,3,6,7,8 make the total contribution of 76% of their group toxicity amounting to 11% of PCDD/F group toxicity. As to the third priority group, **PeCDD**, there is no need of selecting congeners responsible for the bulk of toxicity since the homologous group toxicity entirely depends on **1,2,3,7,8-PeCDD** content. Its fraction in total PCDD/F mixture toxicity is 7% for this kind of sources.

From the point of view of PCDD/F airborne

**Table 2.9.** Contributions of 2,3,7,8-substituted congeners to toxicity of their homologous groups (organic fuel combustion)

Organic fuels	Contributions of 2,3,7,8-substituted congeners to toxicity of their homologous groups, %					
	PeCDF		HxCDF			
	1,2,3,7,8	2,3,4,7,8	1,2,3,4,7,8	1,2,3,6,7,8	1,2,3,7,8,9	2,3,4,6,7,8
Wood	10	90	38.6	36.6	4.5	20.3
Coal	5.5	94.5	40.5	40.1	2.6	16.8
Oil products	17.8	82.2	41.3	33.6	4.9	20.2
Mean	11.1	88.9	40.1	36.8	4.0	19.1

**Table 2.10.** Contributions of 2,3,7,8 - substituted congeners to the toxicity of their homologous groups (waste incineration)

Homologous group	Congener	Congener contribution to the whole group toxicity, %		
		Gaseous emissions	Fly ash	Mean
PeCDF	1,2,3,7,8-PeCDF	8.5	8.1	8.3
	2,3,4,7,8-PeCDF	91.5	91.9	91.7
HxCDF	1,2,3,4,7,8 HxCDF	28.7	38.3	33.5

transport modelling **2,3,4,7,8-PeCDF** seems most preferable for this group of congeners. For better characteristic of emission toxicity it is necessary to include 1,2,3,4,7,8 - HxCDF, 1,2,3,6,7,8 - HxCDF and 1,2,3,7,8 - PeCDD.

### 2.4.2. Waste incineration Solid municipal wastes (SMW)

Mixture toxicity of this group of sources is formed by four groups: **PeCDF**, **HxCDF**, **PeCDD** and **HxCDD**. Table 2.10 demonstrates distribution of inputs of 2,3,7,8 - substituted congeners to emissions of gases and fly ash and calculated mean values.

**PeCDF** group making the major portion of mixture toxicity contains two toxic congeners. At the same time 2,3,4,7,8 - PeCDF makes 90% contribution in regard to TEQ of all 17 toxic congeners - more than 25%.

**HxCDF** group has four toxic congeners. Inputs of three of them are almost equal and amount to about 30%; the fraction of 1,2,3,7,8,9 - HxCDF is accounted for 5% of the toxicity of a given group and obviously this contribution may be neglected.

	1,2,3,6,7,8- HxCDF	29.2	32.1	30.7
	1,2,3,7,8,9- HxCDF	8.2	1.6	4.9
	2,3,4,6,7,8- HxCDF	33.9	28.1	31
PeCDD	1,2,3,7,8 - PeCDD	100	100	100
HxCDD	1,2,3,4,7,8- HxCDD	25.1	17	21.1
	1,2,3,6,7,8- HxCDD	41.1	41.5	41.3
	1,2,3,7,8,9- HxCDD	33.8	41.5	37.6

### Medical wastes

The distribution of congeners inside the group with respect of toxicity of priority homologous groups is demonstrated in Table 2.11.

**Table 2.11.** Contributions of 2,3,7,8 - substituted congeners to the toxicity of their homologous groups

Homologous group	Congener	Contribution to toxicity of its homologous group (%)
HxCDF	1,2,3,4,7,8 - HxCDF	28.3
	1,2,3,6,8,9 - HxCDF	31.7
	1,2,3,7,8,9 - HxCDF	3.3
	2,3,4,6,7,8 - HxCDF	36.7
PeCDF	1,2,3,7,8-PeCDF	9.3
	2,3,4,7,8-PeCDF	90.7
PeCDD	1,2,3,7,8-PeCDD	100

Since the contribution of 2,3,4,7,8 - PeCDF to **PeCDF** group toxicity is about 90% and the fraction of this group in TEQ is 35.5%, simple calculations show that this congener makes maximum contribution (32%) among all toxic congeners. Three toxic congeners of **HxCDF** group, namely, 1,2,3,4,7,8 - HxCDF, 1,2,3,6,8,9 -HxCDF and 2,3,4,6,7,8 - HxCDF are responsible for 95% of this group toxicity therefore 1,2,3,7,8,9 -HxCDF contribution can be neglected and the congener itself may be

excluded from compounds of interest for the long-range transport.

### Industrial wastes

The distribution of toxicity with congeners inside prioritized homologous groups in various industrial wastes is illustrated in Table 2.12.

**HxCDF** group is responsible for the bulk of toxicity (38.3%). The main contribution makes four congeners and more than a half of toxicity is accounted for 1,2,3,4,7,8-HxCDF (about 20%). 1,2,3,6,8,9 - HxCDF is responsible nearly for 27% of its group toxicity. The fraction of these congeners exceeds 80% accounting for 32% of TEQ of PCDD/F group. **PeCDF** group provides 30.6% of TEQ but 80% of it is accounted for 2,3,4,7,8-PeCDF being a quarter in TEQ. Hence 2,3,4,7,8 - PeCDF congener makes the greatest contribution to the toxicity of this group of sources. Differences in contributions of **HxCDF** group toxic congeners distinguish two compounds 1,2,3,4,7,8-HxCDF and 1,2,3,6,8,9-HxCDF important in view of the long-range transport calculations and another two are excluded from considerations.

**Table 2.12.** Contributions of 2,3,7,8 - substituted congeners to their homologous group toxicity

Homologous group	Congener	Contributions of congeners to their homologous group toxicity, %					Mean
		Electrode astes	PVC mean	PCB	Wood wastes	Chemical industry wastes	
		<i>Hagenmaier et al., 1994</i>	<i>Christman et al., 1989a &amp; Theisen et al., 1989</i>	<i>Ke Jiang et al., 1997</i>	<i>Oehme, Muller, 1995</i>	<i>Майстренко и др., 1998</i>	
HxCDF	1,2,3,4,7,8-HxCDF	81.6	39	70.8	36	58.1	57.1
	1,2,3,6,7,8-HxCDF	16.3	34	20.1	30	33.7	26.8

	1,2,3,7,8,9-HxCDF	0.9	6	4.9	3	1.2	3.2
	2,3,4,6,7,8-HxCDF	1.2	21	4.1	31	7.0	12.9
PeCDF	1,2,3,7,8-PeCDF	27.5	22	21.6	11	16.2	19.7
	2,3,4,7,8-PeCDF	72.5	78	78.4	89	83.8	80.3
PeCDD	1,2,3,7,8 – PeCDD	100	100	100	100	100	100

### Combustion sources as a whole

Averaged contributions of congeners to the toxicity of prioritized homologous groups are presented in Table 2.13.

**2,3,4,7,8-PeCDF** congener is most important for these sources because its contribution to the TEQ is almost 30%. The congeners of **HxCDF** group with substitution in positions 1,2,3,4,7,8 - and 1,2,3,6,7,8 provide almost 70% of the group toxicity being about 23% of total PCDD/F mixture toxicity. About 30% of TEQ is accounted for 1,2,3,7,8,9 - HxCDF and 2,3,4,6,7,8 - HxCDF. 1,2,3,7,8 - PeCDD from the third prioritized **PeCDD** group makes 8% contribution to TEQ of PCDD/F mixture.

#### 2.4.3. Production processes

Many industrial processes can be PCDD/F sources of emission to the atmosphere. In this

study we are forced to restrict ourselves by one of directions of metallurgy, namely by secondary processing of non-ferrous metals. Since literature sources containing information on PCDD/F content in ferrous metallurgy emission, primary aluminium, copper etc. production as a rule estimate it as TEQ and do not give data on the content of 17 toxic congeners.

#### Non-ferrous metal secondary processing

The distribution of 2,3,7,8 - substituted congener contributions to their homologous group toxicity of the considered homologous group is shown in Table 2.14.

TEQ of PCDD/F mixture is specified by the congeners with contributions as follows: 2,3,4,7,8 - PeCDF (36%), 1,2,3,4,7,8 - HxCDF (14%), 1,2,3,7,8 - PeCDD (11%) and 1,2,3,6,7,8 - HxCDF (about 7%).

**Table 2.13.** Contributions of 2,3,7,8 - substituted congeners to the toxicity of their homologous groups

Wastes	Contributions of 2,3,7,8 - substituted congeners to the toxicity of their homologous groups, %					
	PeCDF		HxCDF			
	1,2,3,7,8	2,3,4,7,8	1,2,3,4,7,8	1,2,3,6,7,8	1,2,3,7,8,9	2,3,4,6,7,8
Solid municipal	8.3	91.7	33.5	30.7	4.9	31
Medical	9.3	90.7	28.3	31.7	3.3	36.7
Industrial	19.7	80.3	57.1	26.8	3.2	12.9
Mean	12.4	87.6	39.6	29.7	3.8	26.9

**Table 2.14.** Contributions of 2,3,7,8 - substituted congeners to the toxicity of their homologous groups

Processes of non-ferrous metal secondary processing	Contributions of 2,3,7,8 - substituted congeners to the toxicity of their homologous groups, %					
	PeCDF		HxCDF			
	1,2,3,7,8	2,3,4,7,8	1,2,3,4,7,8	1,2,3,6,7,8	1,2,3,7,8,9	2,3,4,6,7,8
Copper and aluminum scrap processing	4.4	95.6	41.4	35.1	0	23.4
Secondary processing of aluminum	25.9	74.1	67.7	17.6	7.4	7.4
Mean	15.2	84.8	54.5	26.4	3.7	15.4

## 2.5. Conclusions

This section describes the analysis of literature data on the composition of emissions from the main sources of PCDD/F input to the atmosphere with the goal to select individual compounds (congeners) for the evaluation of their transport over long-distances within the EMEP grid.

The main criterion for the selection is the contribution to the TEQ of PCDD/F mixture emitted from sources of the following types:

- combustion of organic fuel;
- waste incineration;
- secondary processing of non-ferrous metals.

As a result of the investigation three priority homologous groups contributing not less than 70%) to PCDD/F mixture toxicity – **PeCDF**,

**HxCDF** and **PeCDD**. For priority groups the contribution of 2,3,7,8-substituted congeners to the toxicity of their groups are studied. The congeners adequately describing toxic properties of emissions are selected for the long-range transport modelling (Table 2.15).

2,3,4,7,8-PeCDF, out of all 17 PCDD/F congeners, makes the maximum contribution to emissions from all considered sources, i.e. about 50%) – combustion of organic fuel, about 30%) waste incineration and more than 30%) –secondary processing of non-ferrous metals has been selected as indicator congener (reference) for provisional calculations by the regional model developed by *M.Pekar et al.* [1999].

**Table 2.15.** Contributions of 2,3,7,8-substituted congeners to the toxicity of priority homologous groups and their toxicity coefficients

N/N	Contributions of congeners to its homologous group toxicity, %	Emission source			I – TEF
		Organic fuel combustion	Waste incineration	Non-ferrous metal secondary processing	
1	PeCDF 2,3,4,7,8-PeCDF	89	88	85	0.5
2	HxCDF 1,2,3,4,7,8-HxCDF	40	40	55	0.1
	1,2,3,6,7,8-HxCDF	37	30	26	0.1
3	PeCDD 1,2,3,7,8-PeCDD	100	100	100	0.5

### 3. The analysis PCDD/F mixture composition in the environmental media on the base of measurements

#### 3.1. Peculiarities of measurement data presentation

The pollution of the environment by compounds of polychlorinated dioxins and furans has come under active study during recent 10-15 years. During this period very sensitive methods of analysis of natural media, emissions, waste water, industrial wastes as well as biological media including tissues, organs and liquids of animals and humans have been developed. Due to revealed high toxicity of a certain group of congeners they received a particular attention. Methods of analysis were oriented to their separation from the group of dibenzo-p-dioxins and furans and subsequent quantification. Mass concentrations of toxic congeners are within femto- and picograms. These low values are very difficult for the analysis, they require expensive equipment reagents and skilled personnel thereby making congener specific measurements very expensive. Due to different reasons up till now we fail to determine the quantity of this or that congener in natural media.

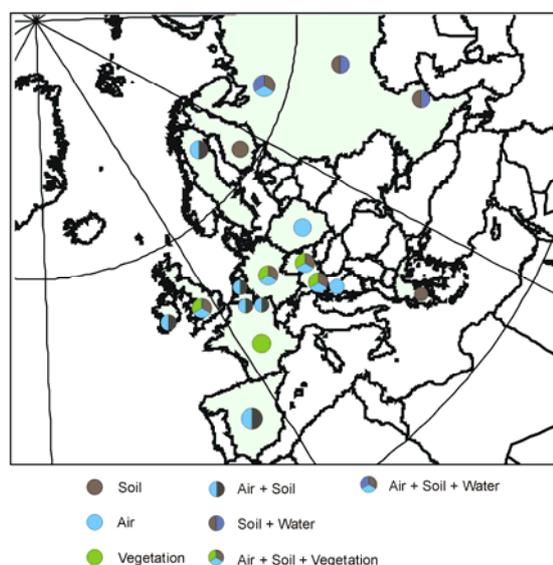
As it is known, PCDD/F group consists of more than 200 compounds and can be characterized by overall mixture toxicity. Its calculations are made with the use of different national and international TEF. At present most widespread are NATO and WHO systems described in more details in Section 1 of the report.

PCDD/F content in natural media represented in TEQ or in dioxin equivalent is an important characteristics and it is legislated in a lot of countries. These standards define maximum

permissible concentrations in air of industrial zones and residential area, permissible content in waste water and chemical products, surface and ground water approximately safe levels of content in soils and bottom sediments, food.

Hygienic investigations indicated that the bulk of PCDD/F enters the human organism with food (94.77%), respiration – 5%, the remained 0.23% - with water and through skin [Куценок и др., 1998]. Pollution levels of air and other natural compartments (in TEQ) allow assessing risks for the population health and ecosystems. For this reasons measurement data are presented most often in dioxin equivalents.

MSC-E is continuously collecting measurement data on PCDD/F content in natural media. Their geography and compartments of the natural environment where measurements were carried out are illustrated in Figure 3.1.



**Figure 3.1.** Location of measurements on PCDD/F obtained under national and international programmes (1988-97)

The pollution by dioxins in countries of European Economic Union is described in detail in [Buckley-Golder *et al.*, 1999]. It contains a great deal of actual information about PCDD/F content in air and deposition, soils and bottom sediments, vegetation and biological samples. In sections dedicated to countries there is information on national programmes of PCDD/F monitoring as well as measurement data represented in dioxin equivalent.

Not all EEC countries have information about PCDD/F pollution of their territories as yet. Some countries only plan to carry out measurements, for example, Portugal, or select as priority object food products and biological material like France.

Data on the environmental pollution by compounds from PCDD/F group in countries not participating in EEC in particular in East European countries have not yet been summarized, may be except for the Czech Republic. Often these data are absent or they are difficult to access.

For this report we have collected and systematized data on PCDD/F content in the natural media of some European countries. Data on Russia and Germany are tabulated in Annex A.

PCDD/F concentrations represented in dioxin equivalent are summarized (integral) indices preventing from estimating the role of these or those toxic congeners in the formation of these concentrations. The analysis with the goal to reveal similarities and differences in distributions of contributions of PCDD/F homologous groups to a specific object on the territorial level or in time is possible only on the base of congener specific determination, i.e. if mass concentrations of all PCDD/F toxic congeners are available. The data collected in MSC-E on all measured 2,3,7,8-substituted

(toxic) congeners in some European countries are tabulated in Annex B. Investigations of toxic congener distributions and their role in the formation of TEQ of samples for different natural media are seldom to be found in the literature. Such a study has been carried out for the atmospheric pollution and deposition in [Lohmann and Jones, 1998].

In the following sections we describe investigations made on the base of analysis of available measurements of toxic congener concentrations in natural media.

### **3.2. The selection of PCDD congeners for calculations of their long-range transport on the base of measurement data analysis**

This section describes the methodology and analysis results of the distribution of toxic congener contributions to TEQ of air, soil and vegetation samples with the use of literature data. This study forestalls the investigation of PCDD/F behaviour in the environment by mathematical modelling and allows passing on from a group of substances which are difficult to be characterized by some "mean physical-chemical properties" to a congener with individual properties specified experimentally or predicted with high probability. The analysis of distributions of contributions of homologous groups and congeners to the TEQ of samples taken in the environment should supplement and refine the results discussed in Section 2.

Like in the analysis of emission composition in this case the key criterion of sampling is considered a relative value, namely the contribution to the TEQ. In toxicity calculations we used literature data on the determination of mass concentrations of toxic congeners in different media. Calculations of TEQ were made with the use of NATO and WHO International Systems of TEF. At first we

analysed contributions of homologous groups and selected the group of the highest contribution and then selected congeners in view of its contribution to toxicity in its homologous group.

### 3.3. The analysis of the contribution of PCDD/F homologous groups and congeners to sample toxicity for different environmental media

PCDD/F inflow to the atmosphere from different sources and their content in air of cities and clean regions are certainly related to each other. The analysis of PCDD/F emission composition discussed in Section 2 specified homologous groups and congeners responsible for the formation of TEQ.

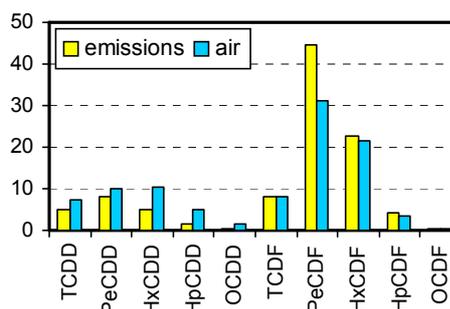
*R.Lohmann and K.Jones* [1998] have studied for the first time the role of homologous groups and toxic congeners in air pollution. Using a great number of measurements they came to the conclusion on the priority of 2,3,4,7,8-PeCDF congener in many investigated regions, i.e. 26 measurements made in Europe, Japan, America and Australia.

Figure 3.2 illustrates the comparison of homologous groups to TEQ of emissions, discussed in Section 2, with the results obtained by *R.Lohmann and K.Jones* [1998] for air. It is obvious that both profiles are alike.

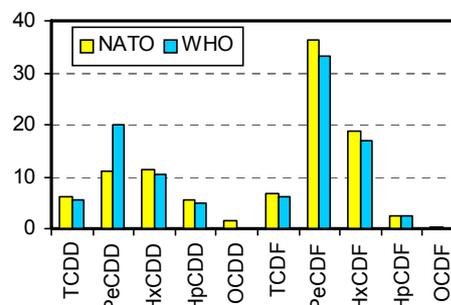
Peculiarities of the distribution of homologous group and congener contributions in the atmosphere we studied by measurement data systematized within the framework of POPCYCLING-Baltic project [*Pacyna et al.*, 1999] and by other sources. The content of toxic congeners represented initially in mass concentrations were recalculated in TEF of NATO and WHO systems. Differences in homologous profiles of toxic PCDD/F content in air of Europe with the use of TEF of the two systems are illustrated in Figure 3.3. Obviously the greatest contribution to the total mixture

toxicity calculated by NATO TEF system make homologous groups PeCDF, HxCDF, HxCDD, PeCDD and the contribution of the first two groups are approximately equal (by 11% each). These results are in a good agreement with the conclusions of [*Lohmann and Jones*, 1998].

The application of WHO TEF somewhat changes the distribution of homologous groups, increasing the contribution of PeCDD group to 20% as it is evident in Figure 3.3.



**Figure 3.2.** The comparison of TEQ of emission (obtained in this study) and air samples (obtained by *R.Lohmann and K.Jones* [1998]), %

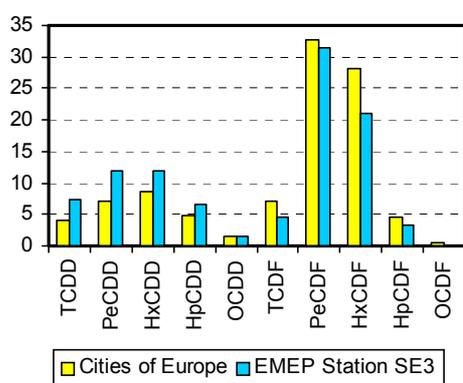


**Figure 3.3.** Contributions of homologous groups to TEQ of air samples obtained on the base of measurements carried out in Europe [*Broman et al.*, 1991a; *Pacyna et al.*, 1999] in NATO and WHO systems, %

With the use of the longest series of measurements of toxic congener content in European cities [*Coleman et al.*, 1998; *Hiester et al.*, 1997, *Abad et al.*, 1997] and at station SE3 [*Pacyna et al.*, 1999] we obtained the following profiles.

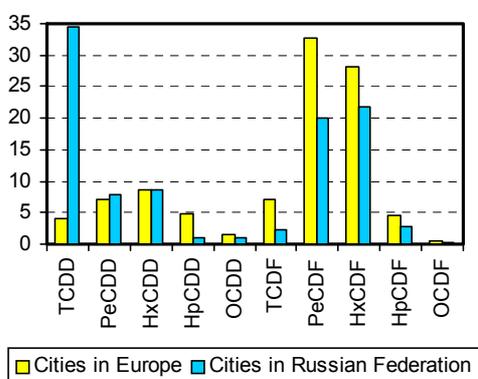
As seen from Figure 3.4 both air in cities and at monitoring station Rervik remote from

emission sources has no principal differences in the distribution of homologous group contributions to the TEQ. In the formation of TEQ the same groups are most important, i.e. PeCDD, PeCDF, HxCDD, HxCDF. Probably the enhanced role of dioxin groups, namely TCDD and PeCDD, might be mentioned. Whether it is the result of local sources or it the effect of global distillation, it is difficult to say. May be it is the result of different time intervals and insufficient data for averaging at station Rörvik.



**Figure 3.4.** Contributions of homologous groups to TEQ of air samples in European cities (London, Manchester, Berlin, Dortmund, Köln, Essen, north-eastern Spain) and at station Rörvik (SE3), %

The most significant differences in homologous group distributions are revealed in air of the same European cities and cities of European part of Russia (see Figure 3.5).



**Figure 3.5.** The comparison of homologous group contributions to TEQ of air in cities samples of Europe and Russia, %

It is evident that in air of Russian cities dominates most toxic 2,3,7,8-TCDD. Measurement data on air pollution in Novodvinsk [Юфим, 1998], Suzdal and Vladimir [Клюев и др.,1998], Ufa and in other cities of Bashkortostan [Майстренко и др.,1998] are of a single character therefore their homologous profile was not included for averaging. For modelling purposes at the first stage we selected three homologous groups: **PeCDD, PeCDF and HxCDF**.

The distribution of mixture toxicity inside these groups was calculated by averaging European data. The obtained results are presented in Table 3.1.

**Table 3.1.** The distribution of mixture toxicity with congeners inside main homologous groups

Homologous group	Congener	Contribution to TEQ (%)
PeCDD	1,2,3,7,8	11
PeCDF	1,2,3,7,8	3.6
	2,3,4,7,8	32.8
HxCDF	1,2,3,4,7,8	7.1
	1,2,3,6,7,8	6.2
	1,2,3,7,8,9	0.04
	2,3,4,6,7,8	5.3

Contributions of four distinguished congeners (shaded) are highest among all 17 toxic congeners. Their overall toxicity is 55%.

Thus data on measured air concentrations confirm the conclusion made on the base of emission data analysis that these four congeners make the main contribution to PCDD/F toxicity.

These congeners have been selected for modelling purposes.

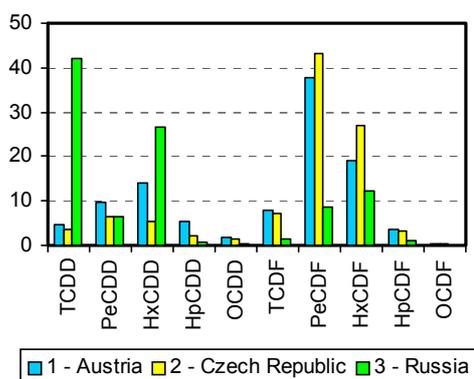
It is worth analysing the distribution of homologous group contributions to PCDD/F mixture toxicity in other environmental compartments introduced to the model (soil, vegetation, sea water).

Data on the content of each of 17 congeners in soil are very scarce. Most often investigators paid their attention to zones affected by waste plants and high ways. There are little data on forest soils and the pollution of background regions. There are no multi-annual observations in one and the same regions besides may be investigations of L.-O.Kjeller *et al.* [1991] and R.Alcock *et al.* [1998] but they analysed archived soils in order to reveal PCDD/F concentration trends during 1846-1886. Although for PCDD/F analysis dried samples are used such long storage can affect the results obtained, in particular for the most old samples.

For the analysis of distribution of homologous group and congener contributions to TEQ we selected two types of measurement data.

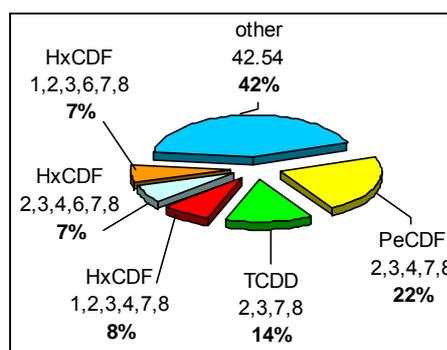
First it is forest soils, see Figure 3.6. For this diagram we used PCDD/F measured concentrations in soil presented in papers [Holoubek *et al.*, 2000; Weiss, 1998 and Майстренко *и др.*, 1998; Ключев *и др.*, 1998].

The diagram shows that a noticeable contribution to PCDD/F mixture toxicity in addition to the selected congeners – PeCDD, PeCDF and HxCDF makes groups of TCDD, TCDF and HxCDD groups.



**Figure 3.6.** Contributions of homologous groups to TEQ of forest soil samples taken in high mountain regions of Austria, the Czech Republic and in Russia: 1 – [Weiss, 1998], 2 – [Holoubek *et al.*, 2000], 3 – [Майстренко *и др.*, 1998 and Ключев *и др.*, 1998], %

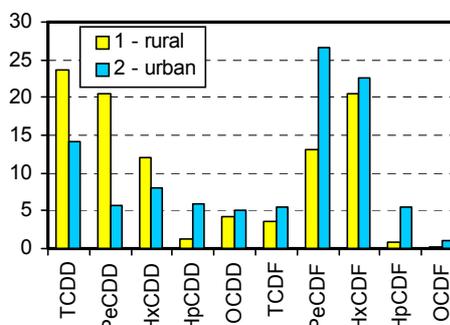
Second we selected soils of industrial and urban zones and the land used for agriculture. The distribution of contributions to TEQ of soils in industrial and urban zones is demonstrated in Figure 3.7. For the construction of this diagram data of [Майстренко *и др.*, 1998; Михайлов *и др.*, 1998; Cole *et al.*, 1999; Schumacher *et al.*, 1997].



**Figure 3.7.** The distribution of toxic congeners contributions to the TEQ of soils in industrial and urban zones.

In the vicinity of different PCDD/F sources maximum contribution to soils makes the same isomer 2,3,4,7,8-PeCDF. 2,3,7,8-TCDD contributes similar fraction. Then come groups of HxCDF. In general the distribution of toxic congeners is relatively of a homogenous character.

In soils of meadows, fields and pasture the distribution of dioxins and furans has a number of distinctions, namely considerable contributions of TCDD, PeCDD, HxCDD and OCDD. It is seen in Figure 3.8.



**Figure 3.8.** The comparison of homologous profiles in agricultural land, industrial and urban zones: 1 – agricultural soils from [Ключев *и др.*, 1998],

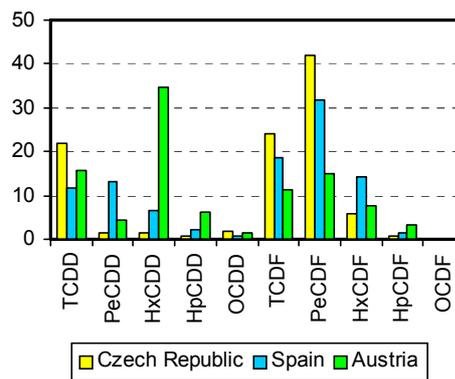
[Михайлов и др., 1998]. 2 – soils of industrial and urban zones from [Майстренко и др., 1998], [Михайлов и др., 1998], [Cole et al., 1999], [Schumacher et al., 1997], %

Congeners with six and more chlorine atoms are stable in soil. According to data of [Mackay et al., 1992] the half-life of hexa-, hepta- and octachlorodibenzo-p-dioxins and octachlorodibezofurans can reach 6 years. According to estimates of [Sinkkonen and Paasivirta, 2000] in regions with temperate climate (Baltic region) congeners from these homologous groups can be preserved in soil more than 100 years. Such a long half-life defines a necessity of studying mechanisms of accumulation and transformation of these compounds in soil, possibilities of their uptake by plants and then along trophic chains.

Thus the analysis of contributions of PCDD homologous groups to TEQ leads to the conclusion about the necessity to consider at further stages tetra chlorodibenzo-p-dioxins, tetrachlorodibenzofurans, hexachlorodibenzo-p-dioxins and (probably) homologous groups of dioxins with eight chlorine atoms.

The contribution of dioxin/furan homologous groups to TEQ of plant samples we investigated by data from [Schumacher et al., 1998, 2000] and [Jones and Duarte-Davidson, 1997], monograph [Weiss, 1998] and [Holoubek et al., 2000].

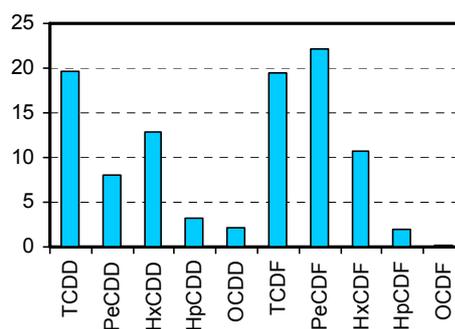
The contribution of homologous groups calculated on the base of collected data is demonstrated in Figure 3.9.



**Figure 3.9.** Contributions of homologous groups to TEQ of plant samples taken in high mountain regions of the Czech Republic (1), Spain (2) and Austria (3), %

Homologous profiles were compared on the base of PCDD/F determination in grass and needles. Obviously it is not quite correct since different species uptake pollutants in different way. However, as seen from Figure 3.9, the contributions of TCDD and TCDF are substantial in all samples, as to silver fir needles sampled in Austrian Alps HxCDD essential contribution is observed.

Figure 3.10 shows PCDD/F averaged homologous profile in plant samples taken from [Schumacher et al., 1998; Jones and Duarte-Davidson, 1997; Weiss, 1998; Holoubek et al., 2000] (Fig. 3.10).



**Figure 3.10.** Contribution of homologous groups to plant samples TEQ, %

Figure 3.10 demonstrates that the main contribution to the toxicity make furans groups and PeCDF fraction is more than 20%.

Nearly 20% and practically equal contributions make groups with four chlorine atoms – TCDD and TCDF. PeCDF group contribution, however, remains maximum, which indicates 2,3,4,7,8–PeCDF congener making the greatest input to the toxicity of vegetation samples.

The investigation of contributions of different PCDD/F groups to sea water toxicity first of all was limited by lack of data. Only single measurements were carried out in the Baltic region [Broman *et al.*, 1991b]. The conclusions made on the base of Figure 3.11 may be considered as qualitative. In particular a considerable contribution to the marine environment pollution makes TCDD and TCDF and the role of HxCDD is slightly decreased.

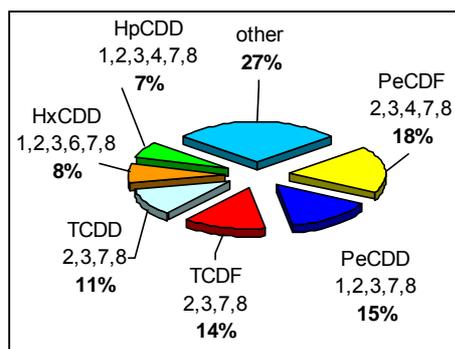


Figure 3.11. Congener contribution to TEQ of sea water sample

### 3.4. Conclusion

On the base of measurement data analysis individual compounds (congeners) for modelling at the first and second stages have been selected. The results are shown in (Table 3.2).

Table 3.2. List of congeners selected on the base of analysis of congener contributions to TEQ of samples taken in different environmental media

Congener	Stage	Basis for including
1,2,3,7,8-PeCDD	I	An essential contribution to the formation of dioxins/furans mixture toxicity in air
2,3,4,7,8-PeCDF		
1,2,3,4,7,8-HxCDF		
1,2,3,6,7,8-HxCDF		
2,3,7,8-TCDD	II	Noticeable contribution to the formation of dioxins/furans mixture toxicity in soil, vegetation and sea water
2,3,7,8-TCDF		
1,2,3,6,7,8-HxCDD		Noticeable contribution to the formation of dioxins/furans mixture toxicity in soil and sea water. Long life-time in soil.
1,2,3,7,8,9-HxCDD		

## 4. Computation experiments

### 4.1. Model parameterization

The model parameterization was performed on the base of the analysis of literature data of *A.A. Bulgakov and D.A. Ioannisian* [1998], *M.I. Pekar* [1999]. The preference in the choice of these or those parameter values was given to experimentally defined rather than theoretically calculated data. For model calculations the following physical-chemical properties of congeners have been chosen.

The data of Table 4.1 indicates that the difference in physical-chemical properties of two selected congeners from HxCDF group lies basically in the Henry's law coefficient values. In particular this difference will result in the fact that wet scavenging of the gaseous phase will be more intensive for 1,2,3,4,7,8-HxCDF than for 1,2,3,6,7,8-HxCDF. In other cases properties of these two congeners are similar. Thus it may be expected that the long-range transport process will be more or less similar for these congeners. The difference between properties of 1,2,3,7,8-PeCDD and 2,3,4,7,8-PeCDF is more significant. An appreciable impact on the long-range transport makes the difference in their half-life period. Due to higher value of this parameter 2,3,4,7,8-PeCDF will be transported for longer distances than 1,2,3,7,8-PeCDD. In particular it results in greater accumulation of 2,3,4,7,8-PeCDF in the marine environment. Besides due to higher value of saturated vapour pressure the fraction of 2,3,4,7,8-PeCDF gaseous component will be greater. A simple

analysis does not allow us to estimate to a full extent the influence of physical-chemical properties of the congeners upon their long-range transport. In particular, it remains unclear whether it is possible to use properties of one of the congeners for the evaluation of their mixture long-range transport (selection of "indicator congener"). To receive the answer to these questions we carried out a number of model experiments described below.

In order to assess the significance of differences in physical-chemical properties of different dioxins/furans congeners for their long-range transport and to investigate the model description of the main processes the following calculations were carried out

- the transport of TEQ of which is distributed between four congeners of the "first priority" in accordance with fractions presented in Table 3.1 above on the assumption that each congener has individual physical-chemical properties;
- four calculation runs of the mixture transport in which physical-chemical properties of one of the congeners are prescribe to the whole mixture.

The calculations were carried out for 1970-98 with spatial resolution 150x150 km with the use of MSCE-POP multi-component model for POP long-range transport. To make allowance for the initial accumulations in natural compartments the model spin-up covered 15-year period with meteorological information of 1970 was carried out. The meteorological data were prepared by Hydrometeorological Centre of Russia. As emission data we used

**Table 4.1.** Main physical-chemical parameters of dioxins/furans congeners (see Table 1.3 for notations)

Homologous group	Congener	$H$ , Pa/m <sup>3</sup> /mol	$P_{OL}$ , Pa	$W$	$T_{1/2}$ , days		
					Air	Soil	Sea water
PeCDD	1,2,3,7,8	3.1	$7.49 \times 10^{-5}$	18000	5.4	710	23
PeCDF	2,3,4,7,8	0.51	$1.77 \times 10^{-4}$	14000	19	710	23
HxCDF	1,2,3,4,7,8	1.4	$8.46 \times 10^{-5}$	10000	21.6	710	71

	1,2,3,6,7,8	0.57	$8.16 \times 10^{-5}$	10000	21.6	710	71
--	-------------	------	-----------------------	-------	------	-----	----

expert estimates made under POLYCYLING-Baltic project [Pacyna et al., 1999]. The dynamics of long-term variations of pan-European emission is considered below in the section "Long-term pollution dynamics".

In the following we consider the description of calculation results and their interpretation. The comparison of calculated and measured concentrations in different media evidence that the physical-chemical parameters used for model parameterization reproduce the behaviour of the considered substances in the environment to a first approximation. The discrepancy for all the media is within an order of magnitude.

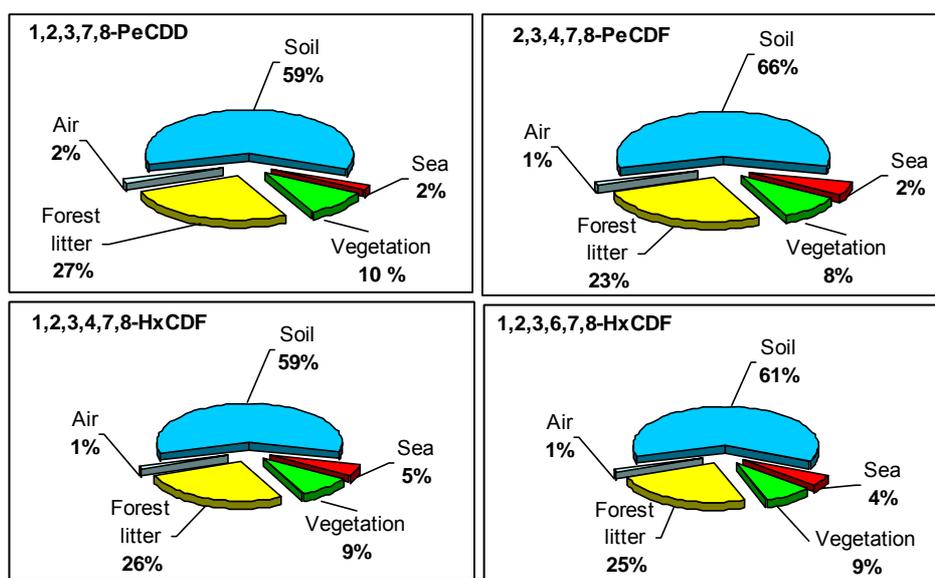
#### 4.2. Balance values

First we consider the balance values, i.e. the contents of PCDD/F in the media for a finite year of calculation, and the values of uptake by the media for the whole period. Uptake implies the total content at the end of the period, plus the degraded matter amount during all the period, minus the initial content

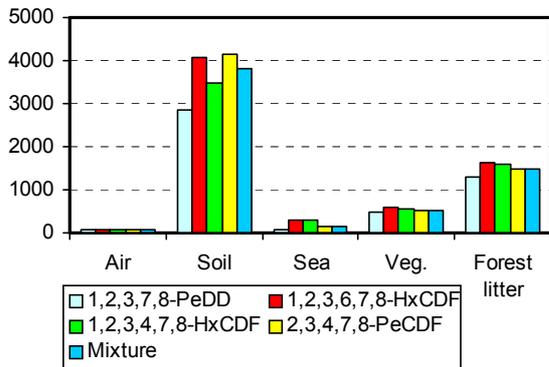
for a given compartment.

Figure 4.1 contains diagrams indicating the distribution of TEQ, between natural media, at the end of calculations, obtained by modelling PCDD/F mixture transport, on the basis of the physical-chemical properties of individual congeners.

The diagrams show that, from the viewpoint of content values in the media, the congener physical-chemical properties of congeners from HxCDF group (1,2,3,4,7,8-HxCDF and 1,2,3,6,7,8-HxCDF) are rather close to each other (the contents in the various media differ by no more than 2 %). The differences between this group and the rest of the congeners, and also between 1,2,3,7,8-PeCDD and 2,3,4,7,8-PeCDF, are more considerable. The difference is more apparent at the soil content, which reaches 7%. Figure 4.2 shows the comparison of contents in the various natural media for the end of the modelling period. A separate column shows the modelling results for the mixture distribution of four congeners in fractions obtained from analysis of the measured data.

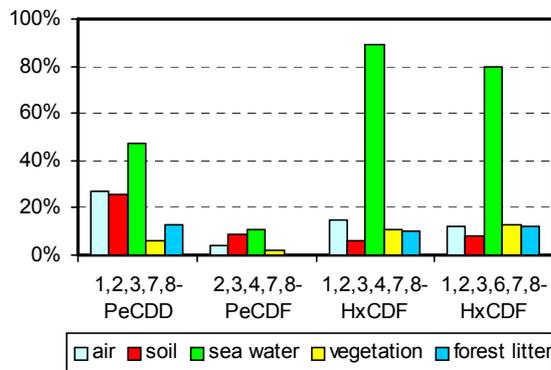


**Figure 4.1.** Distribution of TEQ over the natural media by the end of calculations (1998, the calculations were made using the properties of individual congeners)



**Figure 4.2.** Distribution of TEQ mixture, between the natural media, by the end of the modelling period (1998, calculations with the use of individual congener properties and their mixture), g I-TEQ

Figure 4.3 contains the data on deviations of the contents in the media, obtained by calculations, using the properties of the individual congeners, and appropriate values obtained for the mixture of the congeners.



**Figure 4.3.** Deviation of calculation results obtained with the use of properties of individual congeners from the mixture calculation, with results (in per cent), by the end of the modelling period (1998)

From the diagram represented in this figure one can see that the 2,3,4,7,8-PeCDF congener accurately describes the long-range transport of the mixture, at least from the viewpoint of the content values in the media.

The diagrams represented in Figure 4.1, show that for all considered PCDD/F congeners, the greatest accumulations take place in soil (58-66%) and in forest litter (23-28%). According

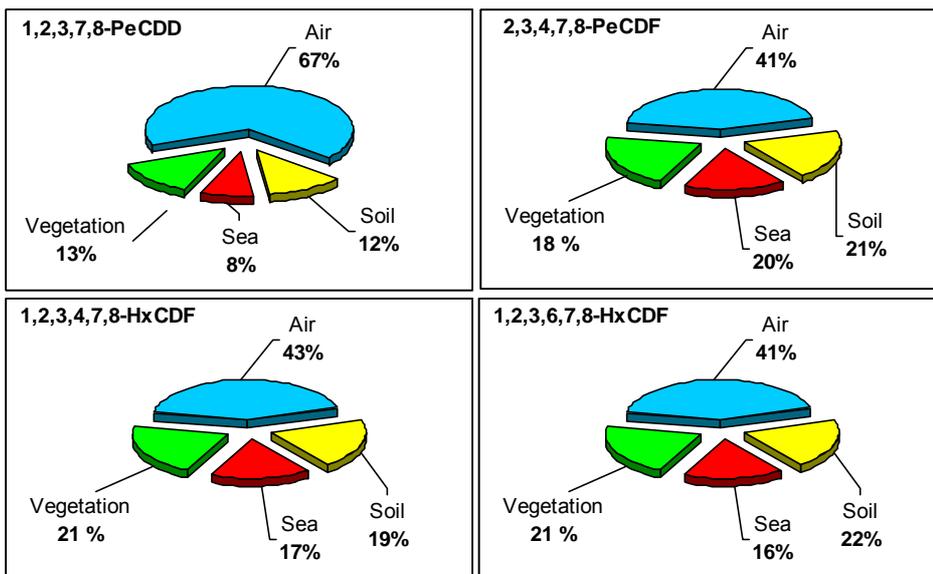
to the model estimations, the fraction of the contents in vegetation is about 10% for all considered congeners, and the fraction in sea varies from 2% up to 5%. Minor calculated PCDD/F content in the sea water is explained by that fact that, according to the parameterization accepted in the model, the PCDD/F half-life in sea is only 3-10 weeks (depending on the congener considered).

The quantity of the substance uptaken by the media over the whole modelling period (the total for the content in a given medium at the end of the calculation period, plus the value of decomposition in this medium, minus the initial content) is also interesting. The fractions of TEQ uptaken by various media for the whole modelling period are shown in Figure 4.4.

The difference in the calculated values of uptake, obtained using the congener properties of the HxCDF domain are not very great, neither are those for the medium contents. The distinction between this group and other congeners, however, becomes more considerable. Thus the value of air uptake of 1,2,3,7,8-PeCDD congener exceeds the similar value for other congeners by approximately 25%, mainly due to the higher air degradation rate of this congener. Moreover, the value of 1,2,3,7,8-PeCDD uptake by the sea medium is lower by approximately 15%, than for other congeners. The reason for it is that the model examines only sources of emission located on the land; and because of the high degradation rate, characteristic of 1,2,3,7,8-PeCDD congener, the atmospheric transport to the sea regions appears to be much lower than for other congeners.

The diagrams represented in Figure 4.4 show that atmospheric air (from 40% up to 67%) is

absorbing the main fraction of PCDD/F emitted within European region. This fact is caused by fast PCDD/F degradation in air. The fractions uptaken by soil, vegetation and sea media are approximately identical and are varying in the range of 10-20%.



**Figure 4.4.** Distribution of TEQ uptaken by the natural media for the whole modelling period (1970 – 1998, the calculations were made using the properties of individual congeners)

Thus:

- *The differences in distribution of various PCDD/F congeners influence significantly their long-range transport from the viewpoint of balance parameters;*
- *The fraction of the substance accumulated in the natural environmental compartments is highest for soil (about 60%) and forest litter (about 30%);*
- *The process of mixture redistribution between media can be described with 2,3,4,7,8-PeCDF congener properties as a first approximation.*

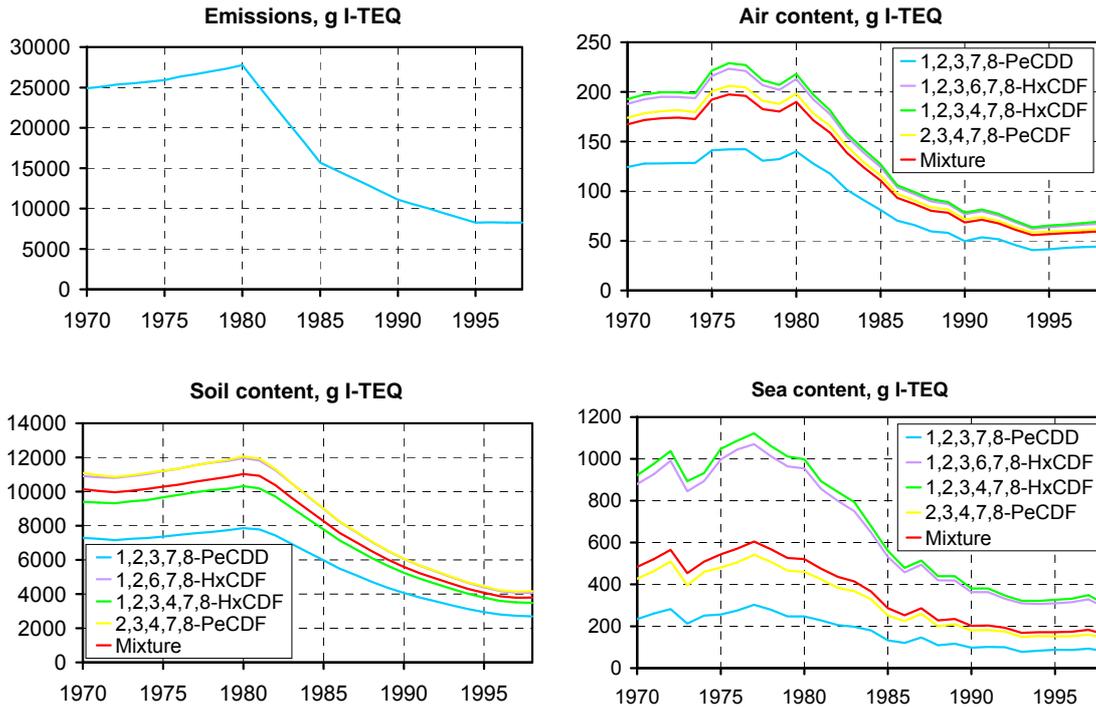
It is necessary, however, to take into consideration the fact that the examination of the balance parameters does not allow the possibility of estimating to a full extent the influence of the distinctions between the physical-chemical properties on the long-range transport process. To examine this question more completely it is necessary to consider the importance of physical-chemical

parameters on the long-term dynamics of accumulation (6-8 years minimum, according to the half-life period of 2 years, as it accepted in the model), and the spatial distribution of pollution throughout European region.

### 4.3. Long-term pollution dynamics

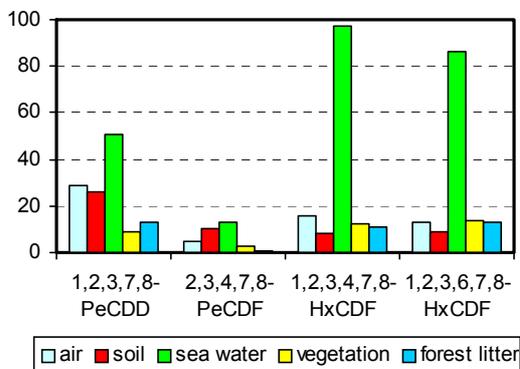
The dynamics of PCDD/F toxicity accumulation in the main natural media of the EMEP-region for the whole modelling period, both for mixture calculation and for calculations using individual congener properties, are represented on the plots in Figure 4.5.

The plots in figure show that the calculated content values using 1,2,3,7,8-PeCDD properties for all examined media is lower than for mixture transport calculations. For almost all media (except for soil) the content values obtained using the congener properties of HxCDF domain (1,2,3,4,7,8-HxCDF and 1,2,3,6,7,8-HxCDF) are close to each other and are also higher than those values obtained for the mixture transport.



**Figure 4.5.** The dynamics of TEQ variations contained in the natural media during the whole modelling period (1970-1998, the calculations were made using the properties of individual congeners and mixture)

The results obtained with the use of mixture and 2,3,4,7,8-PeCDF are in agreement. The maximum deviations of the results of calculations using the properties of particular congeners from that of the calculation of mixture for the considered media, is represented in the diagram of Figure 4.6. It is noticeable that the differences in pollution levels for the whole period of calculation do not greatly exceed the differences for the finite moment of the modelling period.



**Figure 4.6.** Deviations of calculation results made with the use of the properties of the particular congeners from the mixture calculation (%) for the whole modelling period (balance values)

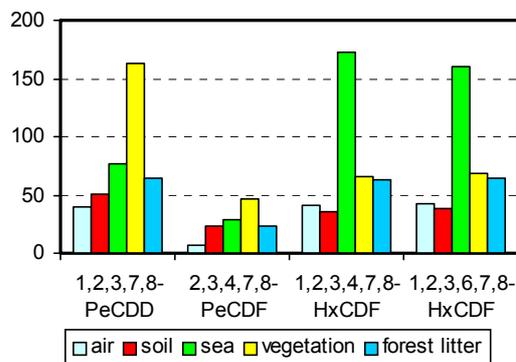
Furthermore, as is visible from the emission variation plots presented in Figure 4.5, the emissions assumed in the model reached a maximum in 1980. After that the general PCDD/F emission decreases 3.4 times by the end of the modelling period. For the same period the air and seawater contents decreases 3.2 times, and the soil content - 2.9 times. These data show that the soil is the main source of PCDD/F accumulation, and is capable of keeping the pollution level over quite a long period of time (the half-life period of examined congeners for soil is about two years). It is also necessary to keep in mind that using the lower rate of degradation [Sinkkonen and Paasivirta, 2000] (see Table 1.3) the delay in the concentration dynamics in soil, relative to emission variations, may turn out to be even more considerable. Thus:

- From the viewpoint of long-term dynamics, the mixture transport can be described with 2,3,4,7,8-PeCDF properties as a first approximation;

- Soil is the main accumulating media of PCDD/F capable of keeping the pollution level over long periods of time.

#### 4.4. Spatial distribution

The diagram in Figure 4.7 shows the differences (in per cent) in spatial distribution between the modelling results, using the properties of individual congeners, and of the mixture calculations (maximum deviation of the distribution calculated using the properties of individual congeners from calculation with the four selected congeners – over the cells of the EMEP-grid).

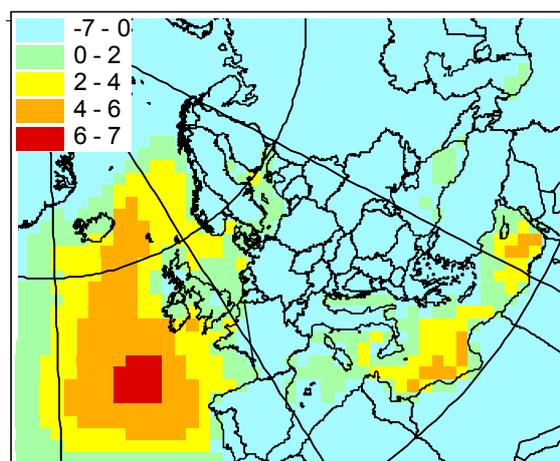


**Figure 4.7.** Maximum deviation over the EMEP grid of compartment concentrations calculated using the properties of individual congeners from the results of mixture calculations (%) by the end of the modelling period (1998).

Thus the calculations made with 1,2,3,7,8-PeCDF properties underestimate the air concentrations, and the calculations using 1,2,3,4,7,8-HxCDF and 1,2,3,6,7,8-HxCDF properties overestimate them. The calculations made using the 2,3,4,7,8-PeCDF properties describe the mixture distribution of PCDD/F in the most accurate way from the viewpoint of the spatial distribution as well. The maximum deviation (over the whole EMEP-grid) of the calculation results, from the calculation of mixture distribution, is about 50 % for

vegetation content but does not exceed 30% in other media.

We present here the map of spatial distribution of value deviations, for air concentrations, obtained in calculations using 2,3,4,7,8-PeCDF properties, from calculated values obtained for mixture distribution for the four selected congeners (Figure 4.8).



**Figure 4.8.** Deviations of air concentrations calculated with 2,3,4,7,8-PeCDF from values obtained with the mixture of four selected congeners, %.

As evident from Figure 4.8 when using the 2,3,4,7,8-PeCDF congener properties, air concentrations above seawater turned out to be mostly underestimated, and those above land are overestimated. It happens because the congeners from the HxCDF domain are more important in the formation of concentrations above the sea. In general, however, calculations made with the help of the 2,3,4,7,8-PeCDF congener properties, describe air concentrations quite accurately, as it was noted above.

The maps of PCDD/F concentration distribution over the main natural media, obtained with 2,3,4,7,8-PeCDF properties, and their comparison with the map of the emission spatial distribution, are given in Figures 4.9 - 4.13.



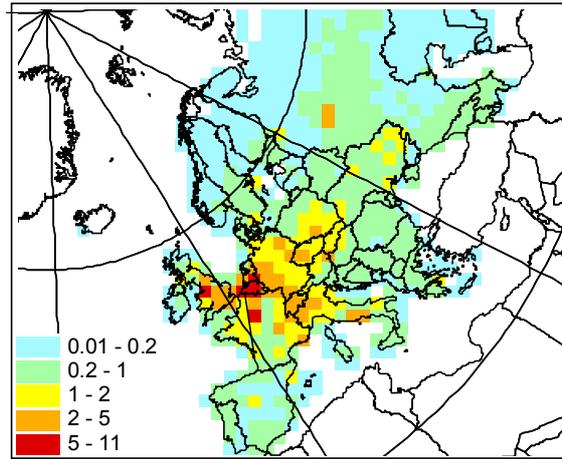


Figure 4.9. Spatial distribution of PCDD/F emission for 1998, ng I-TEQ/m<sup>2</sup>/y

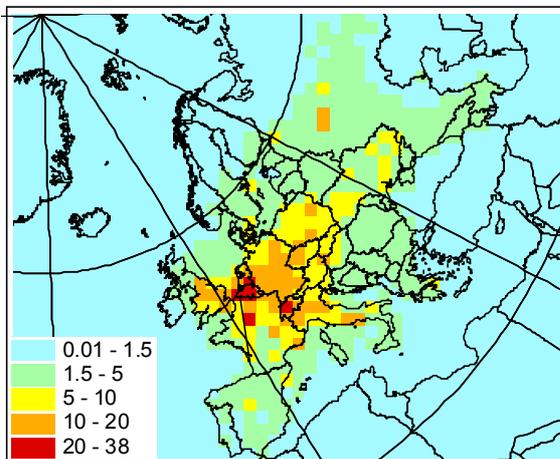


Figure 4.10. PCDD/F concentrations in air for 1998, fg I-TEQ/m<sup>3</sup>

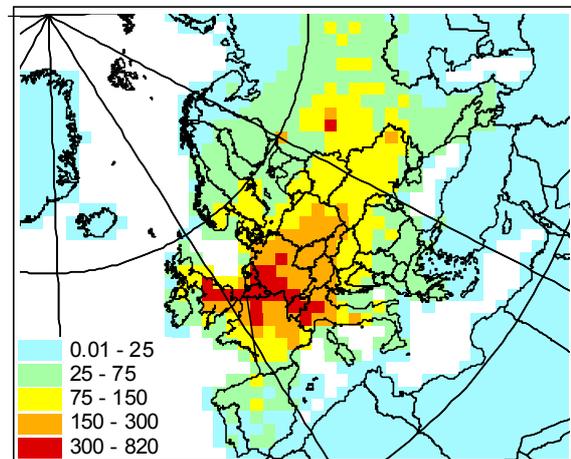


Figure 4.11. PCDD/F concentrations in soil for 1998, fg I-TEQ/g

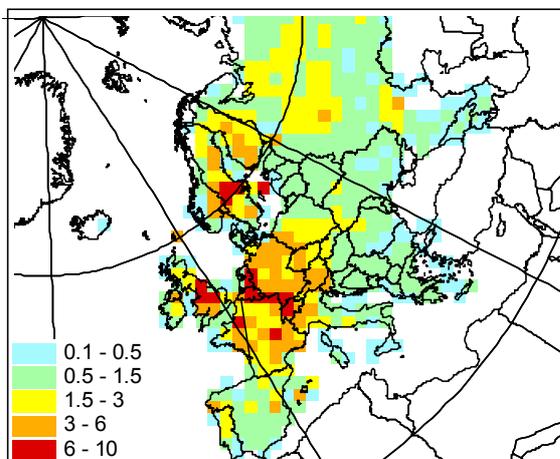


Figure 4.12. PCDD/F concentrations in vegetation for 1998, pg I-TEQ/g dry matter

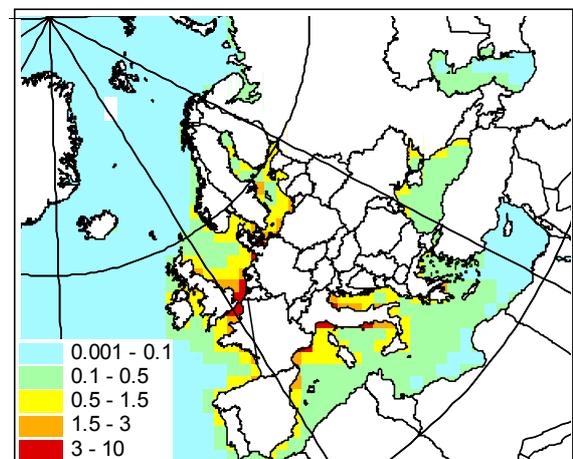


Figure 4.13. PCDD/F concentrations in seawater for 1998, fg I-TEQ/l

The comparison of the given figures shows that in general the concentrations in the atmosphere, soil and vegetation correlate well with emissions. High levels of concentrations in seawater can be seen in the regions close to main sources of emission. The levels of concentrations in all natural media decrease rapidly with increasing distance from main emission sources.

Thus:

- From the viewpoint of spatial distribution of the pollution levels, mixture transport is described by 2,3,4,7,8-PeCDF properties in the most accurate way;
- The maximum deviation of the results of the calculation made using the 2,3,4,7,8-PeCDF congener properties, from the calculation of mixture distribution, is about 50 % for vegetation and does not exceed 30 % for other media.

#### 4.5. Seasonal variations

This section describes seasonal variations of pollution levels in natural media of European region. Mean data was calculated with the use of 2,3,4,7,8-PeCDF congener properties for three years (1996 – 1998) to smooth down random variations of meteorological parameters). The plots of seasonal variations of air and soil concentrations, and also of total (dry + wet) depositions over land, are shown in Figure 4.14.

The upper part of the figure demonstrates seasonal variations of PCDD/F concentrations in air and soil. The scale with concentration range from 0 to 5 fg I-TEQ/m<sup>3</sup> is used for air and from 45 to 55 fg I-TEQ/g – for soil. In this way it is possible to bring into coincidence seasonal variations in one diagram and to see

differences in the behaviour of modelled substances in different media.

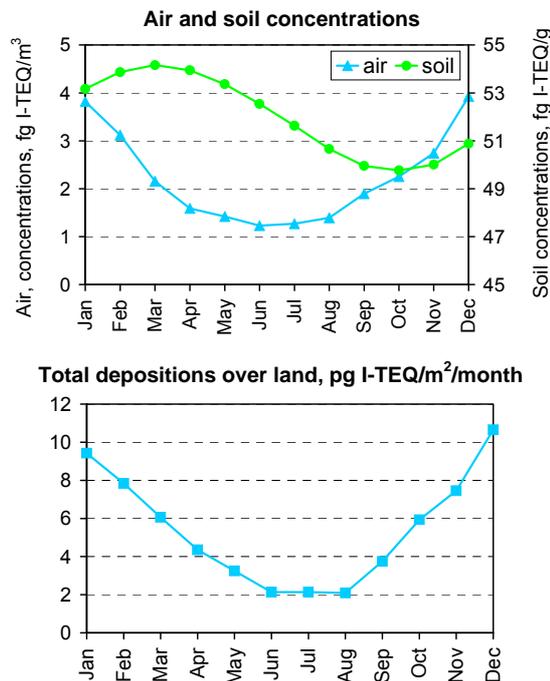
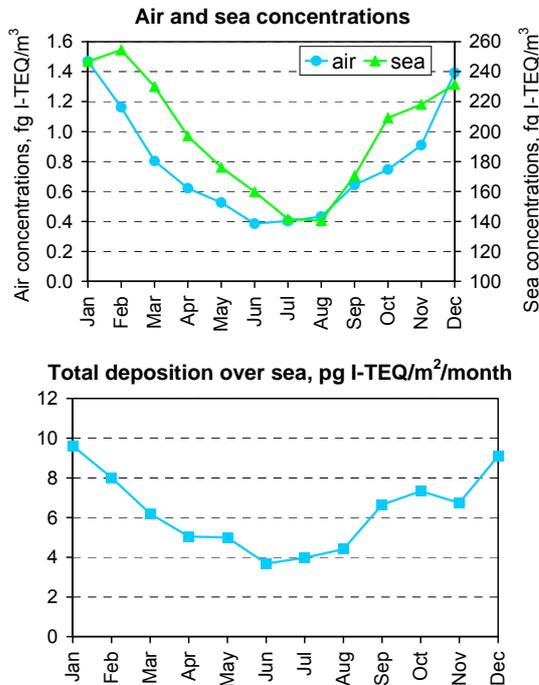


Figure 4.14. Seasonal variations of air and soil concentrations and total depositions over land

As evident from the plots in Figure 4.14 calculated PCDD/F air concentrations demonstrate pronounced seasonal variations with concentration increase in cold months and its decrease in warm ones. These seasonal variations result from both seasonal variations in levels of emission and, more significantly, acceleration of the degradation process in the warm season. A similar seasonal trend in air concentrations is mentioned, in particular, in the work of [Lohmann and Jones, 1998]. The comparison of seasonal variations in air and soil concentrations shows a delay of soil concentration dynamics. This sluggishness is caused by the slower degradation process in soil. It is also noticeable that whilst the seasonal variations in air concentration levels change by a factor of 3-4, the soil concentrations only by about 8%. Seasonal variations of depositions (lower part of the

figure) correspond, in general, to the seasonal variations of air concentrations.

Figure 4.15 shows seasonal variations of air and seawater concentrations, and also total (dry + wet) depositions over sea.



**Figure 4.15.** Seasonal variations of air and seawater concentrations and total depositions over sea

As seen from Figure 4.15 seasonal variations of air concentrations and total depositions over sea, are of the same character as over land. But the dynamics of seawater concentrations lag behind that of air concentrations, although the delay is less than that of soil concentrations. Seasonal variation of seawater concentrations is about 45% as against 8 % for soil concentrations. This is explained mostly by the fact that the degradation rate in sea, taken in the model, is much higher than the rate assumed for soil.

It is also worth noting that, according to the model calculations, the process of re-emission is negligible, both over the land and over the sea.

Thus:

- *The model calculations reveal a pronounced seasonal variations for air concentrations and total depositions with a rise during cold months and a lowering down during warm ones;*
- *The dynamics of seasonal air concentration variations are similar to those obtained by [Lohmann and Jones, 1998] based on measurements;*
- *The seasonal variations of soil concentrations lag behind, in comparison with the trend for air concentration variations.*

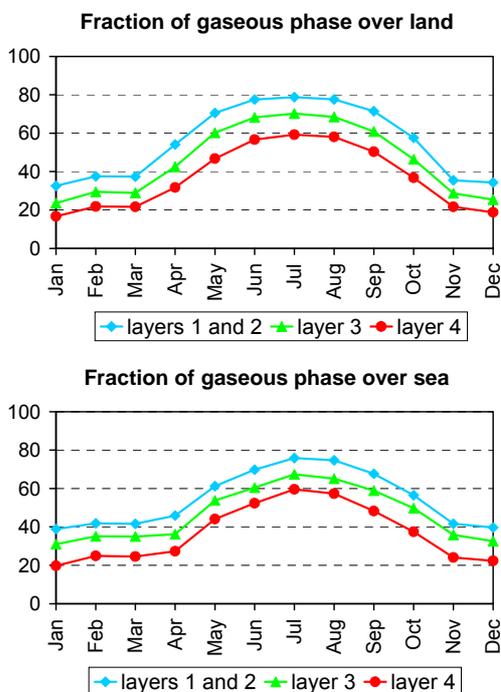
#### 4.6. Structure of deposition and gas/particle partitioning

In this section the analysis of the modelling results is carried out from the viewpoint of pollutant partitioning between the gaseous and aerosol phase, in the atmospheric air, and also from the viewpoint of different deposition types (wet deposition of the gaseous and aerosol phase, dry deposition of the aerosol phase, gaseous exchange with the underlying surface).

First, we should consider partitioning of PCDD/F between the gaseous and aerosol phase in air. The model describes this process on the basis of saturated vapour pressure being strongly temperature-dependent for subcooled liquids [Junge, 1977; Pankow, 1987] therefore the fraction of the aerosol phase in air undergoes seasonal variations connected with temperature regime variations. The temperature dependence of saturated vapour pressure also results in differences of the gaseous and aerosol phase at different heights.

Figure 4.16 shows seasonal variations of the gas phase fraction in various vertical layers of the grid (with reference levels for layer 1 - 50 m, layer 2 - 250 m, layer 3 - 750 m, layer 4 -

1600 m) over land and sea, obtained on the basis of calculations made using the physical-chemical properties of 2,3,4,7,8-PeCDF congener.



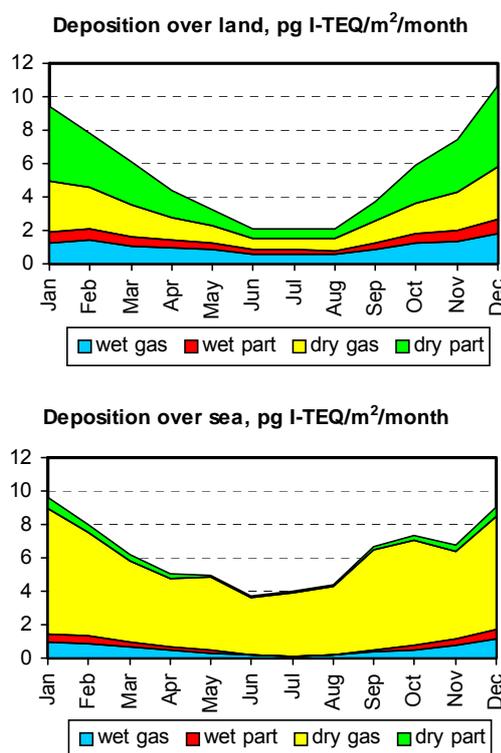
**Figure 4.16.** Seasonal variations of the gaseous phase fraction in air at various heights, %

It is evident that the fraction of the gaseous phase (both over land and sea) decreases with height: in lower atmospheric layers (layers 1 and 2) the fraction of the gaseous phase in summer reaches 80 %, and in upper layers (layer 4) – only 60%. Furthermore, an expressed shift towards the aerosol phase is observed in the cold season. Gas/particle partitioning over land and sea follows a similar pattern.

Partitioning of PCDD/F between gaseous and aerosol phase, was investigated in work by [Lohmann and Jones, 1998], where measured data were taken from various references. For 2,3,4,7,8-PeCDF congener, the fraction of the aerosol phase in various measurements, varies in between 30% and 60% (except for one measurement, where the aerosol phase fraction appeared to be 94%). These

experimental data compare well with the modelled results.

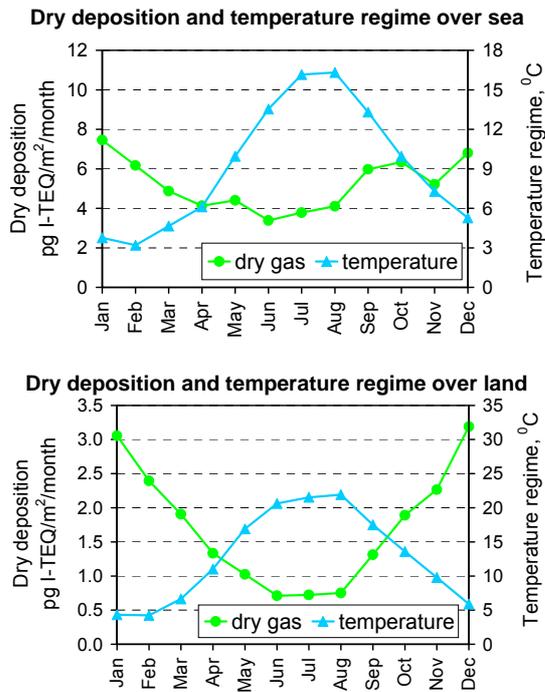
The most significant processes determining the long-range transport of POPs are the processes of wet and dry deposition and gas exchange with underlying surface (dry deposition of the gaseous phase). Figure 4.17 presents diagrams showing total depositions, according to their types, obtained with the use of 2,3,4,7,8-PeCDF properties.



**Figure 4.17.** Structure of total depositions

The diagrams represented in this figure reveal that the main contribution to total deposition over land and sea is made by dry depositions. In addition, the fractions of the gaseous and aerosol phase depositions over land appear to be comparable and vary according to fractions of these phases in the atmospheric air. However, in the case of depositions over sea, the main fraction results from dry deposition of the gaseous phase. As the dry depositions of the gaseous phase (gas exchange with the underlying surface) appears to be rather considerable, investigations of the

dependence of these depositions on the temperature regime, is of great interest. The plots of the seasonal variations of dry depositions of the gaseous phase over land and sea, together with the plots of monthly average temperatures are represented in Figure 4.18.



**Figure 4.18.** Dry deposition of the gaseous phase and temperature regime

On the plots shown in Figure 4.18, one can see that the characteristic dependence of the deposition flux on temperature, conditioned by

temperature dependence of the Henrys law coefficient. Thus, both for sea and for land, the deposition flux decreases with temperature increase. Due to greater temperature variations over land, seasonal variations of the gaseous flux are more pronounced than over sea. Besides it can be mentioned that the gas flux over sea is more subject to meteorological condition variations, than that over sea.

Thus:

- *The distribution of air concentrations of PCDD/F between phases calculated on the basis of the model is subject to seasonal variations, with a rise in the fraction of the gaseous phase in the summer months and a lowering down in winter;*
- *The calculated fraction of the gaseous phase is consistent, in general, with the experimental data;*
- *According to the model estimations, the main contribution to the process of the of PCDD/F deposition from the atmosphere, is dry deposition flux.*

## 5. Conclusions

On the base of analysis of calculated and measured data, PCDD/F congeners for modelling at the first, second and (probably) third stage have been selected.

The four selected congeners 1,2,3,7,8-PeCDD, 2,3,4,7,8-PeCDF, 1,2,3,4,7,8-HxCDF and 1,2,3,6,7,8-HxCDF contribute about 70% of emissions from the considered sources and not less than a half in environmental compartments.

Simulation of long-range transport with priority congeners properties pointed out that:

- Physical-chemical properties of 2,3,4,7,8-PeCDF could be used for evaluation of the long-range transport of dioxins/furans mixture as a first approximation;
- The discrepancy resulted from the application of 2,3,4,7,8-PeCDF congener for the description of four selected congener mixture does not exceed 50% for concentrations in vegetation and 30% for concentrations in other media;
- Model calculations manifest pronounced seasonal variations of air concentrations and total depositions with elevation in cold and decrease in warm months;
- Dry deposition flux contributes most essentially to PCDD/F scavenging both over land and sea;

- Calculated dioxins/furans concentration distribution in air between gaseous and particulate phases demonstrates seasonal variations with the increase of the gas phase fraction in summer and the decrease in winter;
- The calculated gas phase fraction is basically consistent with measurement data;
- Soil is the main reservoir of PCDD/F accumulation and its pollution levels are kept during a long time period;
- Seasonal variations in soil lag behind air concentration ones and they are less by amplitude;

In view of peculiar importance of PCDD/F behaviour at air/soil and air/sea water interfaces, it is necessary to concentrate efforts on soil and sea water model modules for constructing of more accurate parameterization of gaseous exchange with underlying surface.

As a first approximation the model with 2,3,4,7,8-PeCDF describes the environmental pollution within the EMEP domain. More extended discussion on comparison of modelling results with measured data is placed to [Shatalov *et al.*, 2001]. The extension of the list of modelled congeners should make it possible to estimate PCDD/F input to the environment with higher accuracy.

## References:

- Abad E., Caixach J. and J.Rivera [1997] PCDD/PCDF from emission sources and ambient air in northeast Spain. *Chemosphere*, vol.35, No.3, pp.453-463.
- Addink R. and K.Olie [1995] Mechanisms of formation and destruction of polychlorinated dibenzo-p-dioxins and dibenzofurans in heterogeneous systems. *Environ. Sci. Technol.*, vol.29, No.6, pp.1425-1435.
- Aitolla J.-P., Paasivirta J., Vattulainen A., Sinkkonen S., Koistinen J. and J.Tarhanen [1996] Formation of chloroaromatics at a metal reclamation plant and efficiency of stack filter in the removal from emission. *Chemosphere*, vol.32, No.1, pp.99-108.
- Alcock R., McLachlan M., Johnston A. and K.Jones [1998] Evidence for the presence of PCDD/Fs in the environment prior to 1900 and further studies on their temporal trends. *Environ. Sci. Technol.*, vol.32, No.11, pp.1580-1587.
- Atkinson R. [1996] In *Issues in Environmental Science and Technology*; Hester R.E., Harrison R.M., Eds: The Royal Society of Chemistry; Cambridge, UK, 1996, vol.6, pp.53-72.
- Bacher R., Swerev M. and K.Ballschmitter [1992] Profile and patterns of monochloro-through octachlorodibenzodioxins and dibenzofurans in chimney deposits from wood burning. *Environ. Sci. Technol.*, vol.26, No.8, pp.1649-1655.
- Beck A.J., Johnson D.L. and K.C.Jones [1996] The form and bioavailability of non-ionic organic chemicals in sewage sludge-amended agricultural soil, *The Science of the Total Environment*, vol.185, pp.125-149.
- Berdowski J.J.M., Baas J., Bloos J.P.J., Visschedijk A.J.H. and P.Y.J.Zandveld [1997] The European emission inventory of heavy metals and persistent organic pollutants for 1990 by TNO institute of Environmental science, energy research and process Innovation, June 1997.
- Bidleman T.F. [1999] Atmospheric transport and air-surface exchange of pesticides, pp.153-154, in: *Fate of Pesticides in the atmosphere/ Implication for Environmental risk assessment*, Ed by Harrie F.G. et al., Kluwer academic publishers, 1999.
- Bodo B.A. [1998] An Assessment of Environmental and Aquatic Ecosystem Contamination by Persistent Organic Pollutants (POPs) in the Russian Federation, Toronto, Canada, p.152.
- Bonfanti L., Cioni M., Riccarrdi J. and C.Rossi [1994] PCDD/PCDF formation and destruction during co-firing of coal and RDF in a slag forming combustor. *Frezenius, Anal. Chem.*, vol.348, pp.136-140.
- Broman D., Naef C. and Y.Zebuehr [1991] Long-Term High- and Low-volume air sampling of polychlorinated Dibenzo-p-dioxins and Dibenzofurans and polycyclic aromatic hydrocarbons along a transect from urban to remote areas on the Swedish Baltic Coastal, *Environ. Sci. Technol.*, vol.25, No.11, pp.1841-1851, air [Broman et al., 1991a].
- Broman D., Naef C., Rolff C. and Y.Zebuehr [1991] Occurrence and dynamics of polychlorinated dibenzo-p-dioxins and dibenzofurans and polycyclic aromatic hydrocarbons in the mixed surface layer of remote coastal and offshore waters in the Baltic, *Environ. Sci. Technol.*, vol.25, No.11, pp.1851-1864. – water [Broman et al., 1991b].
- Brubaker W.W. and R.A.Hites [1997] Polychlorinated Dibenzo-p-dioxins and Dibenzofurans: Gas-Phase Hydroxyl Radical Reactions and related atmospheric removal, *Environ. Sci. Technol.*, vol.31, No.6, pp.1805-1810.
- Brzuz L.P. and R.A.Hites [1996] Global mass balance for polychlorinated dibenzo-p-dioxins and dibenzofurans. *Environ. Sci. Technol.*, vol.30, No.6, pp.1797-1804.
- Buckley-Golder D., Coleman P., Davies M., King K., Petersen A., Watterson J., Woodfield M., Fiedler H. and A.Hanberget [1999] *Compilation of EU Dioxin Exposure and Health Data*, European Commission DG Environment and UK Department of the Environmental Transport and the Regions (DETR).
- Bulgakov A.A. and D.A.Ioannisian [1998] Review of physical – chemical properties of polychlorinated dibenzo-p-dioxins (PCDDs) and dibenzofurans (PCDFs) in respect to their long-range transport in the atmosphere. // Long-range transport of selected POPs. Part II. Physical – chemical properties of dioxins and furans and factor influencing the transport and accumulation of Persistent Organic Pollutant. EMEP/MSC-E Report 2/98. August 1998. // pp.5-31.
- Casanovas J., Muro R., Eljarrat E., Caixach J. and J.Rivera [1994] PCDF and PCDD levels in different types of environmental samples. *Fresenius, Anal. Chem.*, vol.348, pp.167-170.
- Christman W., Kasiske D., Kloeppel K.D., Partscht H. and W.Rotard [1989] Combustion of polyvinylchloride – an important source for the formation of PCDD/PCDF. *Chemosphere*, vol.19, No.1-6, pp.387-392. [Christman et al., 1989a].
- Christman W., Kloeppel K.D., Partscht H., W.Rotard [1989] Determination of the PCDD/PCDF in ambient air, *Chemosphere*, vol.19, No.106, pp.521-526. [Christman et al., 1989b].
- Chrostovski P. and S.A.Foster [1996] A methodology for assessing congener-specific partitioning and plant uptake of dioxins and dioxin-like compounds. *Chemosphere*, vol.32, No.11, pp.2285-2304.

- Cole J., Mackay D., Jones K. and R.Alcock [1999] Interpreting, Correlating and predicting the multimedia concentrations of PCDD/Fs in the United Kingdom, *Environ. Sci. Technol.*, vol.33, No.3, pp.399-405.
- Coleman P., Donovan B., Campbell G.W., Watterson J., Jones K., Lee R. and A.Peters [1998] Results from the Toxic Organic Micropollutants (TOMPS) network: 1991–1997, Report National Environmental Technology Centre, May 1998.
- Coleman P., Lee R., Alcock R. and K.Jones [1997] Observation on PAH, PCB, and PCDD/F Trends in U.K. Urban Air, 1991-1995, *Environ. Sci. Technol.*, vol.31, No.7, pp.2120-2124.
- Czuczwa J.M. and R.A. Hites [1986] Airborne dioxins and dibenzofurans: sources and fates. *Environ. Sci. Technol.*, vol.20, No.2, pp.195-200.
- Delle Site A. [1997] The vapor pressure of environmentally significant organic chemicals: A review of methods and data at ambient temperature, *J. Phys. Chem. Ref. Data*, vol.26, No.1, pp.157–193.
- Eitzer B.D. and R.A.Hites [1989] Polychlorinated dibenzo-p-dioxins and dibenzofurans in the atmosphere of Bloomington, Indiana. *Environ. Sci. Technol.*, vol.23, No.11, pp.1389-1395.
- Eitzer B.D. and R.A.Hites, [1991] Vapor pressure of chlorinated dioxins and dibenzofurans, *Sci. Total Environ.*, vol.104, pp.9-15.
- Eitzer B.D. and R.A.Hites [1998] Additions and Corrections bei Vapor pressure of Chlorinated Dioxins and Dibenzofurans, 1988, vol.22, pp.1362-1364, *Environ. Sci. Technol.*, vol.32, No.18, pp.2804.
- Govers H.A.J. and H.B.Krop [1998] Partition constants of chlorinated dibenzofurans and dibenzo-p-dioxins, *Chemosphere*, vol.37, No.9-12, pp.2139-2152.
- Hagenmaier H., Lindig C. and J.She [1994] Correlation of environmental occurrence of polychlorinated dibenzo-p-dioxins and dibenzofurans with possible sources. *Chemosphere*, vol.29, No.9-11, pp.2163-2174.
- Halsall C., Coleman and K.Jones [1997] Atmospheric deposition of polychlorinated dibenzo-p-dioxins/dibenzofurans (PCDD/Fs) and polycyclic aromatic hydrocarbons (PAHs) in two UK sites, *Chemosphere*, vol.35, No.9, pp.1919-1931.
- Handbook of physical properties of organic chemicals, [1997], Ed by P.H.Howard, W.M.Meylan, CPC Lewis Publishers, Boca Raton, New York, London, Tokyo, 1997.
- Harnly M., Stephens R., McLaughlin C., Marcotte J., Petreas M. and L.Goldman [1995] Polychlorinated dibenzo-p-dioxin and dibenzofuran contamination at metal recovery facilities, open burn sites, and a railroad car incineration facility. *Environ. Sci. Technol.*, vol.29, No.3, pp.677-684.
- Hiester E., Bruckmann P., Boehm R., Eynck P., Gerlach A., Muelder W. and H.Ristow [1997], Pronounced decrease of PCDD/PCDF burden in ambient air, *Chemosphere*, vol.34, No.5-7, pp.1231-1243.
- Hippelein M., Kaupp H., Doerr G., McLachlan M. and O.Hutzinger [1996] Baseline contamination assessment for the a new resource facility in Germany. Part II: Atmospheric concentrations of PCDD/F, *Chemosphere*, vol.32, No.8, pp.1605–1616.
- Hoekstra E., de Weerd H., de Leer E. and U.Brinkman [1999] Natural formation of chlorinated Phenols, Dibenzo-p-dioxins, and dibenzofurans in Soil of a Douglas Fir Forest. *Environ. Sci. Technol.*, vol.33, No.15, pp.2543-2549.
- Holoubek I, Kocan A., Holoubkova I., Hilscherova K., Kohoutek J., Falandysz J. and O.Roots [2000] Persistent, Bioaccumulative and toxic chemicals in Central and Eastern European Countries – State-of-the-Art report, TOCOEN REPORT N.150a, Brno, Czech Republic, May, 2000.
- Horstmann M. and M.McLachlan [1998] Atmospheric deposition of semivolatile organic compounds to two forest canopies, *Atm. Environ.*, vol.32, No.10, pp.1799-1809.
- Hutsinger H., Kreis S. and H.Vogg [1996] Experiences gained from sampling of chlorine aromatics in the raw gas of waste incineration plants. *Chemosphere*, vol.32, No.1, pp.109-118.
- Jiang Ke, Li L., Chen Y. and J.Jin [1997] Determination of PCDD/Fs and dioxin – like PCBs in Chinese commercial PCBs and emission from a testing PCB incineration. *Chemosphere*, vol.34, No.5/7, pp.941-950.
- Jones K. and R.Duarte-Davidson [1997] Transfers of airborne PCDD/F to bulk deposition collectors and herbage, *Environ. Sci. Technol.*, vol.31, No.10, pp.2937-2943.
- Junge C.E. [1977] Basic considerations about trace constituent in the atmosphere is related to the fate of global pollutant. In: Fate of pollutants in the air and water environment. Part I, I.H. Suffet (ed.) (Advanced in *Environ. Sci. Technol.*, v.8), Wiley-Interscience, New York.
- Kjeller L.-O. and C.Rappe [1995] Time trends in levels, patterns and profiles for polychlorinated dibenzo-p-dioxins, dibenzofurans and biphenils in a sediment core from the Baltic sea. *Environ. Sci. Technol.*, vol.29, No.2, pp.346-355.
- Kjeller L.-O., Jones K., Johnston A., Rappe C., [1991], Increases in the polychlorinated dibenzo-p-dioxin and – furan content of soil

- and vegetation since the 1840s, *Environ. Sci. Technol.*, vol.25, No.9, pp.1619-1627.
- Koester C.J. and R.A.Hites [1992] Wet and dry deposition of chlorinated dioxins and furans. *Environ. Sci. Technol.*, vol.26, No.7, pp.1375-1382.
- Koistinen J., Stenman O., Haahti H., Suonperä M., J.Paasivirta [1997], Polychlorinated Diphenyl Ethers, Dibenzop-dioxins, Dibenzofurans and Biphenyls in seals and sediment from the Gulf of Finland, *Chemosphere*, vol.35, No.6, pp.1249-1269.
- Kwok E.S.C., Atkinson R. and J.Arey [1995] Rate constants for the gas-phase reaction of the OH Radical with Dichlorobiphenyls, 1-Chlorodibenzo-p-dioxin, 1,2-Dimethoxybenzene and Diphenyl Ether: Estimation of OH Radical Reaction Rate Constants for PCBs, PCDDs and PCDFs, *Environ. Sci. Technol.*, vol.29, No.6, pp.1591-1598.
- Laue G., Herrmann D., Moeder M. and R.Herzschuh [1994] Analysis of slag and filter dusts from aluminium recycling processes. *Chemosphere*, vol.29, No.9-11, pp.1947-1956.
- Lee R., Green N., Lohmann R. and K.Jones [1999] Seasonal, anthropogenic, air mass, and meteorological influences on the atmospheric Concentrations of polychlorinated Dibenzo-p-dioxins and Dibenzofurans (PCDD/Fs): Evidence for the importance of diffuse combustion sources, *Environ. Sci. Technol.*, vol.33, No.17, pp.2864-2871.
- Lindner G., Jenkins A.C., McCormack J. and R.C.Adrian [1990] Dioxins and furans in emissions from medical incinerators. *Chemosphere*, vol.20, No.10-12, pp.1793-1800.
- Lohmann R. and K.Jones [1998] Dioxins and furans in air and deposition: Dioxins and furans in air and deposition: A review of levels, behaviour and processes, *Sci. Total Environment*, vol.219, pp.53-81.
- Lorber M., Pinsky P., Gehring P., Braverman C., Winters D. and W.Sovocool [1998] Relationships between dioxins in soil, air, ash, and emissions from a municipal solid waste incinerator emitting large amounts of dioxins. *Chemosphere*, vol.37, No.9-12, pp.2173-2197.
- Mackay D., Shiu W.Y. and K.C.Ma [1992] Illustrated handbook of physical-chemical properties and environmental fate for organic chemicals, vol. II, Polynuclear aromatic hydrocarbons, polychlorinated dioxins and dibenzofurans, Lewis Publishers, Boca Raton, Ann Arbor, London, Tokyo, p.597.
- Miyata H., Aozasa O., Mase Y., Ohta S., Khono S. and S.Osada [1994] Estimated annual emission of PCDDs, PCDFs and non-ortho chlorine substituted coplanar PCBs from flue gas from urban waste incinerators in Japan. *Chemosphere*, vol.29, No.9-11, pp.2097-2105.
- NATO-CCMS [1988]: International Toxicity Equivalency Factor (I-TEF) method of risk assessment for complex mixtures of dioxins and related compounds, Report Number 176, August 1988, North Atlantic Treaty Organization, Committee on the Challenges of Modern Society.
- Nielsen P.R. and P.Blinksbjerg [1989] Emission of dioxins (PCDD and PCDF) from some secondary sources; combustion of straw, coal and waste oil from automobiles. *Chemosphere*, vol.19, No.1-6, pp.731-734.
- Oehme M. and M.D.Mueller [1995] Levels and congener patterns of polychlorinated dibenzo-p-dioxins and dibenzofurans in solid residues from wood-fired boilers. Influence of combustion conditions and fuel type. *Chemosphere*, vol.30, No.8, pp.1527-1539.
- Olie K., Berg M.V.D. and O.Hutzinger [1983] Formation and fate of PCDD and PCDF from combustion processes. *Chemosphere*, vol.12, No.4/5, pp.627-636.
- Paasivirta J., Sinkkonen S., Mikkelsen P., Rantio T. and F.Wania [1999] Estimation of vapor pressures, solubilities and Henry's law constants of selected persistent organic pollutants as function of temperature, *Chemosphere*, vol.39, No.5, pp.811-832.
- Pacyna et al., [1999], Environmental cycling of selected persistent organic pollutants (POPs) in the Baltic region (POPCYCLING-Baltic), coordinator: J.Pacyna, 1999.
- Pandapatam B., Kumar Y., Guo I. and A.J.Liem [1997] Comparison of PCDD and PCDF emission from fuel boilers and hospital waste incinerators. *Chemosphere*, vol.34, No.5-7, pp.1065-1073.
- Pankow J.F. [1987] Review and comparative analysis of the theories on partitioning between the gas and aerosol particulate phases in the atmosphere. *Atmos. Environ.*, vol.21, pp.2275-2283.
- Parma Z., Vosta J., Horejs J., Pacina J. M. and D.Thomas [1995] Atmospheric emission inventory guidelines for persistent organic pollutants (POPs). A report prepared for external affairs Canada. Prepared by in association with axysts Environmental consulting Ltd Sidney, British Columbia, Canada. Prague, The Czech. Republic, July, pp.91-92.
- Pekar M., Pavlova N., Gusev A., Shatalov V., Vulykh N., Ioannisian D., S.Dutchak, Berg T. and A.-G.Hjellbrekke [1999] Long-range transport of selected persistent organic pollutants. Joint report of EMEP centres: MSC-E and CCC, EMEP MSC-E Report 2/99, July 1999.
- Pitea D., Todeschini R., Lasagni M., Moro G., Bonati L. and G.Chiesa [1989] The combustion of municipal solid wastes: PCDD

- and PCDF in MSW and in emissions. A chemometric approach. *Chemosphere*, vol.19, No.1-6, pp.751-757.
- Sakai S., Hiraoka M., Takeda N. and K.Shiozaki [1994] Formation and emission of non-ortho CBs in municipal waste incineration. *Chemosphere*, vol.29, No.9-11, pp.1979-1986.
- Sakai S., Hiraoka M., Takeda N. and K.Shiozaki [1996] Behaviour of coplanar PCBs and PCNs in oxidative conditions of municipal waste incineration. *Chemosphere*, vol.32, No.1, pp.79-88.
- Schetter G. [1989] Assessment of PCDD and PCDF emissions from refuse incineration plants. *Chemosphere*, vol.1-6, pp.589-596.
- Schumacher M., Domingo J. Llobet J., Suenderhaut W. and L.Mueller [1998] Temporal variation of PCDD/F concentrations in vegetation samples collected in the vicinity of a municipal waste incinerator (1996-1997), *Science Total. Environ.*, vol.218, pp.175-183.
- Schumacher M., Granero S., Llobet J., de Kok H. and J.Domingo [1997] Assessment of baseline levels of PCDD/F in Neighborhood of a new hazardous waste incinerator in Catalonia, Spain, *Chemosphere*, vol.35, No.9, pp.1947-1958.
- Schumacher M., Granero S., Rivera J., Mueller L., Llobet J. and J.Domingo [2000] Atmospheric deposition of PCDD/Fs near an old municipal solid waste incinerator: levels in soil and vegetation, *Chemosphere*, vol.40, No.6, pp.593-600.
- Shatalov V., Malanichev A., Vulych N., Berg T. and S.Manø [2001] Assessment of POP transport and accumulation in the environment. EMEP Report 4/2001 (in print).
- Sinkkonen S. and J.Paasivirta [2000] Degradation half-life times of PCDDs, PCDFs and PCBs for environmental fate modeling, *Chemosphere*, vol. 40, pp.943-949.
- Theisen J., Funcke W., Balfanz E. and J.Koenig [1989] Determination of PCDFs and PCDDs in fire accidents and laboratory combustion tests involving PVC - containing materials. *Chemosphere*, vol.19, No.1-6, pp.423 - 428.
- Thoma H. [1988] PCDD/F – concentrations in chimney soot from house system. *Chemosphere*, vol.17, No.7, pp.1369-137.
- Tiernan T.O., Taylor M. L., Garrett J. H., Van Ness G.F., Solch J. G., Deis D. A. and D.J.Wagel [1983] Chlorodibenzodioxins, chlorodibenzofurans and related compounds in the effluents from combustion processes. *Chemosphere*, vol.12, No.4/5, pp.595-606.
- Turrio-Baldassarri L., Carere A., di Domenico A., Iacovella N. and Rodriquez [1994] PCDD, PCDF and PCB contamination of air and inhalable particulate in Rome, Fresenius, J. *Anal. Chem.*, vol.348, pp.144-147.
- Vartiainen T., Manni J., Korhonen M., Kinnunen K., Strandman, [1997], Levels of PCDD, PCDF and PCB in Dated Lake Sediments in Subarctic Finland, *Chemosphere*, vol.34, No.5-7, pp.1341-1350.
- Wallenhorst T., Krauss P. and H.Hagenmaier [1997] PCDD/F in ambient air and deposition in Baden-Wuerttemberg, Germany, *Chemosphere*, vol.34, No.5-7, pp.1369-1378.
- Weiss P. [1998] Persistente organische Schadstoffe in Hintergrund-Waldgebieten Oesterreichs, Monographien Band 97, Wien, 1998, S.242.
- Weiss P., Lorbeer G. and S.Scharf [2000] Regional aspects and statistical characterisation of the load with semivolatile organic compounds at remote Austrian forest sites, *Chemosphere*, vol.40, pp.1159-1171.
- Yufit S., Adibi J., Grosheva E. and E.Kolpakova [2000], Final Report. Phase I in the data collection, data analysis, and development of methods for estimating dioxin emissions and environmental levels in Russia, p.37.
- Амирова З.К., Круглов Э.А., Ложкина Е.А., Халилов Р.Р., [1998], Об уровнях содержания ПХДД/ПХДФ в биопробах и объектах окружающей среды по результатам исследований, проведенных в различных городах России, с. 150 – 164, в Диоксины. Супертоксиканты XXI века. Федеральная программа, Информационный выпуск, № 2, Москва, Государственный комитет РФ по охране окружающей среды, Всероссийский институт научной и технической информации.
- Государственный доклад « О состоянии окружающей природной среды Российской Федерации в 1999 году», Москва, 2000, с. 80 – 82.
- Государственный доклад « О состоянии окружающей природной среды Российской Федерации в 1997 году», Москва, 1998, с. 99 – 107.
- Грошева Е.И., Данилина А.Е., Тычкин Л.В., [1998], Оценка загрязнения территории России диоксинами и диоксиноподобными токсикантами, в сб.: Диоксины. Супертоксиканты XXI века. Федеральная программа, Информационный выпуск, №2, Госкомэкологии России, ВИНТИ, Москва, 1998,с.20-70.
- Клюев Н.А., Юфит С.С., Винокуров И.Ю., Мир-Кадырова Е.Я., Сойфер В.С., Коротков М.Г., Бродский Е.С., Жильников В.Г., [1998], Загрязнение Владимирской области диоксиновыми ксенобиотиками и полиароматическими углеводородами, в сб.: Диоксины-супертоксиканты XXI века. Регионы России, Информационный выпуск №3, Госкомэкологии России,

- ВИНИТИ, Москва, 1998, с. 82 – 101.
- Куценко В.В., А.Е.Данилина, Е.В.Протопопов, [1998], Диоксины. Супертоксиканты XXI века, Диоксины и экологическая безопасность России, CDROMS\dioxins, Федеральная программа, Информационный выпуск, № 1, Москва, Государственный комитет РФ по охране окружающей среды, Всероссийский институт научной и технической информации.
- Майстренко В.Н., Круглов Е. А., Амирова З.К. и Р.З. Хамитов [1998] Полихлорированные диоксины и дибензофураны в окружающей среде и пищевых продуктах республики Башкортостан. в сб. : Диоксины - супертоксиканты XXI века. Регионы России. Информационный выпуск № 3, Госкомэкологии России, ВИНТИ, Москва, 1998, с.102 - 114.
- Майстренко В.Н., Хамитов Р.З. и Г.К. Будников [1996] Эколого-аналитический мониторинг супертоксикантов. М.; Химия, 319 с. (с. 135)
- Михайлов Г.М., Филатов Б.Н., Семенов С.Ю., Симонов В.Н., [1998], Загрязнение окружающей природной среды диоксином и состояние здоровья населения Астраханской области, в сб.: Диоксины-супертоксиканты XXI века. Регионы России, Информационный выпуск, №3, Госкомэкологии России, ВИНТИ, Москва, 1998, с. 126 – 149.
- Михайлов Г., [1998], Диоксин в низовьях Волги и здоровье населения, Материалы Субрегионального совещания
- “Национальная стратегия и план действий по снижению выбросов и уничтожению стойких органических загрязнителей (СОЗ)”, Москва, 14-17 июля 1998 г., с. 126 – 129.
- Первунина Р.И., Самсонов Д.П., Кирюхин В.П., Рахманова Т.И., Жирюхина Н.П., 1998, Изучение загрязнения окружающей природной среды диоксином и родственными соединениями в некоторых городах и районах России, в сб.: Диоксины. Супертоксиканты XXI века. Федеральная программа, Информационный выпуск, № 2, Госкомэкологии России, ВИНТИ, Москва, 1998, с. 64 – 82.
- Ревич Б., Аксель Е., Двойрин В., Сотсков Ю., Онищенко Т., Мизерницкий Ю., Колбенева Л., Первунина Р., Самсонов Д., Музуров И., Дубков В., Зейлерт, 1998, Диоксины в окружающей среде г. Чапаевска Самарской области и здоровье населения, в сб.: Диоксины. Супертоксиканты XXI века. Федеральная программа, Информационный выпуск, № 2, Госкомэкологии России, ВИНТИ, Москва, 1998, с. 36 – 64.
- Юфит С.С., Ключев Н.А., Бродский Е.С., [1998], Характер диоксинового загрязнения Архангельского региона, в сб.: Диоксины-супертоксиканты XXI века. Регионы России, Информационный выпуск №3, Госкомэкологии России, ВИНТИ, Москва, 1998, с. 10-35.



	Air, pg I-TEQ/m <sup>3</sup>	Deposition ng I-TEQ/kg	Surface water, pg I-TEQ/l	Bottom sediments, ng I-TEQ/kg	Soils, ng I-TEQ/kg
<b>Russian Federation</b>					
Republic of Karelia		Snow cover 4.3 <b>0.6</b> <i>Государственный доклад, [1998]</i>	14.0 <b>3.0</b> <i>Государственный доклад, [1998]</i>		5.9 <b>0.5</b> <i>Государственный доклад, [1998]</i>
Leningrad region		Snow cover 8.0 <b>0.6</b> <i>Государственный доклад, [1998]</i>	12.0 <b>4.0</b> <i>Государственный доклад, [1998]</i>		5.0 <b>1.7</b> <i>Государственный доклад, [1998]</i>
Archangelsk region	Novodvinsk c. 43.8; <i>С.С.Юфим и др., [1998]</i>		5.0 <b>0.5</b> <i>Государственный доклад, [1998]</i>  North Dvina River Archangelsk c. – 5.27 Novodvinsk c. – 4.61 <i>Е.И.Грошева и др., [1998]</i>	North Dvina r. Archangelsk c. 3.1; Novodvinsk c. 1.53; Kotlas (port) 0.214; Background sites 0.07–0.086; Vycheгда r. 0.073–1.8; Emtsa r. 0.144–0.611; Mekhrenga r. 0.324 Khataritsa r. 5.34; Puksa r. 1.46–1.8 <i>Е.И.Грошева и др., [1998]</i>	<b>0.4 – 76.7</b> <i>Е.И.Грошева и др., [1998].</i>  Archangelsk c. (landfill) – 4.4; (furniture factory) – 2.2; (TPS area) – 0.4; Solombala v. (silted fields of PPM) – 10.9; (WWC area) – 76.7; Novodvinsk c. (landfill) – 0.4; (vicinity of chlorine production plant) – 5.2; <i>С.С.Юфим и др., [1998]</i>
Kaliningrad region					1.5 <b>0.7</b> <i>Государственный доклад, [1998]</i>
Jamalo-Nenetsk autonomic okrug		Snow cover 0.35 <b>0.25</b> <i>Государственный доклад, [1998]</i>			
Komi Republic		Snow cover – 3.8 <b>0.3</b> <i>Государственный доклад, [1998]</i>			6.3 <b>0.40</b> <i>Государственный доклад, [1998]</i>
Tver region		Snow cover 7.4 <b>0.7</b> <i>Государственный доклад, [1998]</i>	6.0 <b>2.0</b> <i>Государственный доклад, [1998]</i>		5.8 <b>1.6</b> <i>Государственный доклад, [1998]</i>
Jaroslavl region			River water (Volga) in the region of Jaroslavl c. – 0.68 Rybinsk c. – 0.14 <i>Государственный доклад, [1998]</i>		
Ivanov region			17 <b>5.0</b> <i>Государственный доклад, [1998]</i>		

	Air, pg I-TEQ/m <sup>3</sup>	Deposition ng I-TEQ/kg	Surface water, pg I-TEQ/l	Bottom sediments, ng I-TEQ/kg	Soils, ng I-TEQ/kg
Moscow region			30 <i>Государственный доклад, [1998]</i>		Shchelkovo c. and neighborhood 0.13–11.17 <i>Государственный доклад, [1998]</i>
Tula region		Snow cover 8.4 <b>0.9</b> <i>Государственный доклад, [1998]</i>			7.0 <b>2.0</b> <i>Государственный доклад, [1998]</i>
Nizhnii Novgorod region					8.0 <b>0.7</b> <i>Государственный доклад, [1998]</i>
Vladimir region	Suzdal c. 24 Vladimir c. 910 Kolchugino c. 580 <i>Н.А.Клюев и др., [1998]</i>				Forest soil (n = 1); 2.79 Pasture (n = 1) 0.045 Sampling depth – 0–20 cm; Meadow (n = 1) 3.45 Sampling depth – 0–20 cm; Soil near Juriev-Polski-Kolchugino road (n = 1) 0.016 Sampling depth - 0 – 20 cm <i>Н.А.Клюев и др., [1998]</i>
Kaluga region			Shanya r. 04.1993; 34.3–432; Ugra r. 04.1993 96.6–183.1; Shanya r. 10.1994; 0.0044 <i>Р.И.Первунина и др., [1998]</i>	Shanya r. in the region of Gireevo village 15.25 pg/kg	Region of Gireevo village 18.28 pg/kg <i>Р.И.Первунина и др., [1998]</i>
Chuvash Republic		Snow cover 13.6 <b>2.3</b> <i>Государственный доклад, [1998]</i>	11 <b>2.0</b> <i>Государственный доклад, [1998]</i>		8.9 <b>2.6</b> <i>Государственный доклад, [1998]</i>
Kirov region		Snow cover 5.0 <b>1.2</b> <i>Государственный доклад, [1998]</i>	14 <b>5.0</b> <i>Государственный доклад, [1998]</i>		
Tatarstan Republic		Snow cover 5.6 <b>0.9</b> <i>Государственный доклад, [1998]</i>	12 <b>3.0</b> <i>Государственный доклад, [1998]</i>  Belaya r. – 4.9; <i>Е.И.Грошева и др., [1998]</i>		8.6 <b>1.9</b> <i>Государственный доклад, [1998]</i>
Saratov region		Snow cover 11 <b>0.8</b> <i>Государственный доклад, [1998]</i>	7.5 <b>1.5</b> <i>Государственный доклад, [1998]</i>		8.0 <b>0.6</b> <i>Государственный доклад, [1998]</i>
Volgograd region		Snow cover 7.3 <b>1.2</b> <i>Государственный доклад, [1998]</i>			3.8 <b>0.60</b> <i>Государственный доклад, [1998]</i>

	Air, pg I-TEQ/m <sup>3</sup>	Deposition ng I-TEQ/kg	Surface water, pg I-TEQ/l	Bottom sediments, ng I-TEQ/kg	Soils, ng I-TEQ/kg
Astrakhan region			15 <b>5.0</b> <i>Государственный доклад, [1998]</i>	0.008–4.65 <i>Г.М.Михайлов, [1998]</i>	4.5 <b>0.50</b> <i>Государственный доклад, [1998]</i> 0.05 – 10.8 <i>Г.М.Михайлов, [1998]</i>
Krasnodar territory			17 <b>8.0</b> <i>Государственный доклад, [1998]</i>		10.0 <b>2.6</b> <i>Государственный доклад, [1998]</i>
Samara region	Чапаевск с. <u>0.1– 1130</u> 116 <i>Б.Ревич и др., [1998]</i>	Snow cover 5.6 <b>0.9</b> <i>Государственный доклад, [1998]</i>	10 <b>2.0</b> <i>Государственный доклад, [1998]</i>		7.0 <b>0.8</b> <i>Государственный доклад, [1998]</i>  Urban soil, 1994, Distance from plant 2 km (n=7): <u>40.4 – 298.0</u> 141.3 2–7 km (n=7): <u>8.9 – 71.2</u> 36.8 7–10 km (n=1): 3.9; 10–15 km (n=9) <u>0.1– 3.6</u> 0.9 <i>Б.Ревич и др., [1998]</i>
Kaliningrad region					1.5 <b>0.7</b> <i>Государственный доклад, [1998]</i>
Bashkortostan Republic	Ufa с. and Sterlitamak с. 150; Residential area 66; <i>В.Н.Майстренко и др., [1998]</i>	Snow cover, Ufa с., Background regions – 2.9–8.3 <i>Государственный доклад, [1998]</i>	5.0 <b>2.2</b> <i>Государственный доклад, [1998]</i>  Belaya r. – 4.9; Yuryuzan r. – 2.6; I r. – 5.2; Zilair r. – 2.3; Sakmara r. – 2.3; Suren r. – 2.7; Ufa r. – 2.9; (the Urals mountains) <i>В.Н.Майстренко и др., [1998]</i>		Urban soil of Ufa and Sterlitamak с. 1–20; Agricultural land: <u>100 – 1200</u> 350; steppe area 0.15; <i>В.Н.Майстренко и др., [1998]</i>
Perm region		Snow cover 0.7–6.0 <i>Государственный доклад, [1998]</i>			6.0 <b>1.0</b> <i>Государственный доклад, [1998]</i>
Orenburg region (partially)		Snow cover 5.4 <b>1.6</b> <i>Государственный доклад, [1998]</i>			8.0 <b>2.0</b> <i>Государственный доклад, [1998]</i>

Notes: 8.0 – mean level;

**2.0** - background regions

## *ANNEX A*

### **Measurement data on PCDD/F content in different natural objects in Germany and the Russian Federation**

Air, fg I-TEQ / m <sup>3</sup>	Deposition and precipitation, pg I-TEQ/m <sup>2</sup> /d (a) pg I-TEQ/l or fg I-TEQ/m <sup>3</sup>	Surface water, pg I-TEQ/l or fg I-TEQ/l	Bottom sediments, ng I-TEQ/kg d.m.	Soils, ng I-TEQ/kg d.m.	Forest litter, ng I-TEQ/kg d.m.	Vegetation, ng I-TEQ/kg d.m.
<b>Germany</b>						
Typical ambient concentration 1993: Rural area – 25– 70; Urban area – 70-350; <i>Buckley-Golder et al., [1999]</i>	Typical deposition 1992: rural area – 5–20; urban – 10–85; <i>Buckley-Golder et al., [1999]</i>			Typical concentration Rural area – 1– 5; Urban area – 10–30; <i>Buckley-Golder et al., [1999]</i>	Typical concentration litter/forest (mean): rural area – 35; urban area – 48; <i>Buckley-Golder et al., [1999]</i>	<b>Grass samples:</b> Typical range: 1.3–7.7; Max – 10.9 <i>Buckley-Golder et al., [1999]</i> <b>Spruce needles</b> 10.92, (n = 26), <u>0.18–1.20</u> 0.53 04.93, (n = 26), <u>0.27–3.45</u> 1.12 <i>Buckley-Golder et al., [1999]</i>
North Rhine – Westphalia Lands, High impact, 1991-92; (n = 1) 78 <i>Buckley-Golder et al., [1999]</i>	Contaminated: 1991-92 (n = 1) 17 Urban background 1993-94 (n=13) <u>7-35</u> 20 <i>Buckley-Golder et al., [1999]</i> Urban, 1992 <u>9.7–83</u> 26 <i>Hiester et al., [1993]</i> Cited <i>Lohmann and Jones, [1998]</i>		Rhine r. 1984–85 (n = 48) <1–310 <i>Evers et al., [1988],</i> Cited <i>Bodo, [1998]</i>	Typical concentration Rural area: <u>0.002–112</u> 6.1 rural and conurbation: <u>0.3–8.9</u> 3.2 conurbation background: <u>0.04–5741</u> 68.6 conurbation contaminated: <u>0.3–8.3</u> 1.9 urban area: <u>0–50</u> 4.8 contaminated: <u>0–230</u> 9.5 <i>Buckley-Golder et al., [1999]</i>		Contaminated, 01.1994, <b>Grass</b> (n=1), 10.9 <i>Buckley-Golder et al., [1999]</i>

Air, fg I-TEQ / m <sup>3</sup>	Deposition and precipitation, pg I-TEQ/m <sup>2</sup> /d (a) pg I-TEQ/l or fg I-TEQ/m <sup>3</sup>	Surface water, pg I-TEQ/l or fg I-TEQ/l	Bottom sediments, ng I-TEQ/kg d.m.	Soils, ng I-TEQ/kg d.m.	Forest litter, ng I-TEQ/kg d.m.	Vegetation, ng I-TEQ/kg d.m.
Cities of North Rhine – Westphalia Lands (industrial region of Rhine – Ruhr region): Köln: 11.87–10.88 130 <i>Hiester et al.</i> , [1997]			Rhine r., 1989–96 (n = 11) <u>15.8–103</u> 47.4 (special. Haz. Situation); 1995–96 <u>11.6–37.2</u> 25.7 (special. Haz. Situation) <i>Buckley-Golder et al.</i> , [1999]	Soil pollution levels per use pattern: Forest: Rural: 0.04–38; Conurbation/ background:0.04–36.3; Urban: 0–50; Contaminated: 0.05–139 <i>Buckley-Golder et al.</i> , [1999]		
Köln 11.93–10.94 40 <i>Hiester et al.</i> , [1997]			Elbe r., Lower Saxony (environmental surveillance) – 09.94 (n = 11) <u>1.17–19.2</u> 5.12 <i>Buckley-Golder et al.</i> , [1999]	Forest coniferous rural: 0.004–112; <i>Buckley-Golder et al.</i> , [1999]		
Duisburg: 11.87–10.88 332 <i>Hiester et al.</i> , [1997]				Forest deciduous: rural: 0.02–102; <i>Buckley-Golder et al.</i> , [1999]		
Duisburg: 11.93–10.94 124 <i>Hiester et al.</i> , [1997]				Forest mixed: Rural: 0.06–5.4; Conurbation, background: 0.2–1856 <i>Buckley-Golder et al.</i> , [1999]		
Essen: 11.87–10.88 204 <i>Hiester et al.</i> , [1997]				Parkland/garden, rural: 1–3.1; conurbation, background: 3.6–4.9; <i>Buckley-Golder et al.</i> , [1999]		

Air, fg I-TEQ / m <sup>3</sup>	Deposition and precipitation, pg I-TEQ/m <sup>2</sup> /d (a) pg I-TEQ/l or fg I-TEQ/m <sup>3</sup>	Surface water, pg I-TEQ/l or fg I-TEQ/l	Bottom sediments, ng I-TEQ/kg d.m.	Soils, ng I-TEQ/kg d.m.	Forest litter, ng I-TEQ/kg d.m.	Vegetation, ng I-TEQ/kg d.m.
Essen: 11.93–10.94 76 <i>Hiester et al.</i> , [1997]				No vegetation, Rural and conurbation: 1.0; <i>Buckley-Golder et al.</i> , [1999]		
Dortmund: 11.87–10.88 224 <i>Hiester et al.</i> , [1997]				Clearfelled area, Rural: 0.008–0.2; <i>Buckley-Golder et al.</i> , [1999]		
Dortmund: 11.93–10.94 120 <i>Hiester et al.</i> , [1997]				Arable: Rural: 0.003–3.7; Conurbation/ Background: 2.8–74; Contaminated: 0.2–25; <i>Buckley-Golder et al.</i> , [1999]		
Borken: 11.91–10.92 78 <i>Hiester et al.</i> , [1997]				Fallow: Rural: 0.003–0.03; Rural and conurbation: 0.9–7.7; Conurbation, background: 3.0–41 Urban: 0.1–17; Contaminated: 0.2–230; <i>Buckley-Golder et al.</i> , [1999]		
Borken: 11.91–10.92 78 <i>Hiester et al.</i> , [1997]				Meadow: Rural: 0.004–29.5; Rural and conurbation: 0.3–8.9; Conurbation, background 0.7–235; Conurbation, Contaminated: 1.0–4.6; <i>Buckley-Golder et al.</i> , [1999]		

Air, fg I-TEQ / m <sup>3</sup>	Deposition and precipitation, pg I-TEQ/m <sup>2</sup> /d (a) pg I-TEQ/l or fg I-TEQ/m <sup>3</sup>	Surface water, pg I-TEQ/l or fg I-TEQ/l	Bottom sediments, ng I-TEQ/kg d.m.	Soils, ng I-TEQ/kg d.m.	Forest litter, ng I-TEQ/kg d.m.	Vegetation, ng I-TEQ/kg d.m.
Eifel: 11.91–10.92 19 <i>Hiester et al., [1997]</i>				Pasture: Rural: 0.002–5.6; Rural and conurbation: 1.4–6.5; Conurbation, Contaminated: 3.5; Urban: 0–18; Contaminated: 0.2–24; <i>Buckley-Golder et al., [1999]</i>		
Düsseldorf: 11.91–10.92 42 <i>Hiester et al., [1997]</i>				Industrial, Conurbation, background: 0.05–5742; <i>Buckley-Golder et al., [1999]</i>		
Berlin: Dahlem, upper class living area 1986–87 (n=10), 140 <i>Christmann et al., [1989b]</i> Kreuzberg, lower class living area 02.1988 (n = 2) 53 <i>Christmann et al., [1989b]</i>	Rhineland – Palatinate, urban, 1993-1994, (n = 24), <u>0.5 – 24</u> 9 <i>Buckley-Golder et al., [1999]</i>			Residential, Conurbation, contaminated: 0.5; <i>Buckley-Golder et al., [1999]</i>		
	Hamburg, 1990 – 16; 1993 – 11; 1995 – 13; <i>Friesel et al., [1996]</i> Cited <i>Lohmann and Jones, [1998]</i> Urban background 07.1995 (n=12) <u>1-7</u> 3 <u>2-10</u> 6 <i>Buckley-Golder et al., [1999]</i>			Sport site, campsite, playground: Rural and conurbation: 3.1; Conurbation, background: 0.7; Conurbation, contaminated: 1.0–3.2; <i>Buckley-Golder et al., [1999]</i>		

Air, fg I-TEQ / m <sup>3</sup>	Deposition and precipitation, pg I-TEQ/m <sup>2</sup> /d (a) pg I-TEQ/l or fg I-TEQ/m <sup>3</sup>	Surface water, pg I-TEQ/l or fg I-TEQ/l	Bottom sediments, ng I-TEQ/kg d.m.	Soils, ng I-TEQ/kg d.m.	Forest litter, ng I-TEQ/kg d.m.	Vegetation, ng I-TEQ/kg d.m.
				Area of lakes, ponds, river, Conurbation, contaminated: 0.3–0.9; <i>Buckley-Golder et al.</i> , [1999]		Brandenburg, Conurbation background, 11.1993, <b>Grass</b> - (n = 2), <u>1.3 – 1.5</u> Point source nearby, 11.1993, <b>Grass</b> - (n = 8) <u>2.5 – 7.7</u> , 4.4 <i>Buckley-Golder et al.</i> , [1999]
Gelsenkichen-Buer, In the north of the highly industrialized Ruhr region, Winter 1987–88, (n=5), 140 Recklinghausen, 05.87–09.87 90–200, <i>Chrismann et al.</i> , [1989b]			R. Elbe 1992 – 25–381, 1993 – 10– 68, <i>Schramm et al.</i> , [1995], Cited <i>Bodo.</i> , [1998] 28.08.1995 (n = 3) <u>17.5–76</u> 40.4 <i>Buckley-Golder et al.</i> , [1999]	<u>1.7–684</u> 20 (median) <i>Buckley-Golder et al.</i> , [1999]		
Bavaria, 1992 – 1993 (n = 36): rural – <u>3.3 – 88.4</u> 22.5 impacted – <u>3.0 – 85.3</u> 31.2 <i>Buckley-Golder et al.</i> , [1999]	Clearing – 1081;  Coniferous – 2114;  Deciduous – 3304 (pg/m <sup>2</sup> /yr) <i>Horstmann and McLachlan.</i> , [1998]			Arable land: (n = 120) <1 <i>Buckley-Golder et al.</i> , [1999]		<b>Spruce needles:</b> Cities of Bavaria, 1990 Nürnberg – 4.47; Passau – 1.17; Hoff – 1.15; Schwandorf – 1.83. <i>Buckley-Golder et al.</i> , [1999]
Bavaria, Augsburg, 03.18.1992-02.17.1993 (8 stations) <u>14 – 120</u> 49 <i>Hippelein et al.</i> , [1996]				Rural, 1989- 1990, Ap, (ploughing layer - 20 cm), (n = 27), <u>n.d. – 3.7</u> 0.41 Ah, (humus layer - about 10 cm), (n = 46), <u>n.d. – 5.6</u> 0.46	Rural, 1989-90, Of, (n = 20), <u>n.d. – 38</u> 11.9 <i>Buckley-Golder et al.</i> , [1999]	

Air, fg I-TEQ / m <sup>3</sup>	Deposition and precipitation, pg I-TEQ/m <sup>2</sup> /d (a) pg I-TEQ/l or fg I-TEQ/m <sup>3</sup>	Surface water, pg I-TEQ/l or fg I-TEQ/l	Bottom sediments, ng I-TEQ/kg d.m.	Soils, ng I-TEQ/kg d.m.	Forest litter, ng I-TEQ/kg d.m.	Vegetation, ng I-TEQ/kg d.m.
				Ah, (humus layer - about 10 cm), (n = 15), <u>0.04 – 3.9</u> 1.01 Ah, (humus layer - about 10 cm), (n = 2), <u>0.97 – 3.1</u> <i>Buckley-Golder et al.</i> , [1999]		
Bavaria, Augsburg: 92-93 (n = 125) before start of MWI: <u>14 – 120</u> 49 after start of MWI : <u>7.6 – 206</u> 52 <i>Buckley-Golder et al.</i> , [1999]				Urban, 1989-90, Ap, (ploughing layer - 20 cm), (n = 41), <u>n.d. – 5</u> 0.7 Ah, (humus layer - about 10 cm), (n = 27), <u>n.d. – 18</u> 3.9 Ah, (humus layer - about 10 cm), (n = 30), <u>0.04 – 17</u> 2.6 Ah, (humus layer - about 10 cm), (n = 30), <u>0.97 – 13</u> 1.8 Ah/Ap (n = 4), <u>0.1 – 17</u> 4.8 <i>Buckley-Golder et al.</i> , [1999]	Urban, 1989-90, Of, (n = 32), <u>n.d. – 50</u> 14.9 <i>Buckley-Golder et al.</i> , [1999]	
Bavaria, Burgkirchen: 93-96 (n = 98) After start of MWI <u>4.4 – 78</u> 27 <i>Buckley-Golder et al.</i> , [1999]				Contaminated, 1989-90, Ap, (ploughing layer - 20 cm), (n = 41), <u>n.d. – 25</u> 2.69	Contaminated, Of, 1989-90, (n=7), <u>21 – 139</u> 51.3 <i>Buckley-Golder et al.</i> , [1999]	

Air, fg I-TEQ / m <sup>3</sup>	Deposition and precipitation, pg I-TEQ/m <sup>2</sup> /d (a) pg I-TEQ/l or fg I-TEQ/m <sup>3</sup>	Surface water, pg I-TEQ/l or fg I-TEQ/l	Bottom sediments, ng I-TEQ/kg d.m.	Soils, ng I-TEQ/kg d.m.	Forest litter, ng I-TEQ/kg d.m.	Vegetation, ng I-TEQ/kg d.m.
				Ah, (humus layer - about 10 cm), (n = 38), <u>n.d. – 24</u> 3.73 Ah, (humus layer - about 10 cm), (n = 6), <u>0.05 – 29</u> 5.9 Ah, (humus layer - about 10 cm), (n = 18), <u>n.d. – 42</u> 5.38 Ah/Ap, (n = 15), <u>0.7 – 230</u> 21.26 <i>Buckley-Golder et al.,</i> [1999]		
Bavaria, urban 1992-93 (n = 12) <u>5 – 68</u> 23 1992-93 (n=13) <u>4 – 67</u> 27 1992-93 (n=61) <u>3 – 343</u> 33 1992-93 (n=107) <u>3 – 179</u> 29 Fall-winter 1992 (n=6) <u>5 – 36</u> 19 <i>Buckley-Golder et al., [1999]</i>				Contaminated, near waste plants Ap, (ploughing layer - 20 cm), (n = 11), <u>0.2 – 7.35</u> 1.26 Ah, (humus layer - about 10 cm), (n = 12), <u>0.2 – 2.3</u> 0.78 Ah, (humus layer - about 10 cm), (n = 3), <u>0.69–1.44</u> Ah, (humus layer - about 10 cm), (n = 7), <u>0.47 – 1.63</u> 0.94 Ah/Ap, (n = 8), <u>0.22 – 2.45</u> 1.6 <i>Buckley-Golder et al., [1999]</i>	Contaminated near waste plant 1989-90, Of, (n = 2), <u>3.72 – 3.87</u> <i>Buckley-Golder et al.,</i> [1999]	

Air, fg I-TEQ / m <sup>3</sup>	Deposition and precipitation, pg I-TEQ/m <sup>2</sup> /d (a) pg I-TEQ/l or fg I-TEQ/m <sup>3</sup>	Surface water, pg I-TEQ/l or fg I-TEQ/l	Bottom sediments, ng I-TEQ/kg d.m.	Soils, ng I-TEQ/kg d.m.	Forest litter, ng I-TEQ/kg d.m.	Vegetation, ng I-TEQ/kg d.m.
Hessia, Winter 90-95 (n=56) <u>11-216</u> 68 Winter 90-95 (n=73) <u>30-464</u> 118 Spring 90-95 (n = 61) <u>4-812</u> 30 Spring 90-95 (n=77) <u>2-705</u> 59 Summer 90-95 (n =67) <u>3- 433</u> 18 Summer 90-95 (n = 87) <u>6 – 232</u> 40 Autumn 89-95 (n = 68) <u>11-379</u> 70 Autumn 89-95 (n = 88) <u>27-454</u> 112 <i>Buckley-Golder et al., [1999]</i>	Hessia, 1989–95 (n=72) <u>2 – 181</u> 21 1989–95 (n=34) <u>1 – 120</u> 21 1989–95 (n=73) <u>0 – 32</u> 5 1989–95 (n=70) <u>0 – 23</u> 4 <i>Buckley-Golder et al., [1999]</i> Hessen, urban, 1990 – 10; 1991 – 9; 1992 – 4, <i>Liebl et al., [1993]</i> cited <i>Lomann and Jones,[ 1998]</i>			Hausgardens: 10 <i>Buckley-Golder et al., [1999]</i>		
Hessen : 1990 <u>80 – 150</u> 100 <i>König et al., [1993]</i> Cited <i>Lohmann and Jones,[1998]</i>						
Thuringia, urban 10.93-10.94, (n = 12) <u>18 – 210</u> 92 10.93–10.94, (n = 12) <u>15 – 126</u> 61	Thuringia, urban 1993-94, (n = 12) <u>10 – 407</u> 73 1993–94, (n = 12) <u>11 – 169</u> 52					

Air, fg I-TEQ / m <sup>3</sup>	Deposition and precipitation, pg I-TEQ/m <sup>2</sup> /d (a) pg I-TEQ/l or fg I-TEQ/m <sup>3</sup>	Surface water, pg I-TEQ/l or fg I-TEQ/l	Bottom sediments, ng I-TEQ/kg d.m.	Soils, ng I-TEQ/kg d.m.	Forest litter, ng I-TEQ/kg d.m.	Vegetation, ng I-TEQ/kg d.m.
10.93–10.97, (n = 48) <u>9 – 231</u> 71 <i>Buckley-Golder et al., [1999]</i>	1993–97, (n = 48) <u>3 – 464</u> 29 <i>Buckley-Golder et al., [1999]</i>					
Baden- Wuerttemberg,	Baden- Wuerttemberg, Stuttgart, Summer 1992 <u>16-47</u> 30 Winter 1992 <u>9.0 – 52</u> 26 Karlsruhe, Summer 1992 <u>6.8-63</u> 31 Winter 1992 <u>7.5 – 220</u> 79 Karlsruhe – Eigenstein, Summer 1992 <u>23-39</u> 31 Winter 1992 <u>9.5 – 110</u> 49 <i>Wallenhorst, [1996], cited Lohmann and Jones, [1998]</i>					
Baden –Wuerttemberg, Rural area, 04.92-03.93, (n = 12); <u>8 – 54</u> 21	Baden – Wuerttemberg, Rural area, 04.92-03.93, (n=85); <u>1 – 26</u> 7					

Air, fg I-TEQ / m <sup>3</sup>	Deposition and precipitation, pg I-TEQ/m <sup>2</sup> /d (a) pg I-TEQ/l or fg I-TEQ/m <sup>3</sup>	Surface water, pg I-TEQ/l or fg I-TEQ/l	Bottom sediments, ng I-TEQ/kg d.m.	Soils, ng I-TEQ/kg d.m.	Forest litter, ng I-TEQ/kg d.m.	Vegetation, ng I-TEQ/kg d.m.
Rural area with elevated regions (Black Forest), 04.92-03.93, (n = 12); <u>5 – 49</u> 18 Suburban area, 04.92-03.93, (n = 24); <u>18 – 71</u> 36 Urban area, 04.92-03.93, (n = 24); <u>21 – 217</u> 83 Multi type impact area, 04.92-03.93, (n = 36); <u>14 – 130</u> 62 <i>Wallenhorst et al., [1997]</i>	Rural area with elevated regions (Black Forest), 04.92-03.93, (n = 8); <u>4 – 2666</u> 298 Suburban area, 04.92-03.93, (n=31); <u>6 – 106</u> 31 Urban area, 04.92-03.93, (n=33); <u>8 – 134</u> 37 Multi type impact area, 04.92-03.93, (n=40); <u>6 – 97</u> 25 <i>Wallenhorst et al., [1997]</i>					
Baden –Wuerttemberg,	Baden-Wuerttemberg, Hornisgrinde, rural Summer 1992 <u>6.2-83</u> 51 Winter 1992 <u>18 – 87</u> 47 <i>Wallenhorst, [1996], cited Lohmann and Jones,[1998]</i> Mountain Hornisgrinde, 1993-94 (n = 5); <u>9 – 16</u> 13 <i>Wallenhorst et al.,[1997]</i>					Baden- Wuerttemberg, Mountain Hornisgrinde, 1992-93 <b>Grass</b> – 4.4; 1994 grass bottom – 4.7; grass top – 0.2; <i>Wallenhorst et al., [1997]</i>

**ANNEX B**

**LIST OF COUNTRIES FOR WHICH DATA ON PCDD/F CONTENT IN  
DIFFERENT NATURAL OBJECTS FOR ALL 17 TOXIC CONGENERS  
ARE AVAILABLE**

Country	Observation period	Studied medium and sample number	Presented data, measurement units, I-TEQ	Reference	Notes
<b>EEC countries</b>					
<b>Austria</b>	1992-98	Air-155 samples	fg I-TEQ/m <sup>3</sup>	<i>Buckley-Golder et al.</i> , [1999]	
	1987-93	Soils-90 samples	ng I-TEQ/kg d.m.		
		Vegetation - 95 samples	ng I-TEQ/kg d.m.		
	1988 1994	Air, Brixlegg, South Graz	fg I-TEQ/kg	<i>R.Lohmann and K.Jones</i> , [1998]	
	1993	Humus layer, (n=25)	ng I-TEQ/kg	<i>P.Weiss et al.</i> , [2000]	
	1993	Spruce needles, (n=24)	ng I-TEQ/kg	<i>P.Weiss et al.</i> , [2000]	
<b>United Kingdom</b>	1992-97	Air, Different number of years, cities and territories (from 2 to 79)	fg I-TEQ/m <sup>3</sup>	<i>Buckley-Golder et al.</i> , [1999]	
	1992-97	Air, Industrial cities - Manchester, Cardiff, Bolsover, Rural (clear areas) - Hazelrigg, East coast	fg I-TEQ/m <sup>3</sup>	<i>R.Lohmann and K.Jones</i> , [1998]	
	1990-93	Depositions, Manchester, Cardiff	pg I-TEQ/m <sup>2</sup> per day	<i>R.Lohmann and K.Jones</i> , [1998]	
	1992-93	Depositions (fluxes); Different number of years, cities and territories (from 2 to 36)	ng TEQ/m <sup>2</sup> ·a pg TEQ/m <sup>2</sup> ·d	<i>R.Lohmann and K.Jones</i> , [1998]	
	1985-97	Soils; Different number of years and territories (from 5 to 103)	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
	1992-97	Bottom sediments; Sample number for averaging is not indicated	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
	end of 80 <sup>ies</sup> ; 1993 to 1995	Vegetation, 67 samples, 24 samples, 11 samples of grass	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	Near source
<b>Belgium</b>	1992	Air, Flanders	fg I-TEQ/m <sup>3</sup>	<i>R.Lohmann and K.Jones</i> , [1998]	
	1993	Depositions, Flanders Background, Urban	pg I-TEQ/m <sup>2</sup> per day	<i>R.Lohmann and K.Jones</i> , [1998]	
	1992-93? To 1993	Air, Sample number for averaging is not indicated	fg I-TEQ/m <sup>3</sup>	<i>Buckley-Golder et al.</i> , [1999]	
	After surveillance of air pollution	Soils, Sample number for averaging is not indicated	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	

Country	Observation period	Studied medium and sample number	Presented data, measurement units, I-TEQ	Reference	Notes
	1993 and 1997	Depositions, Sample number for averaging is not indicated	ng TEQ/m <sup>2</sup> ·a pg TEQ/m <sup>2</sup> ·d	<i>Buckley-Golder et al.</i> , [1999]	
<b>Germany</b>	1987–97	Air - Sample number for averaging is not indicated, but data on 849 samples are processed in Databases UBA	fg I-TEQ/m <sup>3</sup>	<i>Buckley-Golder et al.</i> , [1999]	
	1987	Air, Koeln, Duisburg (urban)	fg I-TEQ/m <sup>3</sup>	<i>R.Lohmann and K.Jones</i> , [1998]	
	1993	Air, Essen, Dortmund	fg I-TEQ/m <sup>3</sup>	<i>R.Lohmann and K.Jones</i> , [1998]	
	1985	Air, Cities of North Rhine–Westphalia Lands (urban)	fg I-TEQ/m <sup>3</sup>	<i>Buckley-Golder et al.</i> , [1999]	
	1990	Air, Hessen Lands (urban and rural)	fg I-TEQ/m <sup>3</sup>	<i>R.Lohmann and K.Jones</i> , [1998]	
	1990–92	Depositions, Hessen Lands(urban)	pg I-TEQ/m <sup>2</sup> d	<i>R.Lohmann and K.Jones</i> , [1998]	
	1992	Depositions, Cities of North Rhine–Westphalia Lands (urban)	pg I-TEQ/m <sup>2</sup> d	<i>R.Lohmann and K.Jones</i> , [1998]	
	1990, 1993	Hamburg	pg I-TEQ/m <sup>2</sup> d	<i>R.Lohmann and K.Jones</i> , [1998]	
	1992	Stuttgart and other cities and industrial site of Baden-Wuerttemberg	pg I-TEQ/m <sup>2</sup> d	<i>R.Lohmann and K.Jones</i> , [1998]	
	1993-94 ?	Air, 108 samples	fg I-TEQ/m <sup>3</sup>	<i>Th.Wallenhorst et al.</i> , [1997]	
	1993-94	Depositions, Mountain Hornisgrinde, 197 samples of dry depositions	pg I-TEQ/m <sup>2</sup> d	<i>Th.Wallenhorst et al.</i> , [1997]	
	1990-97	Depositions (fluxes) – Sample number for averaging is not indicated, but data on 387 samples are processed in Databases UBA	pg TEQ/m <sup>2</sup> ·d	<i>Buckley-Golder et al.</i> , [1999]	
	1991-97	Soils, 1594 samples	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
	1989–96	Bottom sediments – 28 samples from main Germany rivers	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
	To 1990	Vegetation, spruce needles	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	

Country	Observation period	Studied medium and sample number	Presented data, measurement units, I-TEQ	Reference	Notes
<b>Greece</b>	1996	Soils, Sample number for averaging is not indicated	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
<b>Ireland</b>		Air, Mace Head, remote	fg I-TEQ/m <sup>3</sup>	<i>R.Lohmann and K.Jones</i> , [1998]	
	1993-98	Soils, Different number of years and territories (from 1 to 14)	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
<b>Spain</b>	1995	Air, Catalonia, urban, rural	fg I-TEQ/m <sup>3</sup>	<i>R.Lohmann and K.Jones</i> , [1998]	
	To 1996	Soils, Sample number for averaging is not indicated	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	Near incinerator
	To 1998	Bottom sediments, Sample number for averaging is not indicated	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
	To 1997	Vegetation, Sample number for averaging is not indicated	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
<b>Italy</b>	1993 1991	Air: Florence – 18 samples; Rome – 10 samples	fg I-TEQ/m <sup>3</sup>	<i>Buckley-Golder et al.</i> , [1999]	
	11.90-04.91	Air, Rome	fg I-TEQ/m <sup>3</sup>	<i>L.Turrio-Baldassarri et al.</i> , 1994	
	1990-91	Air, Rome	fg I-TEQ/m <sup>3</sup>	<i>R.Lohmann and K.Jones</i> , [1998]	
	1992-93	Soils, Different number of years and territories (from 6 to 69)	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
	1992–97	Bottom sediments, total 31 samples; Different number of sampling point (from 5 to 8)	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
<b>Luxembourg</b>	1992–94	Air, Sample number is not indicated	fg I-TEQ/m <sup>3</sup>	<i>Buckley-Golder et al.</i> , [1999]	
	Years are not indicated	Soils, Sample number is not indicated	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
	1993	Bottom sediments, Sample number is not indicated	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
	1993-94	Vegetation Sample number is not indicated	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	

Country	Observation period	Studied medium and sample number	Presented data, measurement units, I-TEQ	Reference	Notes
<b>Netherlands</b>	1991–93	Air, 45 samples, different number of years and sampling point (from 10 to 12)	fg I-TEQ/m <sup>3</sup>	<i>Buckley-Golder et al.</i> , [1999]	
	1990-98	Soils, Different number of years and territories (from 6 to 69)	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
	1980–90	Bottom sediments, Sample number for averaging is not indicated	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
<b>Finland</b>	To 1994–95	Soils, Sample number is not indicated	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
	1990-96	Bottom sediments, 2-4 samples (background and reference sites); 1-18 samples (contaminated sites)	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
<b>France</b>	Sampling time is not indicated	Vegetation Vegetables Sample number for averaging is not indicated	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
<b>Sweden</b>	1988–93	Air, Sample number is not indicated	fg I-TEQ/m <sup>3</sup>	<i>Buckley-Golder et al.</i> , [1999]	
	1987-90	Air, Stockholm, Gothenburg, Roervik (coast)	fg I-TEQ/m <sup>3</sup>	<i>R.Lohmann and K.Jones</i> , [1998]	
	1990	Soils, 20 samples	Ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	
	Sampling dates are not indicated	Bottom sediments 100 samples	ng I-TEQ/kg d.m.	<i>Buckley-Golder et al.</i> , [1999]	

Country	Observation period	Studied medium and sample number	Presented data, measurement units, I-TEQ	Reference	Notes
<b>Countries of East Europe</b>					
<b>Czech Republik</b>	1994-96	Air Prague, Sample number for averaging is not indicated, concentration range is given	fg I-TEQ/m <sup>3</sup>	<i>I.Holoubek et al., [2000]</i>	
	1994-96	Soils, Krkonoše Mountains, Sample number for averaging is not indicated	pg I-TEQ/g d.m.	<i>I.Holoubek et al., [2000]</i>	
<b>Yugoslavia</b>	1997-98	Air, Zagreb, Sample number for averaging is not indicated, concentration range is given	fg I-TEQ/m <sup>3</sup>	<i>I.Holoubek et al., [2000]</i>	
<b>Poland</b>	1995	Air, Krakow, Sample number for averaging is not indicated, concentration range is given	fg I-TEQ/m <sup>3</sup>	<i>R.Lohmann and K.Jones, [1998]</i>	
<b>Russian Federation</b>					
Archangelsk region		Air, Archangelsk c., Novodvinsk c.	pg I-TEQ/m <sup>3</sup>	<i>C.C.Юфит и др., 1998</i>	
		Water ecosystems of Archangelsk region	pg I-TEQ/l	<i>Государственный доклад, [1998]</i>	
		Surface water Vycheгда r., Puksa r., Khataritsa r.		<i>C.C.Юфит и др., 1998</i>	
		Soils near sources in cities – Archangelsk and Novodvinsk		<i>S.Yufit et al., [2000]</i>	
		Bottom sediments (river) North Dvina r., Vycheгда r., Emtsa r., Pinega r., Mekhrenga r.		<i>C.C.Юфит и др., 1998</i>	
Karelia		Water ecosystems of Archangelsk region	pg I-TEQ/l	<i>Государственный доклад, [1998]</i>	
		Soils		<i>Государственный доклад, [1998]</i>	
	24.07.00	Bottom sediments, Onega l. (Petrazavodsk c.)		<i>S.Yufit et al., [2000]</i>	

Country	Observation period	Studied medium and sample number	Presented data, measurement units, I-TEQ	Reference	Notes
Leningrad region		Water ecosystems of Leningrad region	pg I-TEQ/l	<i>Государственный доклад, [1998]</i>	
		Soils	ng I-TEQ/kg	<i>Государственный доклад, [1998]</i>	
Kaliningrad region		Soils	ng I-TEQ/kg	<i>Государственный доклад, [1998]</i>	
Jamalo-Nenetsk autonomic okrug		Soils	ng I-TEQ/kg	<i>Государственный доклад, [1998]</i>	
Komi Republic	1996-97	Surface water, Vychegda r.	pg I-TEQ/l	<i>З.К.Амирова и др., [1998]</i>	
	1996-97	Soils, Ezhvinsk region	ng I-TEQ/kg	<i>З.К.Амирова и др., [1998]</i>	
		Soils	ng I-TEQ/kg	<i>Государственный доклад, [1998]</i>	
	28.06.00	Bottom sediments, Sysola r.	ng I-TEQ/kg	<i>S.Yufit et al., [2000]</i>	
	1996-97	Bottom sediments, Vychegda r.		<i>З.К.Амирова и др., [1998]</i>	
Pskov region	21.08.00	Bottom sediments, Velikaya r.		<i>S.Yufit et al., [2000]</i>	
Tver region		Water ecosystem of Tver region	pg I-TEQ/l	<i>Государственный доклад, [1998]</i>	
		Soils	ng I-TEQ/kg	<i>Государственный доклад, [1998]</i>	
Kostroma region		Bottom sediments, Volga r. (Kostroma c.)	ng I-TEQ/kg	<i>S.Yufit et al., [2000]</i>	
Jaroslavl region		Surface water: Jaroslavl and Rybinsk cities (in water intake – before treatment)	pg I-TEQ/l	<i>Государственный доклад, [2000]</i>	
Ivanov region		Water ecosystem of Ivanov region	pg I-TEQ/l	<i>Государственный доклад, [1998]</i>	
Moscow region		Water ecosystem of Moscow region	pg I-TEQ/l	<i>Государственный доклад, [1998]</i>	
		Soils, Shchelkovo c.	ng I-TEQ/kg	<i>Государственный доклад, [2000]</i>	
Vladimir region	29.09.00	Bottom sediments in Klyazma and Oka rivers	ng I-TEQ/kg	<i>S.Yufit et al., [2000]</i>	
Kursk region	12.07.00	Soils, Solid waste disposal «Starkovo»	ng I-TEQ/kg	<i>S.Yufit et al., [2000]</i>	
	12.07.00	Bottom sediments, Seim r.	ng I-TEQ/kg	<i>S.Yufit et al., [2000]</i>	
Tula region		Soils	ng I-TEQ/kg	<i>Государственный доклад, [1998]</i>	
Nizhnii Novgorod region		Soils	ng I-TEQ/kg	<i>Государственный доклад, [1998]</i>	

Country	Observation period	Studied medium and sample number	Presented data, measurement units, I-TEQ	Reference	Notes
Cuvash Republic		Water ecosystem of Cuvash Republic	pg I-TEQ/l	<i>Государственный доклад</i> , [1998]	
		Soils	ng I-TEQ/kg	<i>Государственный доклад</i> , [1998]	
		Soils, industrial zone Novocheboksarsk c. and Alymkasy v. (clear zone)	ng I-TEQ/kg	<i>З.К.Амирова и др.</i> , [1998]	
Kirov region		Water ecosystem of Kirov region	pg I-TEQ/l	<i>Государственный доклад</i> , [1998]	
Udmurdia		Bottom sediments, Storage pond Ighevsk c.	ng I-TEQ/kg	<i>S.Yufit et al.</i> , [2000]	
Tatarstan Republic		Water ecosystem of Tatarstan Republic	pg I-TEQ/l	<i>Государственный доклад</i> , [1998]	
		Soils	ng I-TEQ/kg	<i>Государственный доклад</i> , [1998]	
	13.07.00	Bottom sediments, Pobedilovskii bay	ng I-TEQ/kg	<i>S.Yufit et al.</i> , [2000]	
Saratov region		Water ecosystem of Saratov region	pg I-TEQ/l	<i>Государственный доклад</i> , [1998]	
		Soils	ng I-TEQ/kg	<i>Государственный доклад</i> , [1998]	
	12.07.00	Soils Solid waste disposal Saratov c.	ng I-TEQ/kg	<i>S.Yufit et al.</i> , [2000]	
	12.07.00	Bottom sediments Gussenka r. and Volga r. (Saratov c.)	ng I-TEQ/kg	<i>S.Yufit et al.</i> , [2000]	
Samara region	1994	Air, Чапаевск	pg I-TEQ/m <sup>2</sup>	<i>Б.Ревич и др.</i> , [1998]	
		Water ecosystem of Samara region	pg I-TEQ/l	<i>Государственный доклад</i> , [1998]	
		Soils	ng I-TEQ/kg	<i>Государственный доклад</i> , [1998]	
Volgograd region		Soils	ng I-TEQ/kg	<i>Государственный доклад</i> , [1998]	
Bashkortostan Republic		Surface water Belay, Yuryuzan, I, Ufa, Sakmara, Zilair, Suren r.	pg I-TEQ/l	<i>В.Н.Маистренко и др.</i> , [1998]	
		Water ecosystem of Bashkortostan Republic	pg I-TEQ/l	<i>Государственный доклад</i> , [1998]	
		Soils	ng I-TEQ/kg	<i>Государственный доклад</i> , [1998]	
		Soils, Ufa c. and suburb	ng I-TEQ/kg	<i>S.Yufit et al.</i> , [2000]	

Country	Observation period	Studied medium and sample number	Presented data, measurement units, I-TEQ	Reference	Notes
Astrakhan region		Water ecosystem of Astrakhan region	pg I-TEQ/l	<i>Государственный доклад, [1998]</i>	
		Soils	ng I-TEQ/kg	<i>Государственный доклад, [1998]</i>	
		Soils, Residential area of Astrakhan c., a/c field in Akhtubinsk region, zones affected by high ways	ng I-TEQ/kg	<i>Г.М.Михайлов и др, [1998]</i>	
		Bottom sediments: Akhtuba r., Buzan r., Volga delta, Astrakhan biosphere reserve	ng I-TEQ/kg	<i>Г.М.Михайлов и др, [1998]</i>	
		Bottom sediments: Volga r.	ng I-TEQ/kg	<i>S.Yufit et al., [2000]</i>	
Krasnodar territory		Water ecosystem of Krasnodar territory	pg I-TEQ/l	<i>Государственный доклад, [1998]</i>	
		Soils	ng I-TEQ/kg	<i>Государственный доклад, [1998]</i>	
Adygeya autonomic oblast		Bottom sediments, Krasnodar storage pond	ng I-TEQ/kg	<i>S.Yufit et al., [2000]</i>	
Dagestan Republic		Bottom Terek r., 200 km from Makhachkala		<i>S.Yufit et al., [2000]</i>	
Perm region		Soils	ng I-TEQ/kg	<i>Государственный доклад, [1998]</i>	
Orenburg region		Soils	ng I-TEQ/kg	<i>Государственный доклад, [1998]</i>	

Country	Observation period	Studied medium and sample number	Presented data, measurement units	Reference
<b>Austria</b>	02.88-07.88, (n=4)	Air, Brixlegg, Tyrol	Congener-specific analysis, $\text{pg/m}^3$	<i>W.Chrismann et al.</i> [1989b]
	1993	Forest litter, 25 sampling sites up to 1670 m height	Congener-specific analysis, $\text{ng/kg}$	<i>P.Weiss</i> , [1998]
	1993	Vegetation, silver fir needles, Fichtennadeln	Congener-specific analysis, $\text{ng/kg}$	<i>P.Weiss</i> , [1998]
<b>United Kingdom</b>	1991-95, mean per year	Air, in London and Manchester	Congener-specific analysis, $\text{fg/m}^3$	<i>P.Coleman et al.</i> , [1997]
	Autumn 1995, Summer 1996	Air, semirural, Hazelrigg	Congener-specific analysis, $\text{fg/m}^3$	<i>R.Lee et al.</i> , [1999]
	1992-93 Autumn	Air, Bolsover, Derbyshire, Industrial site, background site	Congener-specific analysis, $\text{pg/m}^3$	<i>K.Jones and R.Duarte-Davidson</i> , [1997],
		Air, Urban and rural	Congener-specific analysis, $\text{pg/m}^3$	<i>J.Cole et al.</i> , [1999]
	1993	Depositions, Bolsover, Derbyshire, Industrial site, background site	Congener-specific analysis, $\text{pg/m}^2 \text{ day}$	<i>K.Jones and R.Duarte-Davidson</i> , [1997]
	1991-92	Manchester and Cardiff	$\text{pg/m}^2 \text{ day}$	<i>C.Halsall et al.</i> , [1997]
		River water	Congener-specific analysis, $\text{pg/m}^3$	<i>J.Cole et al.</i> , [1999]
		Soils, Urban and rural	Congener-specific analysis, $\text{ng/kg}$	<i>J.Cole et al.</i> , [1999]
		Bottom sediments in rivers, urban and rural	Congener-specific analysis, $\text{ng/kg}$	<i>J.Cole et al.</i> , [1999]
		Vegetation grass, herbage	Congener-specific analysis, $\text{ng/kg d.w.}$	<i>J.Cole et al.</i> , [1999]
	1983, 1957, 1962, 1967, 1972, 1977, 1982, 1992	Soils Archived soil from the Woburn Ley Arable	Congener-specific analysis, $\text{ng/kg d.w.}$	<i>R.Alcock et al.</i> , [1998]
	1980, 1985, 1988, 1992	Vegetation Archived herbage from Park Grass	Congener-specific analysis, $\text{ng/kg d.w.}$	<i>R.Alcock et al.</i> , [1998]
		Vegetation grass, Bolsover, Derbyshire, industrial site and background site	Congener-specific analysis $\text{ng/kg d.w.}$	<i>K.Jones and R.Duarte-Davidson</i> , [1997]
	<b>Germany</b>	During smog period, 29.12.86-12.01.87 (n=10), 1987 – (n=5); 1987 – (n=3)	Air, Berlin, GelsenkichenBuer, Recklinghausen	Congener-specific analysis, $\text{pg/m}^3$
1992		Air, Augsburg,	Congener-specific analysis, $\text{fg/m}^3$	<i>M.Hippelein et al.</i> , [1996]

Country	Observation period	Studied medium and sample number	Presented data, measurement units	Reference
	1987-88 annual average 1993-94 annual average	Air, cities of North Rhine – Westphalia Lands: Köln, Essen, Duisburg, Dortmund	Congener-specific analysis, fg I-TEQ/m <sup>3</sup>	<i>E.Hiester et al.</i> , [1997]
	1986–96	Air, Bayreth	Congener-specific analysis, pg/m <sup>3</sup>	<i>M.Horstmann and M.McLachlan</i> , [1998]
	1995-96	Air, Bayreth, Berlin, Zingst	Congener-specific analysis, pg/m <sup>3</sup>	<i>J.Pacyna et al.</i> , [1999]
<b>Spain</b>	To 1997	Soils, Catalonia, Spain	Congener-specific analysis, ng/kg d.m.	<i>M.Schumacher et al.</i> , [1997]
	1996	Soils, San Adria del Besos, Barselona, seaside Mediterranean sea, (n=24)	Congener-specific analysis, ng/kg d.m.	<i>M.Schumacher et al.</i> , [2000]
	1996	Vegetation, herbage, at the same sites	Congener-specific analysis, ng/kg	<i>M.Schumacher et al.</i> , [2000]
	06.97	Vegetation, (n=24)	Congener-specific analysis, ng/kg d.m.	<i>M.Schumacher et al.</i> , [1998]
<b>Italy</b>	11.90–04.91	Air,	Congener-specific analysis, %	<i>L.Turrio-Baldassarri et al.</i> , [1994]
<b>Netherlands</b>		Soils, Beech and Douglas fir	Congener-specific analysis, ng/kg d.w.	<i>E.Hoekstra et al.</i> , [1999]
<b>Finland</b>	1994, 1940–88	Bottom sediments, Subarctic Finland (Lapland), 3 lake, dated sediment cores	Congener-specific analysis pg/kg d.w.	<i>T.Vartiainen et al.</i> , [1997]
	08.1994	Vegetation Ekokem, moss and lichen	Congener-specific analysis, pg/kg d.w.	<i>J.Pacyna et al.</i> , [1999]
	08.1994	Vegetation from: Ivalo, Kuusamo, Lieksa, Lammi, Jyvaeskylae, Kuopio moss and lichen	Congener-specific analysis, pg/kg d.w.	<i>J.Pacyna et al.</i> , [1999]
	1996	Vegetation near pulpmill – spruce needles (pine needles)	Congener-specific analysis, pg/kg d.w.	<i>J.Pacyna et al.</i> , [1999]
<b>Sweden</b>	1988–90	Air, urban and EMEP station Rorvik	Congener-specific analysis pg/m <sup>3</sup>	<i>J.Pacyna et al.</i> , [1999]
	06.88–07.88	Sea water, Baltic Sea (open sea and coastal region)	Congener-specific analysis, pg/m <sup>3</sup>	<i>D.Broman et al.</i> , [1991b]
	1985, 1978, 1970, 1962, 1954, 1938, 1922, 1906, 1882	Bottom sediments, Northwestern part of the Baltic Proper	Congener-specific analysis, pg/g d.w.	<i>L.O.Kjeller and K.Rappe</i> , [1995]
	1992, 1993	Gulf Finland (n=3), Gulf Finland near Gotland (n=3)		<i>J.Koistinen et al.</i> , [1997]

Country	Observation period	Studied medium and sample number	Presented data, measurement units	Reference
<b>Czech Republic</b>		Air, High mountains ecosystems	Congener-specific analysis, pg/m <sup>3</sup>	<i>I.Holoubek et al., [2000]</i>
	1994-96	Soils, Krkonoše Mountains	Congener-specific analysis, pg/g	<i>I.Holoubek et al., [2000]</i>
		Soils, High mountains ecosystems	Congener-specific analysis, pg/g	<i>I.Holoubek et al., [2000]</i>
		Vegetation, needle, High mountains ecosystems	Congener-specific analysis, pg/g	<i>I.Holoubek et al., [2000]</i>
<b><i>Russian Federation</i></b>				
Archangelsk region	1993-94	Air, Novodvinsk c.	Congener-specific analysis, pg/m <sup>3</sup>	<i>С.С.Юфит и др., [1998]</i>
	1993-94	Water, North Dvina r., water intake of Archangelsk and Novodvinsk cities	Congener-specific analysis, pg/l	<i>С.С.Юфит и др., [1998]</i>
Vladimir region	To 1997	Air. Vladimir, Suzdal and Kolchugino cities	Congener-specific analysis, pg/m <sup>3</sup>	<i>Н.А.Клюев и др., [1998]</i>
	To 1997	Soils, meadows, pasture and zones affected by high ways and industrial zones of Vladimir and Kolchugino cities	Congener-specific analysis, pg/g	<i>Н.А.Клюев и др., [1998]</i>
Astrakhan region		Soils: Residential area of Astrakhan city, zones affected by high ways, landfill in Akhtubinsk, field in Akhtubinsk region	Congener-specific analysis, pg I-TEQ/g	<i>Г.М.Михайлов и др., [1998]</i>
		Bottom sediments: Akhtuba r., Glavnyi bank r., Baklanenok r., Buzan r. Damchink site of Astrakhan biosphere reserve	Congener-specific analysis, pg I-TEQ/g	<i>Г.М.Михайлов и др., [1998]</i>
	1997	Soils 7 samples	Congener-specific analysis, pg I-TEQ/g	<i>Г.М.Михайлов, [1998]</i>
	1997	Bottom sediments 9 samples	Congener-specific analysis, pg I-TEQ/g	<i>Г.М.Михайлов, [1998]</i>
Bashkortostan Republic		Air: Residential area in Ufa and Sterlitamak cities	Congener-specific analysis, pg/m <sup>3</sup>	<i>В.Н.Майстренко и др., [1998]</i>
		Soils: Industrial centers rural regions, reserves	Congener-specific analysis, ng/kg	<i>В.Н.Майстренко и др., [1998]</i>

Notes: d.m. – dry matter;

d.w. – dry weight