SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY

Intermediary report – January 2003

CHAIN MODEL FOR THE IMPACT ANALYSIS OF CONTAMINANTS IN PRIMARY FOOD PRODUCTS
CP-27

Vito – LUC - RUG

SPSD II

PART 1
SUSTAINABLE PRODUCTION AND CONSUMPTION PATTERNS

- GENERAL ISSUES
- AGRO-FOOD
- ENERGY
- TRANSPORT

This research project is realised within the framework of the Scientific support plan for a sustainable development policy (SPSD II)

Part I "Sustainable production and consumption patterns"

The appendixes to this report are available at :
http://www.belspo.be (FEDRA)

Published in 2003 by the
Belgian Public Planning Service Science Policy
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(Vito contract 011191)

Chain model for the impact analysis of contaminants in primary food products

project CP/67/271

Scientific report 2002

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Study financed by the OSTC

2002/IMS/R/

Vito

January 2003

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0 PROJECT TITLE

Chain model for the impact analysis of contaminants in primary food products

1 INTRODUCTION

1.1 Context and summary

Food safety is one of the major issues on the Agenda of the European Commission and the Belgian government. Incidents like the dioxin- and BSE-crisis lead to important economic losses and to concern about the protection of public health through the food chain. At the European level, the White Paper on Food Safety (EC, 2000) was published, including the organisation of a European Food Authority which defines priorities for research and regulation. At the Belgian level, the Federal Agency of Food Safety was established. Following these initiatives, regulatory initiatives for setting limits on contaminants in human and animal food products are accelerated (EC, 2001a; EC, 2001b; EC, 2002). The European Commission is well aware that risk assessment strategies and models are essential for the construction of a food safety policy.

Existing instruments such as LCA and HACCP are primarily concerned with environmental impact, quality control and risk-assessment in the production and distribution part of the food chain, i.e., after the products have left the farm (post-farm gate). Quality control and risk evaluation of the food chain starting from the farm to the primary food products (pre-farm gate) is gaining importance because of the direct link with consumers and because products from the farm are the basic products for the producing industries. This is clearly acknowledged by the food processing industry and the retailers (see e.g., EUREPGAP, GFSI initiatives).

An integrated instrument that calculates transfer of contaminants from the inlet of the farm to primary food products (crops, cereals, meat, eggs, milk), and that assesses impacts of contaminated primary food products on public health and related costs is urgently needed. Currently, no generic modeling tools are available that predict the impact of contaminants in the environment to the primary food chain. Related multimedia models such as EUSES (ECB, 1997), used for the regulation of pesticides and chemicals, may be incomplete for this purpose. Detailed mechanistic models dealing with specific processes in the food chain do not offer an overall picture of the transfer and impact.

1.2 Objectives

The main objectives of the research project are:

- to develop a generic method for the calculation of contaminant transfer in the agro-ecosystem to primary food products
- to develop a methodology for the impact analysis of contaminated primary food products
- to couple the transfer and the impact analysis modules in an integrated model environment
- to demonstrate the integrated model for three typical food contaminants (cadmium, dioxins, pesticides)
- to evaluate the model against experimental data

1.3 Expected outcome

Specific model outputs will be:

- a quantitative estimation of the impact of diffuse, local or incidental contamination on the quality of primary food products, and on human health (and related costs)
- a quantitative estimation of impacts of changes in farming practices on the quality of primary food products, and on human health (and related costs)
- indication of locations where safe food may no longer be guaranteed due to (historical) contamination
- a definition of critical points in the primary food chain based on a sensitivity analysis of the integrated model

The added value of the research project is the coupling between various numerical model approaches (i.e., transfer in the soil root zone, crop uptake, animal intake and redistribution, impact on human health and external costs). To estimate impacts of changing boundary conditions (i.e. farming practices, local emissions, …) a dynamic model formulation will be adopted. Uncertainty and variation in the model variables will be incorporated in the model calculations. A sensitivity analysis on the model variables will show the critical points in the primary food chain with respect to human health risks.

2 DETAILED DESCRIPTION OF THE SCIENTIFIC METHODOLOGY

The development of the integrated model, from now on called XtraFOOD (Xenobiotics transfer in the primary FOOD chain), consists of the following tasks:

Task A: development of a model for the contaminant transfer in the agro-ecosystem
    Subtask A.1: transfer in soil
    Subtask A.2: transfer to primary food products
Task B: development of an impact analysis model
    Subtask B.1: exposure modeling and health risk analysis
    Subtask B.2: external cost modeling
Task C: computer programming of the integrated model XtraFOOD
Task D: demonstration and evaluation of XtraFOOD

Tasks A and B are scheduled for the first two working years, i.e. 2002-2003. Task B extends to mid 2004. Tasks C and D are programmed from the second half of 2003 till 2005. Figure 1 illustrates the adopted scientific methodology. Table 1 gives an overview of the research activities of the respective project partners.

Table 1: Overview of the research activities in 2002

Task	Description	Project Partner	Report Paragraphs
A.1	transfer in soil	Vito	3.1; 5.3.1
A.2	transfer to primary food products:		
	- plant uptake	LUC	3.2.1
	- pesticide crop modeling	UG	3.2.2; 5.3.3
	- transfer in cattle	Vito	3.2.3; 5.3.2; 5.3.4; 5.3.5

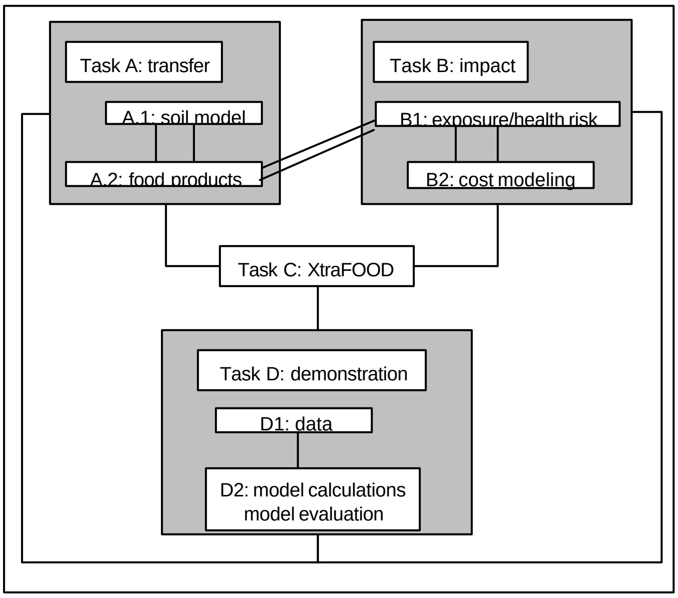

Figure 1: Overview of the scientific methodology

3 DETAILED DESCRIPTION OF THE INTERMEDIATE RESULTS, PRELIMINARY CONCLUSIONS AND RECOMMENDATIONS

The objectives of the first year of the research project were to develop a model for the transfer of chemicals in the agro-ecosystem (Tasks A.1 and A.2). Task A.1 consisted of constructing the soil model including the various contaminant transfers and transformations. Task A.2 contained the transfer modeling to the primary food products (crops, cereals, meat, eggs, milk). Both Tasks were programmed until the end of 2003. We will report here an overview of models for the calculation of transfers in the agro-ecosystem.

Figure 2 shows the various possible transfers of contaminants in a model agro-ecosystem. Contaminants are transferred either directly or indirectly to the food products. Chemicals can enter the agro-ecosystem via the soil through irrigation, (wet and dry) atmospheric deposition or the application of fertilisers. Contaminants can be deposited either directly on the soil or on the aboveground parts of the crop. The application of plant protection products is a direct input term for pesticides to soil or crops. Contaminants can also enter the farm through the import of animal manure or through feed supplies. Contaminants can leave the agro-ecosystem via the soil through volatilisation to the atmosphere, run-off to surface water or leaching to groundwater, or they can be degraded in the soil. Contaminants can leave the agro-ecosystem by exporting animal manure as waste, and by exporting cattle and/or crops as food products. Internal flows are plant uptake (soil->plant) and cattle intake (soil->plant->cattle or soil->cattle). Indirect transfer of contaminants to food products thus partly occurs via the soil system. Crops are closely connected to the soil by their root system, extracting water and nutrients (or contaminants). Cattle ingests plants growing in the soil and soil particles. Modeling the transfer of contaminants in soils of agro-ecosystems therefore is indispensable for the impact analysis. Examples of contaminant transfer modeling in agro-ecosystems can be found in Welsch-Pausch and McLachlan (1998), McLachlan (1997), Harrad and Smith (1997), Fiedler et al. (2000), Keller (2000) and Molenaar (1998).

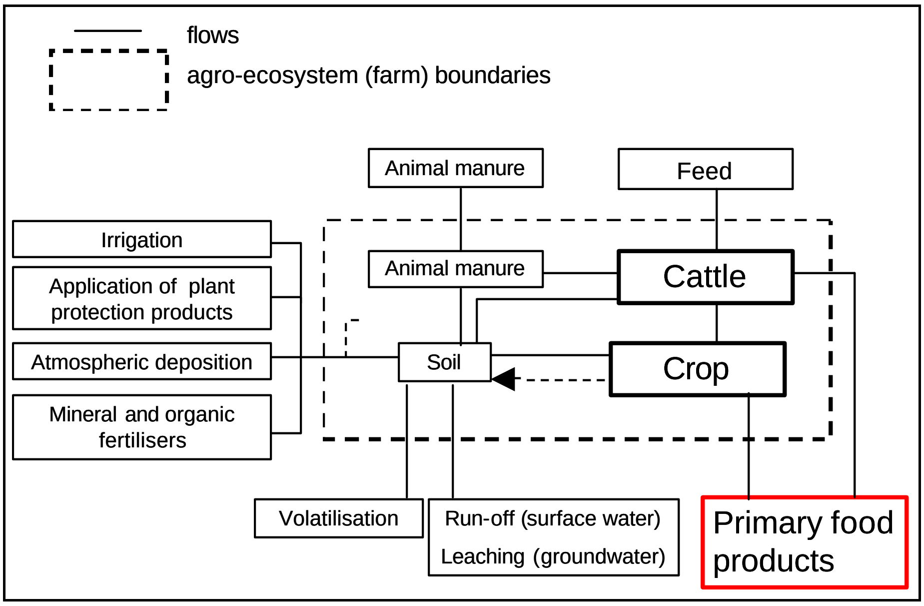

Figure 2: Overview of contaminant flows in the agro-ecosystem to the food chain

3.1 Task A.1: Transfer in soil

Once a contaminant enters the soil from various sources, it is distributed over the liquid, the solid and the gas phase obeying equilibrium between the soil phases. A contaminant in the liquid phase can be leached to groundwater, can be taken up by plant roots or can be degraded. Contaminants attached to the solid phase can be washed off from soil surface by rainfall and run-off to surface water or can be degraded to some extent. Contaminants present in the soil air phase can volatilise and leave the soil at the soil-atmosphere surface.

Existing models of contaminant transfer in soils were reviewed and evaluated for use in the food chain model. A wealth of models exist for describing contaminant behaviour and transport in soils. They vary in complexity in describing the various transfer processes from purely mechanistic white-box to empirical black-box (transfer function) models. Purely mechanistic models may be suitable for modeling and explaining various micro-scale processes (e.g., geochemical models describing chemical reactions at the molecular level, root models describing microscopic uptake processes in the rhizosphere), but are not widely used to large-scale problems or exposure modeling. Proces-based models include mathematical descriptions of processes with lumped variables (variables incorporating various subprocesses, like e.g. a soil-water distribution coefficient that accounts for all chemical reactions between soil water and soil solid phase) which can be measured relatively easily in the lab or the field. Examples of these are models describing water flow and solute transport in the soil-plant-atmosphere continuum (e.g., Hydrus (Simunek et al., 1999); Macro (Jarvis, 2001); SWAP (Kroes et al., 1999); PEARL (Leistra et al., 2001); WAVE (Vanclooster et al., 1996)). They have been mainly implemented in calculating contaminant or pesticide leaching to groundwater, or in nutrient management of agro-ecosystems.

At a third lower level of complexity, transfer of contaminants is modeled using simple black box models with transfer factors or transfer functions representing the soil system. This type of models is frequently used in dynamic exposure assessment of contaminants (Vissenberg and van Grinsven, 1995; CalTOX, 1993; Mackay, 2001). They are suitable for persistent, non- or semi-volatile, and less mobile contaminants accumulating in the food chain. The contaminant quantities or concentrations within a single homogeneous soil compartment are described by a linear first-order differential equation of the form:

$$\frac{dc}{dt} = -kc + I \qquad \textit{(Eq. 1)}$$

where c is the total concentration in soil (mg kg^{-1}), k is the overall first-order rate coefficient (yr^{-1}), and I is the contaminant load to the soil (mg kg^{-1} yr^{-1}). The total soil concentration is the sum of the amount of contaminant in the solid, liquid and gas phase. It is assumed that contaminants are completely mixed in the soil. Contaminants are lost from the soil by a series of transport (advective solute leaching, diffusive volatilisation, run-off, root uptake) and transformation (degradation) processes that can be represented mathematically as first-order losses. The overall rate coefficient k is the sum of the individual first-order rate coefficients (i.e., the volatilisation coefficient, the run-off coefficient, the root-uptake coefficient, the degradation coefficient, and the leaching rate coefficient). The analytical solution of Eq. 1 is given by:

$$c = c_i e^{-kt} + \frac{I}{k}(1 - e^{-kt}) \qquad \textit{(Eq. 2)}$$

where c_i is the initial total contaminant concentration (mg kg^{-1}), and t is time (yr). Eq. 2 shows that the model is non-dimensional in space, i.e. the concentration is independent of space and is predicted for a known volume of soil.

The mathematical equations and the analytical solution (Eq. 2) were programmed in a spreadsheet model, including expressions for phase transfer (distribution between soil phases), run-off, plant uptake, leaching, and volatilisation. Provisions were made for time-variable boundary conditions, i.e. changes in contaminant load at the soil surface (changes in atmospheric deposition, irrigation, local emissions, ...). Mass-balance control calculations were performed to optimize the time discretization and to eliminate errors in the mathematical formulas of the soil model.

For illustration purposes, typical results of transfer calculations in soil are presented in Figure 3. An example of cadmium accumulation in a 25-cm-deep topsoil is shown. The topsoil is initially contaminated with cadmium at a concentration of 2 mg kg^{-1}. Calculations are made with two cadmium deposition rates I, i.e. a minimum deposition rate of 9.73e-4 mg kg^{-1} yr^{-1}and a maximum deposition rate of 3.89e-2 mg kg^{-1} yr^{-1}. This range in deposition rates was measured in an area with non-ferrous industry (VMM, 1998). All deposited cadmium is allowed to dissolve in the rain water. Cadmium disappears from the soil only by leaching to groundwater. The water infiltration rate is 265 mm per year. The soil parameters are typical for agricultural soils. Calculations are made for the coming 100 years. The calculations show the envelope of future cadmium concentrations in soil between minimum and maximum cadmium deposition rates.

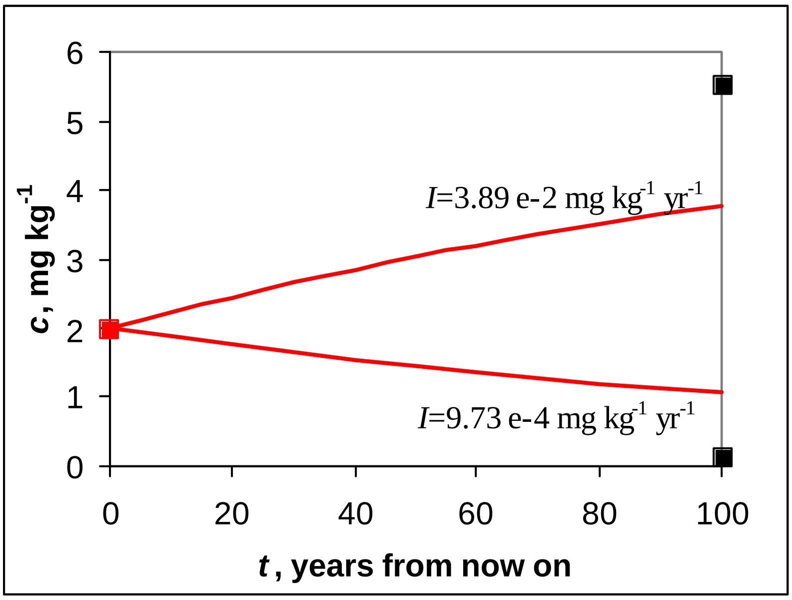

Figure 3: Accumulation of cadmium in an agricultural topsoil initially containing 2 mg kg^{-1} cadmium. Black squares represent steady-state cadmium concentrations for minimum and maximum deposition rates.

3.2 Task A.2: Transfer to primary food products

3.2.1 Soil-plant transfer of trace metals

3.2.1.1 Introduction

The soil-plant transfer of trace metals (such as cadmium) is often described by means of bioconcentration factors (BCF). The BCF is defined as the ratio of the metal concentration in the plant (or part of a plant) and the total metal concentration in the soil. In Belgium as well as in the Netherlands the BCF approach is used for the calculation of intervention values for soil clean-up (C-soil and Vlier-Humaan models). Also in the context of the current project, which aims to model the impact of contaminants in the production of primary food products, the use of bioconcentration factors seems the most appropriate method to estimate the soil plant transfer of metals.

However, the BCF of metals can be very variable and is influenced by both plant and soil factors. Important plant dependent factors are: plant species, plant cultivar and plant organ. In addition harvest time and climatologic conditions play an important role. Soil factors that influence BCF values are e.g. total soil metal content, pollution source, soil type, soil pH and organic matter content. Therefore calculated BCF values differ between studies and may not be valid in other circumstances.

3.2.1.2 Literature data

The BCF values based on a literature study by Bockting and van den Berg (1992), are represented in Table 2. For the calculation of the BCF's the authors tried to use source data meeting the following criteria:

- data based on contaminated soils
- data based on vegetables (edible parts)
- data based on field studies.

Since only very few studies met these selection criteria, the calculated BCF's for Cd, Zn, Ni, Pb, Cu and Cr were based on only 1 dataset of an experimental field treated with sewage sludge (Sauerbeck and Stypereck, 1988). The vegetables involved were potato, white cabbage, green cabbage, carrot, radish, lettuce and spinach. Based on these species a mean BCF for roots on the one hand and for shoots on the other hand was derived. The lack of suited data clearly limits the general significance of the calculated BCF's and is a weak point when one has to estimate the metal content of crops grown under various conditions based on these BCF values.

Table 2: BCF-values currently proposed byBockting and van den berg (1992)

	Root	Shoot
Cd	0.15	0.7
Zn	0.1	0.4
Pb	0.001	0.03
Cu	0.1	0.1
Ni	0.07	0.1
As	0.015	0.030
Cr	0.002	0.02
Hg	0.015	0.03

3.2.1.3 BCF of Cd in function of plant species and soil characteristics (Belgian data)

In Belgium a lot of data are known to exist concerning metal content in vegetables and agricultural crops under field conditions on both polluted and non polluted soils. Since also soil data of these soils are available we tried to calculate BCF's based on these data, and to relate them to soil properties. This may provide useful and more detailed information for the calculation of soil plant metal transfer as compared to the current approach (cfr. 3.2.1.2).

Within the context of the current project and a project funded by OVAM ('Herziening soilsaneringsnormen voor zware metalen. Partim B. Invulling van biobeschikbaarheid in functie van soileigenschappen in humaantoxicologisch onderbouwde soilsaneringsnormen') we collected in our country as much as data as possible on metal concentrations in vegetables and agricultural crops, combined with data on soil properties, in polluted areas as well as in background conditions. In Flanders the following useful studies were found:

1. (Z1) Cadmibel-study (1985-1989).
2. (Z2) 'Saneringsonderzoek van met zware metalen gecontamineerde tuinen in Noord-Limburg' (study ordered by OVAM, 1996).
3. (Z3) Own data (LUC) collected in the 90^{ties} in the province of Limburg.
4. (Z4) 'Afweging van de risico's tot transfer van metalen in de voedselketen: studie van de overdracht via landbouwgewassen geteeld in de onmiddelijke omgeving van vroegere zinkfabrieken (study ordered by OVAM, 2001)
5. (L1) A study of polluted kitchen gardens in Flanders (the owner of the study asked not to give more specifications)
6. (L2) Reports of IWONL projects with convention numbers. D1/4-4701/4620 A (1985), D1/4-4736/5031 A (1987), D1/4-5378/5297 A (1989), D1/4-4228/5428 A (1991) by 'Laboratorium voor

Analytische Agrochemie (Rijksuniversiteit Gent)', Prof. Dr. Ir. A Cottenie and Prof. Dr. Ir. M. Verloo.

Due to the limited number of Flemish data on heavier soil types also a French study (source n° 7) was used providing data from soils polluted by non ferro activities in the North of France. These data can be added to the Flemish data because of similarities in soil type and climate.

7 (L3) Etude d'un secteur pollué par les métaux. 1ère partie. Volume III: Qualité des productions végétale. Programme de recherches concertées. Environnement et Acivités humaines. Rapport de la deuxième phase: 1996-1997 (Ministère de l' Enseignement Supérieur et de la Recherche + Region Nord Pas de Calais + FEDER).

In Wallonia and Brussels the search for useful data is still going on.

3.2.1.4 Calculation of BCF values for Cd and relationship with soil properties

Based on the data sources mentioned in paragraph 3.2.1.3 we were able to calculate BCF's and to find significant relationships between BCF and soil factors for several vegetables. Since no detailed data on soil type were available the data were divided into two main groups prior to analysis. Group 1: sandy soils (soil series Z and S). Group 2: all other soils. Data of sandy soils were found in sources n°1 to 4. These data originate mainly from the north of the province of Limburg and the nearby part of the province of Antwerp. In these regions many polluted soils are found due to the presence of metal smelters. Sources n°5 to 7 delivered information on other soils types and originate mainly from West Flanders, East Flanders and Flemish Brabant.

- *Source data for Cd*

Table 3 to Table 5 give a summary of the data for cadmium on sandy soils.

Table 3: Ranges total soil Cd content and soil pH for all plant species

Cd	min	5th percentile	median	95th percentile	max	mean	number of data	references
Cd $_{tot}$								
potato	0.4	0.7	1.6	9.4	16	2.7±3.3	48	Z1,Z2,Z3
carrot	0.1	0.4	1.5	8.5	23.5	2.8 ±3.2	216	Z1,Z2,Z3
lettuce	0.1	0.5	1.5	8.3	15.5	2.6±2.6	131	Z1,Z2,Z3
celery	0.1	0.4	1.6	8.4	21.5	2.8±3.0	199	Z1,Z2,Z3
mais	1.0	1.1	2.2	4.7	4.8	2.7	20	Z4
pH-KCl	4.2	5.1	6.2	7.1	7.5	6.1±0.6	305	
potato	3.3	3.8	5.3	6.2	6.5	5.2±0.7	48	Z1,Z2,Z3
carrot	3.3	4.1	5.4	6.5	7.1	5.4±0.7	216	Z1,Z2,Z3
lettuce	3.3	4.1	5.5	6.5	7.0	5.4±0.7	131	Z1,Z2,Z3
celery	3.3	4.4	5.5	6.5	7.1	5.5±0.7	199	Z1,Z2,Z3
mais	5.0	5.3	6.0	6.8	6.9	6.1	20	Z4

Table 4: Ranges in total plant Cd content

Cd	min	5th percentile	median	95th percentile	max	mean	number	reference
potato	0.08	0.09	0.36	0.91	1.08	0.39±0.24	48	Z1,Z2,Z3
carrot	0.18	0.37	0.92	2.52	5.87	1.09±0.8	216	Z1,Z2,Z3
lettuce	0.51	1.06	4.30	17.46	29.02	6.04±5.53	131	Z1,Z2,Z3
celery	0.17	0.60	1.95	6.23	15.77	2.77±2.35	199	Z1,Z2,Z3
maïs	0.20	0.21	0.53	2.76	2.78	0.90±	20	Z4

Table 5: Ranges in Cd BCF for various crops

Cd	min	5th percentile	median	95th percentile	max	mean	number	reference
potato	0.03	0.04	0.18	0.79	0.90	0.25±0.23	48	Z1,Z2,Z3
carrot	0.05	0.10	0.52	2.25	7.79	0.82±1.04	216	Z1,Z2,Z3
lettuce	0.15	0.57	2.16	14.49	23.48	3.78±4.36	131	Z1,Z2,Z3
celery	0.03	0.31	1.17	4.83	11.9	1.69±1.74	199	Z1,Z2,Z3
maïs	0.08	0.10	0.21	0.62	0.63	0.30±	20	Z4

- *Calculation of relationships between BCF and soil factors*

Relationships between BCF and soil factors were calculated based on a multiple linear regression model. The general expression for this model is:

$$Y = a + (b*X1) + (c*X2) + (d*X3) + \ldots \qquad (Eq.\ 3)$$

with Y the response variable and $X1 \ldots Xn$ the different predictor variables. The relationships were calculated using the stepwise regression procedure of the statistical program SAS (ref.). A logarithmic transformation of the data was necessary to obtain the normal distribution.

A summary of the calculated relationships is given in Table 6.

Table 6: Summary of the calculated relationships between BCF and soil factors

Crop	LogBCF f(log metal content, pH-KCl)
Potato	$\text{LogBCF-Cd}_{crop} = -0.57 - 0.72\ \text{LogCd}_{soil}$

```
Summary of Stepwise Procedure

Variable     Partial     Model
Entered       R**2       R**2        C(p)        F      Prob>F
CDSOIL       0.4580    0.4580     1.6470     38.87    <0.0001
```

Carrot	$\text{LogBCF- Cd}_{crop} = 0.54 - 0.75\ \text{LogCd}_{soil} - 0.12\ \text{pH-KCl}$

```
Summary of Stepwise Procedure

Variable     Partial     Model
Entered       R**2       R**2        C(p)        F      Prob>F
CDSOIL       0.6313    0.6313     23.5378    366.41    <0.0001
```

```
PHKCL         0.0362   0.6675      2.4221      23.18    <0.0001
```

Crop	LogBCF f(log metal content, pH-KCl)

Lettuce

$LogBCF\text{- }Cd_{crop} = 1.53 - 0.44\ LogCd_{soil} - 0.19\ pH\text{-}KCl$

```
Summary of Stepwise Selection Procedure

Variable    Partial    Model
Entered       R**2      R**2      C(p)       F      Prob>F
CDSOIL      0.2774    0.2774    28.4926   62.57    <0.0001
pHKCL        0.1048    0.3822     3.0000   27.49    <0.0001
```

Celery

$LogBCF\text{- }Cd_{crop} = 1.30 - 0.50\ LogCd_{soil} - 0.20\ pH\text{-}KCl$

```
Summary of Stepwise Procedure

Variable    Partial    Model
Entered       R**2      R**2       C(p)       F      Prob>F
CDSOIL      0.4032    0.4032   62.5259    165.5    <0.0001
PHKCl         0.1208    0.5240    2.6751      61.93   <0.0001
```

Mais

$Log\ Cd_{crop} = 0.54 + 1.55\ LogCd_{soil} – 0.25\ pH\text{-}KCl$

```
Summary of Stepwise Selection Procedure

Variable    Partial    Model
Entered       R**2      R**2       C(p)       F      Prob>F
LOGCDSOIL   0.5342     0.5342     12.971  20.65    0.0003
pHKCl         0.1925     0.7267     3.000  11.97     0.0030
```

Confidence limits (95%) for these relationships were also calculated (results not shown). When data of Wallonia and Brussels become available they will be added to the calculations.

3.2.2 Crop models and pesticides

3.2.2.1 Selection of relevant pesticides

Based on the sales figures, persistence, lipophilicity and toxicity of an active ingredient, a selection of the most important pesticides was made. In the research proposal *atrazine* was chosen for the validation of the final model (partim pesticide fate). Because this compound is phasing out and because of the increasing importance of other (potential) problem compounds, we suggest that also other pesticides should be considered.

A possible way to select the relevant pesticides is to investigate their sales figures, persistence in soil (given by the DT50 (half-life)-value), their accumulation in organisms (given by the log K_{ow}-value) and their possible toxicity to humans (given by the ADI (acceptable daily intake)-value).

For example: diuron is an active substance with a very low ADI-value but the sales figure is high. Based upon those two criteria, the pesticide has been selected. The same exercise has been done for about 400 active ingredients. An overview of the selected pesticides, with the according values for DT50, log K_{ow} and ADI, are given in

Table 7 (all active ingredients have a market of more than 10.000 kg/year).

For the selected pesticides a database will be made containing all representative parameters needed in the transfer model.

Table 7: Selection of pesticides relevant for this study

Active ingredient	*pesticide class*	*persistence (DT50) (days)*	*lipophilicity (log Kow) (-)*	*toxicity (ADI) (mg/kg/day)*
AMITROL	herbicide	0.7	- 0.97	**0.002**
ATRAZINE	herbicide	29	2.6	0.005
BENFLURALIN	herbicide	35.3	**5.29**	0.05
CHLOORPYRIFOS	insecticide	115	**4.82**	0.01
CYPERMETHRIN	insecticide	61	**6.32**	0.05
DICHLOBENIL	herbicide	70	2.7	**0.002**
DIMETHOAAT	insecticide	2.8	0.78	**0.002**
DIURON	herbicide	94	2.81	**0.0007**
ENDOSULFAN	insecticide	50	**4.7**	0.006
FENAMIROL	fungicide	**365**	3.69	0.01
FENTINHYDROXIDE	fungicide	26	4	**0.0005**
FLUAZINAM	fungicide	107	**6.5**	0.004
IMIDACLOPRID	insecticide	**180**	0.57	0.05
LAMBDA-CYHALOTHRIN	insecticide	23	**7**	**0.002**
LENACIL	herbicide	**179**	2.31	0.0125
LINDAAN	insecticide	**365**	3.85	0.001
LINURON	herbicide	**131**	3	0.003
PROSULFOCARB	herbicide	22	**4.65**	0.005
TRITICONAZOOL	fungicide	**292**	3.29	0.02

Remark: The selection criterion (sales figure, persistence, lipophilicity or toxicity) is typed in bold. When pesticide name is written in bold, this means that the selection criterion is sales figure (> 10.000 kg/year). Also the partitioning over the different pesticide classes (herbicide, insecticide, …) is playing a role.

3.2.2.2 Crop models

Based on literature and existing simulation models, a proposal for a model to predict the fate of pesticides in and on crops is made. In literature, a lot of information can be found describing the fate of pesticides in the plant. Based on those studies, a few models have been developed. In most of those models, the fate of pesticides in the environment has been described. This means that the fate of a pesticide in the plant is only a small part of the total study, with as a consequence that in most models, only a few processes are involved.

It is our objective to incorporate the formulas and results, proposed in existing studies and models, into a new model which describes all possible pesticide transfer processes in the plant. After analysing the literature (see reference list under paragraph 5), a proposal for the transfer model is given. At the moment, a model flowchart has been worked out for spraying. It still has to be completed for the other possible application methods (soil treatment, fumigants, …). Furthermore, it is not yet totally complete. In the examined literature, some formulas or data were not available, or different possible calculations were found, so additional study and some experimental work is necessary.

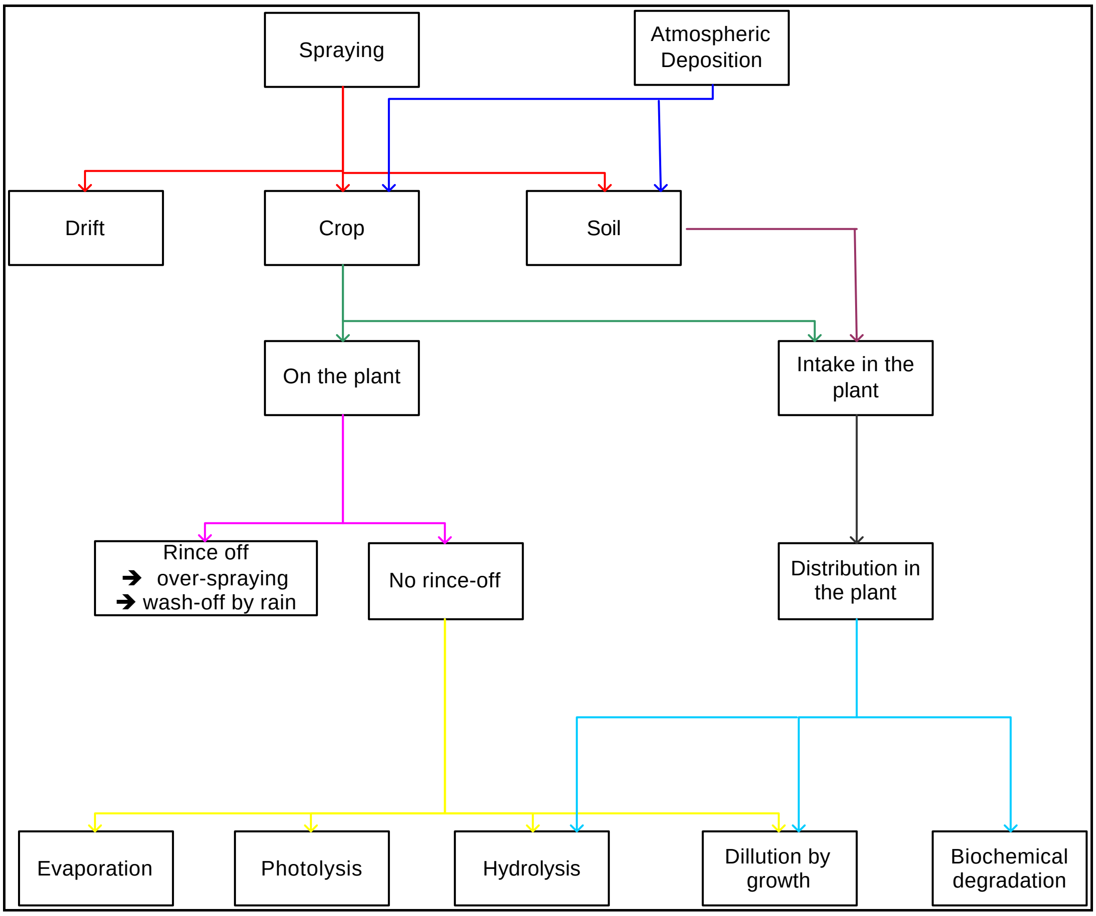

Figure 4: Fate of pesticides in plants

The fate of a pesticide in a plant can be described by a linear first-order differential equation:

$$\frac{dc_p}{dt} = -k\, c_p + J_{in} \qquad (Eq.\ 4)$$

where J_{in}(mg AI/kg plant/day) is the input factor and k is an overall first-order degradation rate constant (d^{-1}). The input factor is given by the amount of active ingredient taken up by roots or deposited on the leaf:

$$J_{in} = \left(\frac{1}{J_{root}} + \frac{1}{J_{leaf}}\right)^{-1} \qquad (Eq.\ 5)$$

The overall pesticide dissipation rate in the plant is determined by diffusion, growth, absorption, transport, wash-off, volatilisation, photodegradation and chemical breakdown (d^{-1}):

$$k_{plant} = \left[\frac{1}{k_{dif}} + \frac{1}{k_{growth}} + \frac{1}{k_{abs}} + \frac{1}{k_{trans}} + \frac{1}{k_{runoff}} + \frac{1}{k_{vol}} + \frac{1}{k_{photo}} + \frac{1}{k_{\deg r}}\right]^{-1} \qquad (Eq.\ 6)$$

The solution of this equation is given by (Trapp, 1995):

$$c_p = c_{p,i} e^{-k_{plant}t} + \frac{J_{in}}{k_{plant}}(1 - e^{-k_{plant}t}) \qquad (Eq.\ 7)$$

where $c_{p,i}$ is the initial plant concentration (mg/kg fw). The value of the influx and degradation factor depends on the part of the plant that is considered. A distinction can be made between:

- *the root zone:*

The input factor is the sum of the amount of active ingredient taken up by the roots and the concentration in the downward sap stream. The degradation factor is the sum of the metabolism factor, the dilution by growth factor and the transport factor from root to stem.

- *the stem:*

The input factor is the sum of the amount of active ingredient brought in by the upward and downward sap stream and taken up from the atmosphere. The degradation factor is the sum of the transport factor from stem to leaf, the transport factor from stem to root, the metabolism factor and the dilution by growth factor.

- *the fruit:*

The input factor is the amount of active ingredient brought in by the upward sapstream. The degradation factor is the sum of the metabolism and the dilution by growth factor.

- *the leave*

Input factor is the sum of the amount of active ingredient brought in by the upward sap stream and the amount penetrated through the leaf surface (absorption). The degradation factor is the sum of the diffusion, metabolism, growth and transfer to stem factor.

- *on the leave*

The input factor is the sum of the amount of active ingredient intercepted by spray application and from atmospheric deposition. The degradation factor is the sum of the growth, the wash-off, the volatilisation, the photolysis, the absorption and the chemical degradation factor.

3.2.2.3 Experimental evaluation

Different plant species will be selected, based on their different shapes, to examine the dilution of pesticide residues by plant growth.

At the moment, very little data are available concerning the decrease of pesticide residues in the fruit and during plant growth. There can be supposed that residues decrease when the fruit grows, due to a "dilution" effect. To examine whether this decrease is important or not, we set up a small experiment to get an idea of the relationship between fruit growth and residue concentration.

Gherkin plants were grown under green house conditions (depth 6.40 m, length 9 m and height 3 m, temperature and air humidity constant at respectively 16°C and 90%). The gherkins were treated once with Decis® (active ingredient: deltamethrin, 25 g a.i./l) with two different techniques:

1) spraying (15 cl/100 m²)

2) vaporizing (40 cl/100 m²)

Gherkin samples were taken at different times and in two different ways:

1) constant size: Samples of gherkins with a normal growth stage (ca 30 – 40 g). This means that, at the moment of treatment, the gherkins had a different size.
2) growing size: Samples of gherkins which had the same size at the moment of treatment. This means that the weight of the gherkins increases each time samples are taken.
The analyses on the "constant size" gherkins were done to investigate the normal breakdown of an active ingredient. When the influence of those processes (volatilization, chemical breakdown,…) is known, the dilution, caused by growth can be measured. This measurement can be carried out by investigation of the "growing size" gherkins. It can be expected that in the "constant size" gherkins, the total amount of residues, expressed in µg/individual an in mg/kg will decrease. In the "growing size" gherkins, the total amount of residues, expressed in mg/kg will decrease, but the amount

expressed in µg/individual will remain constant. Based on those results, a relationship can be set up between the fruit volume and the amount of pesticide residue. The results of the experiment are shown in Table 8.

Table 8: Dilution experiments of deltamethrin in Gherkin plants

			IN THE FRUIT					*ON THE FRUIT*		
treatment	*size*	*day no.*	*weight (g)*	*length (cm)*	*volume (ml)*	*ppm*	*µg/individu*	*radius (cm)*	*area (cm^2)*	*residu (ng/cm^2)*
spraying	normal size	0.5d	35.8	4.7	36	0.078	2.79	1.6	46	61
		1d	35.2	6.8	36	0.052	1.83	1.3	55	33
		2d	42.9	7.5	42	0.036	1.54	1.4	64	24
		3d	43.9	8.7	45	0.025	1.10	1.3	69	16
		4d	46.8	9.0	48	0.021	0.98	1.3	73	13
	growing size	1d	6.5	5.0	7	0.049	0.45	0.6	20	16
		2d	15.5	6.3	16	0.035	0.54	0.9	35	15
		3d	31.0	7.6	31	0.017	0.53	1.1	54	10
		5d	76.6	9.7	82	0.008	0.61	1.6	97	6.3
		7d	56.3	9.8	56	0.002	0.51	1.4	83	1.3
vaporizing	normal size	0.5d	24.3	7.5	24	0.009	0.32	1.0	48	4.6
		1d	25.8	8.1	28	0.013	0.34	1.0	51	6.7
		2d	28.6	8.0	28	0.007	0.21	1.1	54	3.9
		3d	32.3	8.2	30	0.006	0.19	1.1	58	3.3
		4d	35.5	8.4	36	0.004	0.14	1.2	61	2.3
	growing size	1d	6.2	4.9	5	0.019	0.12	0.6	19	6.2
		2d	16.8	6.9	17	0.004	0.06	0.9	38	1.7
		3d	24.7	7.4	25	0.004	0.10	1.0	48	2.1
		5d	46.5	8.9	48	0.001	0.08	1.3	72	0.6
		7d	50.4	9.6	52	0.004	0.11	1.3	78	2.6

The following conclusions can be taken from Table 8:

- Residue-values are remarkably lower at vaporizing.
- It is clear that velocity in the decrease of residue concentration declines much quicker in gherkin samples with growing size than in gherkin samples with normal size. Those results show that a certain dilution occurs. Thus, there is a relation between growth and residue concentration.
- The dilution effect is clear when considering the “growing size”. The concentrations decrease (expressed in ppm or mg/kg) but the total amount of pesticide in the fruit (expressed in µg/individual) stays almost the same.

The experiment is indicative. But it would be interesting to do some other experiments, within the next months with more and different crops. Tomatoes, salad and potatoes are attractive because they have a different shape and possibly a different dilution pattern. Gherkins can be compared with cylinders, tomatoes with balls, potatoes grow under the earth's surface and salad is a leafy vegetable. Most of the fruit and vegetables can be put in one of those classes, so the results of the experiments might be extrapolated to other kinds of fruit and vegetables.

Those future experiments could also be very important in our model. Little data are available concerning plant growth and pesticide dilution, but data are necessary to evaluate and optimize the model.

3.2.3 Cattle models

"Cattle models" include models that calculate contaminant transfer to various animal products, i.e. milk, meat, eggs, organs (liver, kidneys, …). In general, two types of models can describe transfer in cattle: steady state and biokinetic (transient) models (Sweetman et al., 1999). Most exposure models assume steady-state, i.e. the transfer within the animal is fast as compared to transfers in the environment. Feeding studies have shown that the half-life of many persistent organic compounds in milk is about 40-60 days (Olling et al., 1991). Experiments with nonlactating cows show half-lifes of 100-200 days (Richter and McLachlan, 2001). Under normal agricultural conditions of a constant feed for several weeks to months, the steady-state assumption may be valid. In case of incidents with a short release of a large amount of contaminant, kinetic models with a time scale of about 1 day will be necessary to adequately predict the concentration in the animal tissues. Other factors determining whether an animal is in steady-state, are farming practice and lactation state of the cow.

3.2.3.1 Steady-state models

In case steady-state is valid, transfer can be calculated using transfer factors assuming equilibrium between contaminant sources (soil, water, grass, silage, supplement) and animal products. The most commonly used steady-state models for the prediction of concentrations in animal products are bioconcentration factors and biotransfer factors (Stevens, 1991;1992; McLachlan, 1992; Sweetman et al., 1999). The bioconcentration factor (BCF) is defined as the ratio between the contaminant concentration in the animal tissue of interest and the concentration in the contaminant source (grass, silage, supplement …). The biotransfer factor (BTF) is defined as the ratio between the contaminant concentration in the animal tissue of interest and the contaminant intake flux. Both factors are related through:

$$BTF = \frac{BCF}{q} \qquad (Eq.\ 8)$$

where q is the feed intake rate (kg d^{-1}).

A specific transfer factor is the carry-over rate (COR). The dimensionless COR is defined as the ratio between the contaminant flux in the animal product and the contaminant flux in the feed. The assumed advantage of a COR over a BCF or BTF is that it takes into account both feed intake and product output and therefore is less prone to variation and uncertainty. Thomas et al. (1999) found a relative standard deviation in COR values of 17-35% between five cows in a controlled feeding experiment. The same authors (Thomas et al., 1998) showed however that variation in BCFs and CORs in a farm survey study in NW-England was similar. BCFs, and to a lesser extent BTFs, are believed to be more variable because variations in input (grass intake) and/or output fluxes (milk production) are not accounted for.

In literature, various relationships between transfer factors and properties of the chemicals were established. A notable example is the work of Travis and Arms (1988), relating the BCF of organic compounds to the n-octanol/water partition coefficient K_{ow} (implemented in EUSES, 1997):

$$\begin{aligned} \log BCF_{meat} &= -7.6 + \log K_{ow} \\ \log BCF_{milk} &= -8.1 + \log K_{ow} \end{aligned} \qquad (Eq.\ 9)$$

The relationship is valid for compounds with log K_{ow} values between 3 and 6.5. Eq. 9 suggests that transfer to milk is directly related to lipophilicity of the compound. Based on a fugacity-based three-compartiment model for lactating cows, McLachlan (1994) derived relationships between the maximum fraction absorbed E_M (for labile contaminants) and K_{ow}, and between the fraction absorbed E_o (for persistent contaminants showing no transformation or metabolisation) and K_{ow}:

$$\begin{aligned} \frac{1}{E_M} &= 1.2 + 2.875e-8 \cdot K_{ow} \\ \frac{1}{E_o} &= 1.283 + 2.875e-8 \cdot K_{ow} \end{aligned} \qquad (Eq.\ 10)$$

The parameters of Eq. 10 were obtained by fitting the model to data of a mass-balance study of a lactating 4-year-old Simmenthal cow. For persistent compounds, the fraction absorbed E_o is equivalent to the carry-over rate. Eq. 9 implies that the carry-over rate of persistent organic contaminants is independent of K_{ow} over a broad range. For very hydrophobic compounds such as PCDD and TCDD-congeners (log K_{ow} 6-8) the COR decreases with K_{ow}. This means that the approach of Travis and Arms (1988) is not valid for very hydrophobic compounds. An overview of BCFs, BTFs and CORs for organic contaminants is given in the Annex, together with a detailed discussion of biotransfer of heavy metals.

3.2.3.2 Biokinetic (dynamic) models

Under certain circumstances, the steady-state assumption may not be valid, e.g., for transfers in cows that take longer times than the time of exposure (as might be the case in nonlactating cows) or in case the exposure changes rapidly in time (incidents, sudden changes in emission rates). To account for this status of nonequilibrium, dynamic models have been developed. McLachlan (1994) presented a fugacity-based model consisting of three compartments, i.e. the gastro-intestinal tract, blood and fat deposits. Data from a PCB clearance experiment were used to parametrise the model. Freijer et al. (1999), based on earlier work of Olling et al. (1991; 1995), presented their Physiologically Based PharmacoKinetic (PBPK) model for lipophilic contaminants in domestic animals. The model was parametrised using concentration data of an injection experiment of 2378-TCDD into the rumen of lactating and nonlactating cows. Concentration measurements were used to estimate the initial body burden and the daily absorption.

4 FUTURE PROSPECTS AND FUTURE PLANNING

4.1 Year 2003

The transfer model will be further refined with respect to atmosphere-soil and atmosphere-plant interactions. Thusfar, a generic term for atmospheric deposition was used to estimate the input to the soil. Based on the behaviour of the compound in the atmosphere, a distinction between different types of deposition, i.e., dry gaseous, wet deposition, dry particle-bound deposition, will be made. Specific attention will be paid to the interaction with the plant canopy.

The mathematical coupling between the (dynamic) soil model, the (steady state) plant model and the (steady state) cattle model will be made. For specific scenarios, biokinetic models will be further reviewed. Biokinetic models will be programmed as an add-in to the transfer model.

Data will be gathered on soil properties of the 14 Belgian agricultural areas, on the Belgian farming systems (dairy farms, mixed farms, crop production farms, animal housing, manure book keeping…), on specific animal properties (body weight, fat content, milk and meat production) and crop properties related to soil (plant production, water transpiration, irrigation requirements, …), on local and regional atmospheric contaminant emissions/deposition, and on available measured contaminant concentrations in various matrices (feed, grass, soil, milk, meat, eggs, …).

Also the development of the impact analysis model (human exposure, human health effects, and cost modelling) will start in the second half of 2003. The first steps in coupling the transfer and the impact analysis modules into the integrated XtraFOOD model will be made .

4.2 Year 2004-2005

The impact analysis module will be further refined and XtraFOOD will be fully programmed. XtraFOOD will be demonstrated for the selected pesticides, cadmium and dioxins. The results will be evaluated against available measured data. The results will be fed back to the model formulations and parameter values to optimize the model predictions.

5 ANNEXES

5.1 References

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5.2 Publications (submitted)

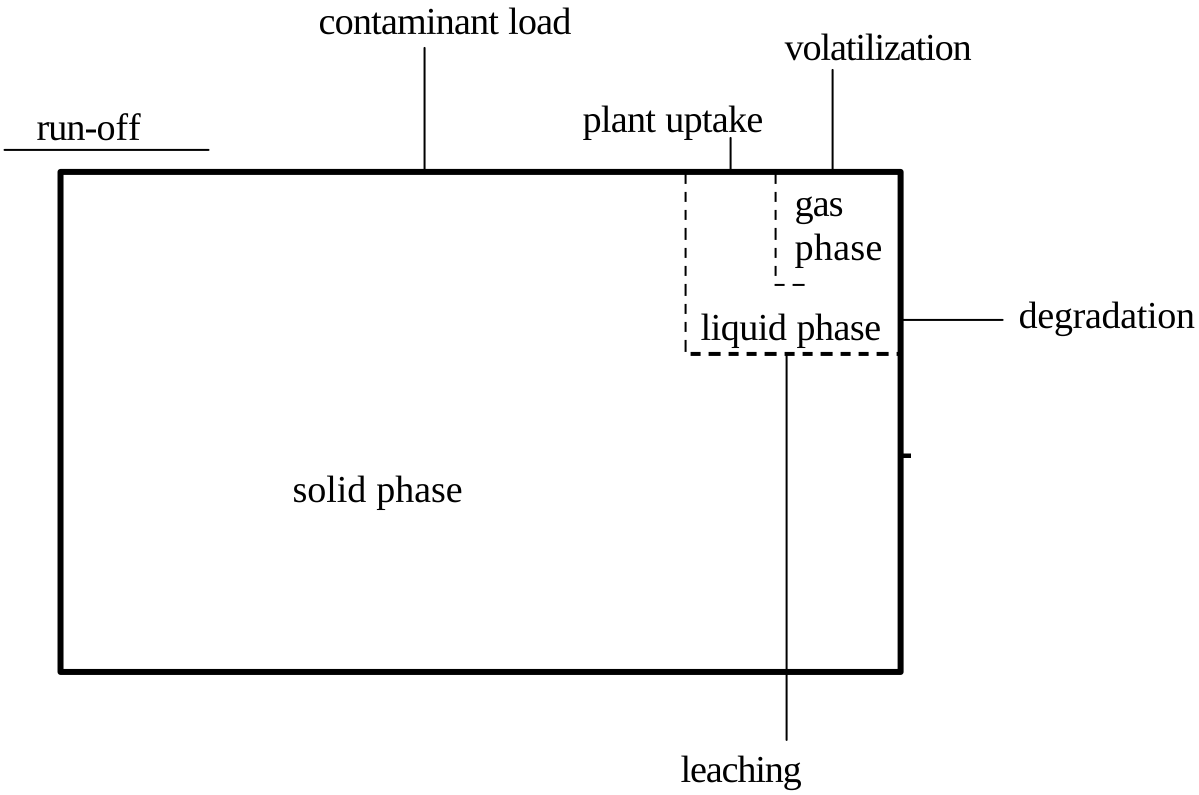
Seuntjens, P., Cornelis, C., Claeys, S., Ruttens, A., Steurbaut, W. and J. Vangronsveld. XtraFOOD: A model for the impact analysis of contaminants in primary food production. Abstract submitted to SETAC Europe 13th annual meeting, Hamburg, 2003.

Seuntjens, P., Cornelis, C., Claeys, S., Ruttens, A., Steurbaut, W. and J. Vangronsveld. XtraFOOD: An impact analysis model for contaminants in primary food production. Abstract submitted to EuroFoodChem XII conference, Bbackge, 2003.

5.3 Detailed results

5.3.1 Soil model

Various soil models are available for the calculation of contaminant behaviour and transport in the soil-plant-atmosphere environment. For the prediction of contaminant transfer from soil to human products, soil models that predict contaminant accumulation are needed (with a time scale in the order of months to years). For this purpose, the soil accumulation model of Vissenberg and van Grinsven (1995) was used. The model accounts for the distribution of chemicals between the gaseous, liquid and solid phase, as well as for plant uptake, volatilization, degradation and leaching. The model is not suitable for mobile contaminants that are transferred relatively fast in soil due to leaching, degradation or volatilization (time scale in the order of days or weeks). Figure A.1 shows the various processes that occur in soils.



The contaminant concentrations within a single homogeneous soil compartment are described by a linear first-order differential equation of the form:

$$\frac{dc}{dt} = -kc + I \qquad \text{(Eq. A.1)}$$

where c is the total concentration in soil (mg kg^{-1}), k is the overall first-order rate coefficient (yr^{-1}), and I is the contaminant load to the soil (mg kg^{-1} yr^{-1}). The total soil concentration is the sum of the amount of contaminant in the solid, liquid and gas phase:

$$rc = q_w c_w + r c_s + q_a c_a \qquad \text{(Eq. A.2)}$$

where r is the bulk soil density (kg m^{-3}), c is the total contaminant concentration in soil (mg kg^{-1}), θ_w is the volumetric water content (m^3 m^{-3}), c_w is the contaminant concentration in soil water (mg m^{-3}), c_s is the contaminant concentration in the soil solid phase (mg kg^{-1}), θ_a is the volumetric air content (m^3 m^{-3}), and c_a is the contaminant concentration in the soil air phase (mg m^{-3}). Phase transition between water and solid phase (sorption) and between water and air phase (volatilization) is modeled using distribution coefficients:

$$K_d = \frac{c_s}{c_w} \qquad \text{(Eq. A.3)}$$

$$H' = \frac{c_a}{c_w} = \frac{K_H}{RT} \qquad \text{(Eq. A.4)}$$

where K_d is the soil-water distribution coefficient (m^3 kg^{-1}), H' is the air-water distribution coefficient (m^3 m^{-3}), K_H is the Henry coefficient (Pa m^3 mol^{-1}), R is the universal gas constant (Pa m^3 mol^{-1}K^{-1}), and T is the absolute temperature (K).

The analytical solution of Eq. A.1 is given by:

$$c = c_i e^{-kt} + \frac{I}{k}(1 - e^{-kt}) \qquad \text{(Eq. A.5)}$$

where c_i is the initial total contaminant concentration (mg kg^{-1}), and t is time (yr). Eq. 2 shows that the predicted concentration is independent of space and valid for a known volume of soil. The model further assumes that contaminants are completely mixed in the soil. Contaminants are lost from the soil by a series of transport (advective solute leaching, diffusive volatilisation, run-off, root uptake) and transformation (degradation) processes that can be represented mathematically as first-order losses. The overall rate coefficient k in Eq. A.1 is the sum of the individual first-order rate coefficients:

$$k = k_v + k_r + k_p + k_b + k_l \qquad \text{(Eq. A.6)}$$

where k_v is the volatilisation coefficient (yr^{-1}), k_r is the run-off coefficient (yr^{-1}), k_p is the root-uptake coefficient (yr^{-1}), k_b is the degradation coefficient (yr^{-1}), and k_l is the leaching rate coefficient (yr^{-1}).

The volatilisation coefficient is given by:

$$k_v = 2\frac{D_{eff}}{d^2} \frac{q_a H'}{(rK_d + q_w + q_a H')} \qquad \text{(Eq. A.7)}$$

where d is the thickness of the soil profile (m) and D_{eff} is the effective diffusion coefficient in soil air (m^2 yr^{-1}):

$$D_{eff} = \frac{q_a^{10/3}}{q_s^2} D_a \qquad \text{(Eq. A.8)}$$

where θ_s is the saturated volumetric water content or porosity (m^3 m^{-3}), and D_a is the molecular diffusion coefficient in air (m^2 yr^{-1}).

The run-off coefficient k_r is given by:

$$k_r = \frac{A}{rd} \qquad \text{(Eq. A.9)}$$

where A is the erosion soil loss (kg m^{-2} yr^{-1}). The soil loss may be calculated using the Universal Soil Loss Equation (Wishmeier and Smith, 1965):

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$ (Eq.
A.10)

where R is the rainfall-run-off erosivity factor, K is the soil erodibility factor, L is the slope-length factor, S is the slope steepness factor, C is the cover management factor, and P is the support practice factor. An extensive use of the USLE is beyond the scope of this project. Therefore, calculated soil losses for various combinations of soil and land-use types in the Belgian agricultural system will be used to determine the run-off coefficient.

The root-uptake coefficient k_p is given by:

$$k_p = BCF \cdot \frac{Y}{rd}$$ (Eq.
A.11)

where BCF is the crop bioconcentration factor (kg $\mathrm{kg^{-1}}$) and Y is the crop yield (kg $\mathrm{m^{-2}}$ $\mathrm{yr^{-2}}$). Estimation procedures of crop BCFs are described in detail in the plant uptake section.

The degradation constant k_b is readily equivalent to the first-order biodegradation constant obtained in degradation experiments. Care should be taken to convert from a degradation constant k_w obtained in water to a degradation constant k_b based on total concentration:

$$k_b = k_w \frac{q}{q + rK_d + q_a H'}$$ (Eq.
A.12)

Finally, the leaching coefficient is given by:

$$k_l = \frac{q}{d} \frac{1}{(q + rK_d + q_a H')}$$ (Eq.
A.13)

where q is the infiltration rate (m $\mathrm{yr^{-1}}$).

5.3.2 XtraFOOD framework

The soil model is embedded in a spreadsheet environment which will later be used for modeling the whole agro-ecosystem in XtraFOOD. Data feeding the soil model are provided in individual sheets:

Spreadsheet 1. contaminant properties (listed per contaminant)
-molecular weight
-vapour pressure
-solubility
-diffusion coefficient in air
-diffusion coefficient in water
-Henry constant
-degradation constant
-octanol-water distribution coefficient
-organic carbon water distribution coefficient
-soil-water distribution coefficient

Spreadsheet 2: soil properties and land-use properties (listed per agricultural region)
-depth of soil profile
-soil bulk density
-fraction organic carbon
-porosity
-water content
-air content
-crop production
-run-off
-evapotranspiration
-irrigation requirement

Spreadsheet 3: farm properties (listed per type of farm and per agricultural region)
-number of animals
-agricultural area
-manure export/import

Spreadsheet 4: cattle properties
-age
-weight
-animal production (meat, eggs, milk)
-fat fractions (meat, milk, eggs)
-animal diet (winter, summer)
-time fractions inside/outside
-manure production
-drinking water consumption

Spreadsheet 5: measured concentrations in various matrices
-soil
-feed
-sludge
-compost
-water
-milk
-meat
-grass
-manure

Besides the soil transfer module, which includes transfer in plants, separate sheets are programmed containing transfer in atmosphere, transfer in cattle and transfer in the whole agro-ecosystem. Mass-balance evaluations are made in the soil module and the agro-ecosystem module.

5.3.3 Fate of pesticide in the plant after spray application

The fate of a pesticide in a plant, can be described by a lineair first-order differential equation :

$$\frac{dc_p}{dt} = -k_{plant}\, c_p + J_{in} \qquad \text{(Eq. A.14)}$$

where J_{in} (mg AI/kg plant/day) is the input factor and k is an overall first-order degradation rate constant (d^{-1}). The input factor is given by the amount of active ingredient taken up by roots or deposited on the leaf:

$$J_{in} = \left(\frac{1}{J_{root}} + \frac{1}{J_{leaf}} \right)^{-1} \qquad \text{(Eq. A.15)}$$

The overall pesticide dissipation rate in the plant is determined by diffusion, growth, absorption, transport, wash-off, volatilisation, photodegradation and chemical breakdown (d^{-1}):

$$k_{plant} = \left(\frac{1}{k_{diff}} + \frac{1}{k_{growth}} + \frac{1}{k_{abs}} + \frac{1}{k_{trans}} + \frac{1}{k_{wash-off}} + \frac{1}{k_{vol}} + \frac{1}{k_{photo}} + \frac{1}{k_{\deg r}} \right)^{-1} \qquad \text{(Eq. A.16)}$$

The solution of this equation is given by (Trapp; 1992) :

$$c_p = c_{p,i} e^{-k_{plant}t} + \frac{J_{in}}{k_{plant}} \left(1 - e^{-k_{plant}t}\right) \qquad \text{(Eq. A.17)}$$

where $c_{p,i}$ (mg AI/kg plant) is the initial pesticide residue concentration in the plant.

5.3.3.1 Pesticide concentration in the plant at time t = 0

At the moment the spray application starts, pesticide residues reach the ground and the plant leaf. The initial pesticide concentration in the plant is given by:

$$c_{p,i} = c_{root,i} + c_{leaf,i} \qquad \text{(Eq. A.18)}$$

where $c_{root,i}$ (mg AI/kg plant) is the initial pesticide concentration in the plant roots and $c_{leaf,i}$ (mg AI/kg plant) is the initial leaf deposited pesticide concentration. Due to the time delay, the initial pesticide root concentration will be 0. The initial pesticide concentration on the leaves can be calculated by:

$$c_{leaf,,i} = \frac{c_{form} * dose * F_{crop}}{B_0 * 10000} \qquad \text{(Eq. A.19)}$$

where c_{form} (mg AI/l) is the concentration active ingredient in the formulation, *dose* (l/ha) is the amount of formulation sprayed, F_{crop} is the crop interception ratio and B_0 (kg plant/m²) is the initial plant biomass.

5.3.3.2 Fate of pesticides in the root

The input factor is given by (Briggs, 1982):

$$J_{in} = \frac{Q_w * RCF * c_{sw}}{V_r}$$ (Eq. A.20)

where Q_w (m^3/d) is the plant transpiration rate, RCF (-) is the root concentration factor ($RCF = 10^{(0.77 \log K_{ow} - 1.52)} + 0.82$ with K_{ow} the octanol/water partition coefficient), V_r (m^3) the root volume and c_{sw} (mg AI/kg) is the concentration pesticide residue in the soil water, which can be given by:

$$c_{sw} = c_{sw,i} e^{-k_{root} t}$$ (Eq. A.21)

where (Schwarzenbach, 1981):

$$c_{sw,i} = \frac{c_{soil}}{K_d * r_{soil} + q + (s - q) * K_{aw} * f}$$ (Eq. A.22)

where c_{soil} (mg AI/kg) the amount of pesticide intercepted by soil at the time of spraying (= c_{form} **dose * (1-F_{crop}))*, r_{soil} (kg/m^3) is the soil density, q (-) is het volumetric soil watercontent, f (-) is the amount of neutral molecules in the soil, s (-) is the soil pore fraction K_{aw} (-) is the air/water partition coefficient and K_d (-) is the water/organic matter partition coefficient, which can be calculated by (Benzler;1982):

$$K_d = OC * K_{oc}/100 * \phi$$ (Eq. A.23)

where OC (-) is the amount of organic carbon in the soil (= *organic material*0.58)* and K_{oc} is the water/organic carbon partition coefficient.

The output factor is given by:

$$k_{root} = \left(\frac{1}{k_{growth}} + \frac{1}{k_{trans}} + \frac{1}{k_{degr}} \right)^{-1}$$ (Eq. A.24) with:

$$k_{growth} = \frac{\ln 2}{t_{*2}}$$ (Eq. A.25)

where t_{*2} (d) is the root volume doubling time.

$$k_{trans} = Q_w * TSCF * V_s^{-1}$$ (Eq. A.26)

where $TSCF$ (-) is the transpiration stream concentration factor (= $0.784 * \exp(-(\log K_{ow} - 1.78)^2/2.44)$) (Briggs; 1982) and V_s (m^3) is the stem volume.

$$k_{degr} = \frac{\ln 2}{t_{1/2}}$$ (Eq. A.27)

where $t_{1/2}$ (d) is the half-life time in the plant.

5.3.3.3 Fate of pesticides in the stem

The stem input factor is given by

$$J_{in} = \left(\frac{1}{J_{root/stem}} + \frac{1}{J_{leaf/stem}} + \frac{1}{J_{atm/stem}} \right)^{-1}$$ (Eq. A.28)

with (Briggs;1983)

$$J_{root/stem} = \frac{Q_w * TSCF * C_r}{V_s}$$ (Eq. A.29)

where Q_w (m^3/d) is the plant transpiration rate, $TSCF$ (-) is the Transpiration Stream Concentration Factor, C_r (mg AI/kg plant) is the concentration active ingredient in the root and V_s (m^2) is the stem volume.

$$J_{atm/stem} = \frac{Q_s * SCF * c_{atm} * 1E6}{V_s * r_{air}}$$ (Eq. A.30)

where Q_s (m^3/d) is the downward sap stream, SCF (-) is the Stem Concentration Factor, c_{atm} (mg AI/m^3) is the amount of active ingredient in the atmosphere, V_s (m^3) is the stem volume and r_{air} (kg/m^3) is the air density.

The stem output factor is given by this equation:

$$k = \left(\frac{1}{k_{stem/leaf}} + \frac{1}{k_{stem/fruit}} + \frac{1}{k_{degr}} + \frac{1}{k_{growth}} \right)^{-1}$$ (Eq. A.31)

with

$$k_{stem/leaf} = Q_w * TSCF * V_{leaf}^{-1}$$ (Eq. A.32)

$$k_{stem/fruit} = Q_w * TSCF * V_{fruit}^{-1}$$ (Eq. A.33)

$$k_{degr} = \frac{\ln 2}{t_{1/2}}$$ (Eq. A.34)

$$k_{growth} = \frac{\ln 2}{t_{*2}}$$ (Eq. A.35)

where Q_w (m^3/d) is the plant transpiration rate, $TSCF$ (-) is the Transpiration Stream Concentration Factor and V_{leaf} (m^3) is the plant leaf volume, V_{fruit} (m^3) is the fruit volume, $t_{1/2}$ (d) is the half-life time in the plant and t_{*2} (d) is the fruit volume doubling time.

5.3.3.4 Fate of pesticides in the fruit

The input factor is given by

$$J_{in} = J_{stem/fruit} = \frac{Q_w * TSCF * c_s}{V_f}$$ (Eq. A.36)

where Q_w (m³/d) is the plant transpiration rate, *TSCF* (-) is de Transpiration Stream Concentration Factor, c_s (mg AI/kg plant) is the concentration of active ingredient in the stem and V_f (m³) is the fruit volume.

The output factor is given by

$$k = \left(\frac{1}{k_{\deg r}} + \frac{1}{k_{growth}} \right)^{-1}$$ (Eq. A.37)

with

$$k_{degr} = \frac{\ln 2}{t_{1/2}}$$ (Eq. A.38)

$$k_{growth} = \frac{\ln 2}{t_{*2}}$$ (Eq. A.39)

where $t_{1/2}$ (d) is the half-life time in the plant and t_{*2} (d) is the fruit volume doubling time.

5.3.3.5 Fate of pesticides in the leaf

The input factor is given by:

$$J_{in} = \left(\frac{1}{J_{stem/leaf}} + \frac{1}{J_{abs}} \right)^{-1}$$ (Eq. A.40)

with:

$$J_{stem/leaf} = \frac{Q_w * TSCF * c_s}{V_l}$$ (Eq. A.41)

J_{abs} = +/- 20% of the total deposited volume

where Q_w (m³/d) is the plant transpiration rate, *TSCF* (-) is the Transpiration Stream Concentration Factor, c_s (mg AI/kg) is de concentration active ingredient in the stem and V_l (m³) is the leaf volume.

The output factor is given by:

$$k = \left(\frac{1}{k_{ditt}} + \frac{1}{k_{\deg r}} + \frac{1}{k_{leaf/stem}} + \frac{1}{k_{growth}} \right)^{-1}$$ (Eq. A.42)

with:

$$k_{dif} = \frac{A_l * G}{K_{la} * V_l}$$ (Eq. A.43)

$$k_{degr} = \frac{\ln 2}{t_{1/2}}$$ (Eq. A.44)

$$k_{growth} = \frac{\ln 2}{t_{*2}}$$ (Eq. A.45)

$k_{leaf/stem}$ = ??

where A_l (m²) is the leaf area, G (m/d) is the leaf conductivity, K_{la} (-) is the leaf/air partition coefficient, V_l (m³) is the leaf volume, $t_{1/2}$ (d) is the half-life time in the plant and t_{*2} (d) is the leaf volume doubling time.

5.3.3.6 Fate of pesticides on the leaf

The leaf input factor can be given by:

$$J_{in} = \left(\frac{1}{J_{interception}} + \frac{1}{J_{atmosphericdeposition}} \right)^{-1}$$ (Eq. A.46)

where $J_{interception}$ (mg AI/kg/d) is equal to $c_{leaf,i}$ and $J_{atmosphericdeposition}$ (mg AI/kg/d) is set zero in this situation.

The leaf output factor is given by

$$k = \left(\frac{1}{k_{growth}} + \frac{1}{k_{washoff}} + \frac{1}{k_{vol}} + \frac{1}{k_{photo}} + \frac{1}{k_{abs}} + \frac{1}{k_{met}} \right)^{-1}$$ (Eq. A.47)

with:

$$k_{growth} = \frac{\ln 2}{t_{*2}}$$ (Eq. A.48)

$$k_{washoff} = \frac{GC * Q}{V_l * K_{ow}}$$ (Charles, 2001) (Eq. A.49)

$$k_{vol} = \frac{LAI * j * K_{aw}}{V_l * K_{ow}}$$ (Charles, 2001) (Eq. A.50)

$$k_{degr} = \frac{\ln 2}{t_{1/2}}$$ (Eq. A.51)

$$k_{photo} = \frac{\ln 2}{t_{1/2photo}}$$ (Eq. A.52)

k_{abs} = ???

where t_{*2} (d) is the leaf volume doubling time, GC (m² plant/m² soil) is the leaf ground cover, Q (m³ rain/m² leaf/d) is the daily precipitation, V_l (m³) is the leaf volume, K_{ow} (-) is the octanol/water partition coefficient, LAI (m² leaf/m² soil) is the Leaf Area Index, j (m/s) is the mean wind velocity, K_{aw} (-) is the air/water partition coefficient, K_{ow} (-) is the octanol/water partition coefficient, $t_{1/2}$ (d) is the half-life time in the plant and $t_{1/2photo}$ (d) is the half-life time of the pesticide due to photodegradation.

Additional calculations

$G = G_c + G_s$ (Eq. A.53)

with: G_c = conductivity of the cuticula
$= (1/G_k + 1/G_a)^{-1}$

$$G_k = \frac{10\wedge(0.704\log Kow - 11.2)}{Kaw * j}$$ (Riederer, 1990) (Eq. A.54)

with: Kow = octanol/water partition coefficient
Kaw = air/water partition coefficient
φ = wind velocity (m/s)

$$G_a = 5^E\text{-}3 * \sqrt{\frac{300g/mol}{M}}$$ (Eq. A.55)

with: M = molar weight AI (g/mol)

$$G_s = \text{conductivity of the stomata} = \frac{1000 * Qw}{dws - dws * h} * \sqrt{\frac{18g/mol}{M}}$$ (Trapp, 1995) (Eq. A.56)

with: Qw = transpiration ratio (m³/d)
h = air humidity
M = molar weight AI (g/mol)

$$dws = \text{saturated air pressure} = \frac{610.7 * 10\wedge\left(\frac{7.5 * (T - 273.15)}{273 + (T - 273.15)}\right)}{Rw * T}$$ (Eq. A.57)

with: Rw = gas constant
T = temperature (K)

$LAI = 0.5 * SA_l * GC$ (Luedeke et al., 1994) (Eq. A.58)

with: SA_l = specific leaf area (m²)
GC = Ground Cover (m² leaf/m² soil)

5.3.4 Transfer of heavy metals in cattle

Heavy metals can be transferred into the food chain by various routes. Primary products as milk, meat, eggs and plants can be contaminated by: soil, air, feed or drinking water. Transfer to cattle from dermal contact is considered to be of no significance (Derks, 1995). The chain model developed by van Hooft (1995) shows that uptake of the elements Cd, Pb, As, Hg, Cu and Zn by cattle results mainly from consumption of feed and ingestion of adhered soil (in case of grazing).

Toxicity and metabolism of metals is influenced by a number of factors, the importance of each of these factors depends on the metal species. Stock, sex, age, milk production, faeces production, metal interactions and diet can influence absorption and accumulation. Most studied is the interaction between essential and toxic metals. The influence of age is subject of recent attention; influence of sex can be important, but information is scarce (Miranda, 2000).

The transfer of trace elements to meat and milk from consumption of feed (and adhering soil) is influenced by a number of factors (Derks, 1992):

- chemical form of the trace element;
- matrix in which the trace element is found (soil or feed);
- concentration of the trace element;
- exposure duration;
- exposure pattern (time between non-continuous exposures);
- synergetic/antagonistic effects of other trace elements or compounds in the diet;
- demand for food;
- pharmacokinetic processes.

The text considers the transfer of a number of trace elements to meat and milk of cattle. A comparison between a number of transfer models is made.

5.3.4.1 Comparison of exposure models and literature data

- *Biotransfer and bioconcentration factors*

Two types of factors are commonly used to quantify the transfer of elements to meat and milk: biotransfer factors (BTFs) and bioconcentration factors (BCFs). They give the relation between the daily exposure dose or the concentration in feed and the concentration in animal tissues.

Following factors can be defined:

- *transfer to muscles, kidneys and liver:*

BTF [d/kg ww]: concentration in tissue [mg/kg ww]/ average daily dose [mg/d];

BCF [kg dw/kg ww]: concentration in tissue [mg/kg ww]/average concentration in feed [mg/kg dw].

- *transfer to milk:*

BTF [d/l]: concentration in milk [mg/l]/average daily dose [mg/d];

BCF [kg dw/l]: concentration in milk [mg/l]/average concentration in feed [mg/kg dw].

Tissue concentrations are expressed on a wet weight basis [mg/kg ww]; feed concentrations are expressed on a dry weight basis [mg/kg dw]. The relationship between BTF and BCF can be expressed as:

$$BTF = \frac{BCF}{q}$$ (Eq. A.59)

where q is the daily feed intake on dry weight basis [kg dw/d].

- *IAEA (International Atomic Energy Agency) model*

Spadaro and Rabl (2002) developed a multimedia model on the models and model parameters of IAEA (1994, 2001) for the calculation of the health impact of metal emissions. Assumptions are linear dose-response relations and steady-state conditions As the model is developed for the quantification of radiological impacts and radiation dose is independent from speciation, speciation is not accounted for. The model calculates concentrations in meat and milk using the equation:

$$C_{meat} = f_{meat} \times (C_{veg,feed} \times R_{feed} + C_{water} \times R_{wat,feed})$$ (Eq. A.60)

and:

$$C_{milk} = f_{milk} \times (C_{veg,\, feed} \times R_{feed} + C_{water} \times R_{wat,\, feed})$$ (Eq.A.61)

where:

C_{milk} is the concentration in milk [$\mathrm{kg/kg_{milk}}$];
$C_{\mathrm{veg,feed}}$ is the concentration in feed [$\mathrm{kg/kg_{feed}}$];
$C_{\mathrm{wat,feed}}$ is the concentration in water [$\mathrm{kg/kg_{water}}$];
R_{feed} is the daily feed intake [$\mathrm{kg_{feed,dw}/d}$];
$R_{\mathrm{wat,feed}}$ is the daily water intake [$\mathrm{kg_{water}/d}$];
f_{milk} is the transfer factor for milk [$\mathrm{d/kg_{milk}}$];
f_{meat} is the transfer factor for meat [$\mathrm{d/kg_{meat}}$].

Daily feed and water consumption for milk and meat production are given in Table A. 1. Table A. 2 gives the biotransfer factors used in the Spadaro-Rabl model.

Table A. 1: Daily feed and water consumption (Source: IAEA, 2001; Spadaro and Rabl, 2002).

Coefficient	**cattle milk production**	**cattle meat production**
R_{feed} [$\mathrm{kg_{feed,dry}/d}$]	16	12
$R_{\mathrm{wat,feed}}$ [$\mathrm{kg_{water}/d}$]	60	40

Table A. 2: Transfer factors for cattle (Source: IAEA, 1994, 2001; Spadaro and Rabl, 2002).

Metal	**f_{meat} [$\mathrm{d/kg_{meat}}$]**	**f_{milk} [$\mathrm{d/kg_{milk}}$]**
As	0.02^{b}	0.0001^{b}

Cd	0.0004[a] (0.001[b])	0.02[b]
Cr	0.009[a] (0.09[b])	0.00001[a] (0.0002[b])
Pb	0.0004[a] (0.0007[b])	0.0003[b]
Hg	0.01[b]	0.00047[a] (0.0005[b])
Cu	0.009[a] (0.01[b])	0.002[b]
Ni	0.005[a] (0.05[b])	0.016[a] (0.2[b])
Zn	0.1[a] (0.2[b])	0.01[b]

[a] IAEA, 1994

[b] IAEA, 2001

Spadaro and Rabl prefer the values from IAEA (1994) because these represent “expected” values. These transfer factors are derived from (radionuclide) transfer experiments, stable concentrations in feed and animal tissue, extrapolations from tracer tests after single dosing, comparison of concentration in meat and milk whether or not directly associated with concentrations in provided feed, and data of other animal species (IAEA, 1994). Values from IAEA (2001) are more conservative and better suited for worst-case approaches. In general exposure doses will be more overestimated and it is expected that real doses are underestimated with more than a factor of 10 (IAEA, 2000). Spadaro and Rabl (2002) only give BTFs for As, Cd, Cr, Pb and Ni. IAEA gives values for Zn and Cu as well.

5.3.4.2 Comparison of experimental data with modelling approaches

Stevens (1991, 1992) collected and processed primary literature data of (predominantly long term) studies and oral bolus experiments and transferred them to BTFs for muscular tissue, kidneys, liver and milk. It is assumed that metal accumulation follows a first-order kinetic process. Transfer under steady-state conditions (and continuous exposure) can then be expressed by a chemical half- life value. Equilibrium conditions are assumed if the duration of the study amounts to at least 7 times the reported biological half life. If the exposure duration is less of if oral administration via bolus is applied, conversion equations were used to transfer the results to steady-state conditions.

The studies of Stevens (1991, 1992) refer most to experiments in which metals were administered in soluble form. In general soluble metal salts are more available for uptake by the body than slightly soluble species; metals in feed are considered to be more available for uptake than in they are present in feed. The calculated BTFs and BCFs are considered to be upper limits (i.e. they represent conservative values when used for estimating transfer to meat and milk). According to the author the BTFs for liver and kidney of cattle are the first quantitative data published.

A comparison between transfer factors from literature and the values that are obtained from model calculations are given in Table A. 3 and Table A. 4. The data of Stevens for transfer to kidney and liver are given in

Table A. 5, whereas Table A. 6 to Table A. 11 give published data on concentrations of As, Cd, Pb, Hg, Cu and Zn reported to be found in liver, kidneys and muscular tissue of cattle.

Table A. 3: Comparison between literature data and model calculations for BTF_{muscle}

Metal	**BTF_{muscle} [d/kg ww]**	
	Literature (Stevens, 1992)	**IAEA** (Table A. 2)
As	$1.3\ 10^{-3}$ $[(0.5\text{-}2.4)\ 10^{-3}]$	$2\ 10^{-2}$ (b)
Cd	$1.7\ 10^{-4}$	$4\ 10^{-4}$ (a) $1\ 10^{-3}$ (b)
Cr	$1.9\ 10^{-3}$ §	$9\ 10^{-3}$ (a) $9\ 10^{-2}$ (b)
Pb	$6.7\ 10^{-5}$	$4\ 10^{-4}$ (a)

		$7\ 10^{-4}$ (b)
Hg	$3.5\ 10^{-4}$ $[(1.8\text{-}4.4)\ 10^{-4}]$	$1\ 10^{-2}$ (b)
Cu	-	$9\ 10^{-3}$ (a) $1\ 10^{-2}$ (b)
Ni	$3.8\ 10^{-4}$ #	$5\ 10^{-3}$ (a) $5\ 10^{-2}$ (b)
Zn	-	$1\ 10^{-1}$ (a) $2\ 10^{-1}$ (b)

(a): IAEA, 1994; (b): IAEA, 2001;
#: calculated from BCF; §: speciation unknown.

Table A. 4: Comparison of literature data and model calculations for BTF_{milk}

Metal	**BTF_{milk} [d/l]**	
	Literature (Stevens, 1992)	**IAEA (Table A. 2)**
As	$3.0\ 10^{-5}$ As(III)	$1\ 10^{-4}$ (b)
Cd	$1.3\ 10^{-6}$	$2\ 10^{-2}$ (b)
Cr	$1.4\ 10^{-5}$ Cr(VI)	$1\ 10^{-5}$ (a) $2\ 10^{-4}$ (b)
Pb	$4.9\ 10^{-5}$	$3\ 10^{-4}$ (b)
Hg	$1.1\ 10^{-5}$	$4.7\ 10^{-7}$ (a) $5\ 10^{-4}$ (b)
Cu	-	$2\ 10^{-3}$ (b)
Ni	$<2.7\ 10^{-5}$	$1.6\ 10^{-2}$ (a) $2\ 10^{-1}$ (b)
Zn	-	$1\ 10^{-2}$ (b)

(a): IAEA, 1994; (b): IAEA, 2001.

Table A. 5: BTFs and BCFs for liver and kindey (Source: Stevens, 1991, 1992)

Metal	**BTF [d/kg ww]**		**BCF [kg ds/kg ww]**	
	Liver	**Kidney**	**Liver**	**Kidney**
As(III)	$2.5\ 10^{-3}$ $[(1.8\text{-}3.0)\ 10^{-3}]$	$2.1\ 10^{-3}$ $[(1.0\text{-}3.6)\ 10^{-3}]$	$3.9\ 10^{-2}$ $[(1.6\text{-}5.9)\ 10^{-2}]$	$3.5\ 10^{-2}$ $[(1.7\text{-}7.2)\ 10^{-2}]$
Cd	$4.8\ 10^{-2}$	$1.9\ 10^{-1}$	$9.6\ 10^{-1}$	3.9
Cr(VI)	$1.8\ 10^{-3}$	$1.6\ 10^{-4}$	$1.8\ 10^{-2}$	$1.6\ 10^{-3}$
Pb	$3.4\ 10^{-3}$ $[(2.4\text{-}4.0)\ 10^{-3}]$	$9.0\ 10^{-3}$ $[(3.9\text{-}12)\ 10^{-3}]$	$6.1\ 10^{-2}$ $[(4.6\text{-}7.3)\ 10^{-2}]$	$1.6\ 10^{-1}$ $[(0.7\text{-}2.2)\ 10^{-1}]$
Hg	$1.5\ 10^{-2}$	$4.9\ 10^{-2}$	$3.1\ 10^{-1}$	$9.9\ 10^{-1}$
Cu	-	-	-	-
Ni	-	-	-	-
Zn	-	-	-	-

Table A. 6: Published data on arsenic concentrations in liver, kidney and muscular tissue of cattle (average concentrations [mg/kg ww]) (Source: Alonso et al., 2000).

Muscular tissue	**Liver**	**Kidney**	**Country**	**Reference**
0.004 (438)	0.043 (437)	0.055 (427)	Spain (calves)	Alonso et al., 2000
0.005 (56)	0.046 (56)	0.068 (56)	Spain (cows)	Alonso et al., 2000

<0.02 (181)	<0.02 (179)	0.03 (177)	Australia	Kramer et al., 1983
-	0.03 (2138)	0.03 (2138)	Canada	Salisbury et al., 1991
-	0.03 (210)	0.05 (209)	Canada (calves)	Salisbury et al., 1991
-	0.01 (571)	-	Norway	Kluge-Berge et al., 1992
<0.015 (29)	<0.015 (68)	<0.015 (29)	Sweden (2 year or older)	Jorhem et al., 1991
0.004 (192)	0.013 (118)	0.048 (180)	the Netherlands (1-8 year)	Vos et al., 1987

( ): number of samples

Table A. 7: Published data on cadmium concentrations in liver, kidney and muscular tissue of cattle (average concentrations [mg/kg ww]) (Source: Alonso et al., 2000).

Muscular tissue	**Liver**	**Kidney**	**Country**	**Reference**
0.001 (438)	0.032 (437)	0.070 (427)	Spain (calves)	Alonso et al., 2000
0.001 (56)	0.097 (56)	0.458 (56)	Spain (cows)	Alonso et al., 2000
0.001 (181)	0.06 (179)	0.37 (174)	Australia	Kramer et al., 1983
0.029 (1812)	0.176 (1100)	0.650 (1227)	Australia	Langlands et al., 1988
-	0.05 (61)	0.23 (256)	Brasil	Aranha et al., 1994
-	0.07 (2138)	0.45 (2138)	Canada	Salisbury et al., 1991
-	0.04 (210)	0.26 (209)	Canada (calves)	Salisbury et al., 1991
0.0013 (113)	0.061 (113)	0.350 (98)	Finland	Niemi et al., 1991
ND (138)	0.052 (350)	-	Finland (heifers and cows)	Tahvonen en Kumpulainen, 1994
0.001 (87)	0.034 (87)	0.222 (87)	Germany (calves)	Kreuzer et al., 1988
0.038 (30)	0.119 (30)	0.342 (30)	Italy	Amodio-Cocchieri en Fiore, 1987
ND *median* (80)	-	0.21 *median* (578)	Norway	Kluge-Berge et al., 1992
0.006 (92)	0.120 (290)	0.610 (291)	Poland	Falandysz, 1993
0.023 (6)	0.316 (6)	0.259 (6)	Slovakia (milk cows, heifers and bulls)	Kottferová en Koréneková, 1995
0.004 (87)	0.09 (69)	0.37 (331)	Slovaka (< 5year)	Doganoc, 1996
0.001 (34)	0.070 (33)	0.39 (68)	Sweden (2 year or older)	Jorhem et al., 1991
0.004 (215)	0.105 (146)	0.522 (210)	The Netherlands (1-8 year)	Vos et al., 1987
-	0.072 (13)	0.155 (13)	United Kingdom (cows and oxes)	MAFF, 1998

( ): number of samples

Table A. 8: Published data on lead concentrations in liver, kidney and muscular tissue of cattle (average concentrations [mg/kg ww]) (Source: Alonso et al., 2000).

Muscular tissue	**Liver**	**Kidney**	**Country**	**Reference**
0.009 (438)	0.053 (434)	0.052 (427)	Spain (kalveren)	Alonso et al., 2000
0.017 (56)	0.057 (56)	0.066 (56)	Spain (koeien)	Alonso et al., 2000
<0.02 (181)	0.05 (180)	0.04 (178)	Australia	Kramer et al., 1983
-	0.12 (61)	0.15 (256)	Brasil	Aranha et al., 1994
-	0.07 (2138)	0.11 (2138)	Canada	Salisbury et al., 1991
-	0.1 (210)	0.15 (209)	Canada (calves)	Salisbury et al., 1991
0.013 (115)	0.057 (113)	0.110 (96)	Finland	Niemi et al., 1991
0.010 [a] (138)	0.037 [a] (350)	-	Finland (heifers and cows)	Tahvonen en Kumpulainen, 1994
0.009 (30)	0.059 (87)	0.150 (87)	Germany (calves)	Kreuzer et al., 1988
0.147 (30)	0.405 (30)	0.573 (30)	Italy	Amodio-Cochieri en Fiore, 1987
ND (47)	-	0.07 (578)	Norway	Kluge-Berge et al., 1992
0.040 (93)	0.160 (290)	0.210 (291)	Poland	Falandysz, 1993
0.014 (6)	0.456 (6)	0.079 (6)	Slovakia	Kottferová en Koréneková, 1995
0.05 (95)	0.1 (68)	0.14 (349)	Slovakia (< 5year)	Doganoc, 1996
<0.005 (34)	0.047 (33)	0.097 (68)	Sweden (2 year or older)	Jorhem et al., 1991
0.03 (214)	0.17 (146)	0.40 (208)	The Netherlands (1-8 year)	Vos et al., 1987
-	0.093 (13)	0.161 (13)	United Kingdom (cows and oxes)	MAFF, 1998

( ): number of samples

[a]: median

Table A. 9: Published data on mercury concentrations in liver, kidney and muscular tissue of cattle (average concentrations [mg/kg ww]) (Source: Vos et al., 1987 en Falandysz, 1993)

Muscular tissue	**Liver**	**Kidney**	**Country**	**Reference**
0.0012	0.0042	0.011	Poland	Falandysz, 1993
0.001 (213)	0.003 (146)	0.008 (207)	The Netherlands	Vos et al., 1987
-	<0.01 (83) [a]	0.011 (982) [a]	The Netherlands [b]	Vaessen en Ellen, 1985
-	0.006 (>100) [c]	-	USA	National Bureau of Standards, 1976 [d]
0.004 (ca. 125)	0.01 (ca. 125)	0.02 (ca. 125)	USA [e]	Doyle en Spaulding, 1978
0.005	0.01	-	USA [e]	Sell et al., 1975 [d]
<0.01	0.01	-	Finland	Stabel-Taucher et al., 1975 [d]
<0.002 (32)	0.002 (4)	-	Finland [f]	Nuurtamo et al., 1980
<0.002 (32)	0.003 (4)	0.007 (4)	Finland [g]	Nuurtamo et al., 1980
-	<0.01	-	Ireland	Stabel-Taucher et al., 1975 [d]
-	0.04	-	Poland	Stabel-Taucher et al., 1975 [d]
-	0.03	-	Australia	Stabel-Taucher et al., 1975 [d]
<0.01 (181)	<0.01 (180)	<0.01 (178)	Australia	Kramer et al., 1983
-	0.005 (190)	0.006 (190)	Australia	Flanjak en Lee, 1979

( ): number of samples;
a: median;
b: data of 1970-’80;
c: concentrations recalculated to mg/kg ww, assumed dry weight 29.5 %;
d: from Doyle and Spaulding, 1978;
e: growing cattle;
f: cows;
g: bulls.

Table A. 10: Published data on copper concentrations in liver, kidney and muscular tissue of cattle (average concentrations [mg/kg ww]) (Source: Alonso et al., 2000).

Muscular tissue	**Liver**	**Kidney**	**Country**	**Reference**
0.677 (438)	64.6 (437)	4.91 (427)	Spain (calves)	Alonso et al., 2000
1.26 (56)	60.3 (56)	3.67 (56)	Spain (cows)	Alonso et al., 2000
1.9 (181)	33.8 (180)	4.9 (178)	Australia	Kramer et al., 1983
1.33 (1795)	23.5 (1101)	4.36 (1226)	Australia	Langlands et al., 1987
0.74 (10)	30.3 (11)	3.4 (11)	Burundi (cows)	Benemariya et al., 1993
-	56.80 (2138)	5.00 (2138)	Canada	Salisbury et al., 1991
-	137 (210)	6.69 (209)	Canada (calves)	Salisbury et al., 1991
1.2 (147)	29 (147)	5.6 (147)	Poland	Falandysz, 1993
0.87 (7)	39 (7)	3.7 (6)	Sweden (2 year or older)	Jorhem et al., 1989
3.292 (6)	28.497 (6)	4.180 (6)	Slovakia (milk cows, heifers and bulls)	Kottferová en Koréneková. 1995
-	-	3.7 (70)	The Netherlands (1-8 year; average 3.4)	Ellen et al., 1989
-	65.5 (13)	4.39 (13)	United Kingdom (cows and oxes)	MAFF, 1998

( ): number of samples

Table A. 11: Published data on zinc concentrations in liver, kidney and muscular tissue of cattle (average concentrations [mg/kg ww]) (Source: Alonso et al., 2000)

Muscular tissue	**Liver**	**Kidney**	**Country**	**Reference**
47.8 (438)	47.7 (437)	14.4 (427)	Spain (calves)	Alonso et al., 2000
52.7 (56)	59.8 (56)	22.0 (56)	Spain (cows)	Alonso et al., 2000
61.9 (181)	50.9 (180)	25.1 (178)	Australia	Kramer et al., 1983
53.5 (1832)	47.6 (1103)	22.2 (1224)	Australia	Langlands et al., 1987
53.7 (10)	63.1 (11)	23.4 (11)	Burundi (cows)	Benemariya et al., 1993
-	41.70 (2138)	20.70 (2138)	Canada	Salisbury et al., 1991
-	70.20 (210)	29.60 (209)	Canada (calves)	Salisbury et al., 1991
34 (147)	42 (147)	22 (147)	Poland	Falandysz, 1993
49 (7)	40 (7)	16 (6)	Sweden (2 year or older)	Jorhem et al., 1989
29.131 (6)	38.705 (6)	16.518 (6)	Slovakia (milk cows, heifers and bulls)	Kottferová en Koréneková, 1995
-	-	17.9 (70)	The Netherlands (1-8 year; average 3.4)	Ellen et al., 1989
-	36.3 (13)	16.1 (13)	United Kingdom (cows and oxes)	MAFF, 1998

( ): number of samples.

5.3.4.3 Discussion

- *Transfer to tissue (muscles, liver, kidney)*

The data of Stevens (1992) indicate that *As* shows low specificity to kind of tissue: the BTFs for liver and kidney are highest, but differ only a factor of 2 from the BTF for muscular tissue. On the other hand, a study of van Hooft (1995) reports almost no accumulation in muscular tissue. This is confirmed by the data of Alonso et al. (2000), who state that arsenic is found rather in liver and kidney than in muscular tissue. In the latter study, published data of arsenic concentrations in liver, kidneys and muscles from cattle in various regions are listed. Although direct comparison is difficult because of differences in age, detection limit, …, a rough idea of concentrations can be seen from the data (Table A. 6).

No significant differences were found in the accumulation of arsenic in liver, kidney, muscles and blood between male and female calves in the age 6 – 12 months (Miranda, 2000). A significant number of samples showed concentrations below the limit of detection, merely for muscular tissue and blood.

In the study of Stevens (1992) the greatest accumulating ability is shown by *Cd*, followed by Hg (liver and kidney). Female calves (age 6 – 12 months) show higher concentrations of Cd in liver and kidney than male calves (Miranda, 2000). The difference in accumulation was only significant for kidneys. These differences are probably caused by a more efficient synthesis of methallothionein in female animals (Webb, 1979).

Stevens' BTFs approach more the most probable value of IAEA (1994) than the conservative value of IAEA (2001).

Anke et al. (1971) reported that after oral administration of $CrCl_3$ to goats in the beginning of their lactation period, highest concentratios (expressed on dry weight) were found in kidneys, followed by blood, skin, bones, liver, spleen, hair, muscles and brains.

It is unclear to which Cr species the BTF_{muscle} from Stevens (1992) is linked. The primary literature (Smart and Sherlock, 1985) only reports that Cr was administered with slaughter waste from chickens. From the data of Stevens (1992), it can be derived that more Cr(VI) is transferred to liver than to kidney. BTFs calculated for Cr(VI) in liver and kidney are less reliable because of the assumptions that had to be made in calculating them. They also conflict with the results of Anke et al. (1971). The studies of IAEA (1994, 2001) do not account for speciation of the metals. BTFs are calculated for Cr(III), Cr(VI) and Cr-total that approach the values of Stevens (1992) and IAEA (1994, 2001) in a better way.

Kidneys also show a high potential for accumulation of *lead*. Analogous effects were reported by van Hooft (1995) and Alonso et al. (2002). No significant differences between male and female calves were noted. Adult female animals can show a higher accumulation during gestation and lactation because of mobilisation of Pb from the bone (Goyer, 1996). These transfer factors are based on the use of an absorption factor for adult ruminants. If the higher absorption factor for young animals is used, the BTF would even be higher.

Compared with earlier studies (Baes et al., 1984; Ng et al., 1968, 1978, 1982), the data of Stevens (1992) are 3 – 6 times higher, except for *Hg*. For this element, the value of Ng et al. is 250 times higher. This difference could not be explained. It should however be noted that (1) the values in the study of Ng et al. are calculated from feed that is not consumed by the cattle, and (2) that the BTF calculated by Stevens (1992) is less reliable. The value of Ng et al. is comparable with the value of Stevens et al, calculated from the primary literature on MeHgCl. Transfer factors calculated with Vlier-humaan are situated between the value of Stevens (1992) and IAEA (2001).

Cu only accumulates in liver (van Hooft, 1995). This is also the conclusion from the data of Alonso et al. (2000; Table A. 10). Van Hooft (1995) reports a non-linear transfer of copper, with dependancy on the Cu concentration in the food. The use of a transferfactor is therefore considered not suitable.

It is reported that female animals accumulate more copper than male animals. This could possible be attributed to the influence of female hormones on the Cu metabolism. Gestating animals show lowering concentrations of copper in the liver because of transfer to the fetus. The study of Miranda et al. (2000) however reports significantly higher levels of Cu in the liver of male calves (6 – 12 months of age). The accumulation in kidney was higher in female animals. An explanation has not been given for these deviating results.

As sufficient experimental data were lacking to calculate accurate BTFs for *Ni*, Stevens (1992) adopted the value from Ng eta al. for the BCF to muscles (6.3 10^{-3} kg dw/kg ww) as a provisional value. From this number a BTF can be derived if the daily feed intake is known. For an assumed feed intake of 15.6 kg dw/d[1], a transfer factor of 3.8 10^{-4} d/kg ww is obtained. This value approaches the value calculated with Vlier-humaan. The BTFs of IAEA are 1 to 2 orders of magnitude higher.

Van Hooft (1995) reports that *Zn* does not accumulate in liver and kidney. Deficiency to zinc is expected rather than toxicity (Veterinaire Inspectie, the Netherlands, 1991). From the data of Alonso et al. (2000), it can be seen that tens of mg Zn/kg ww can be found in liver, kidney and muscles. This is not surprising seen the high tolerance for zinc: cattle can support 27 – 30 mg Zn/ kg bw. Highest concentrations are found in liver and kidney (Table A. 11). Concentrations of Zn were significantly higher in the liver and blood of female calves (6 – 12 months) than in male calves of the same age (Miranda et al., 2000). Kottferová and Koréneková (1997) found that Zn concentrations in hart, liver, kidney and muscles were higher in bulls than in cows. Age of the animals could be an influencing factor.

- *Transfer to milk*

Transfer to meat is larger than transfer to milk. In general the transfer to milk is rather limited. Exceptions are the fat soluble organic mercury and lead compounds (COKZ, 2002). The highest transfer to milk is noted for Pb and As, followed by Cr(VI), Hg and Cd, according to Stevens (1991). The BTF for Pb is about 40 times higher than the BTF for Cd.

Van Hooft (1995) reported transfer factors for Cd to milk: 1 10^{-3}-5.9 10^{-8} d/l (van Bruwaene et al., 1984; Neathery et al., 1974; Stevens, 1991) and 2.3 10^{-5}-5.8 10^{-5} kg/l (Stevens, 1991; International Dairy Federation, 1992). The average concentrations of Cd, Pb and Hg in Dutch milk and dairy products for the period 1997 – 1999 amounted to < 1 µg Cd/kg, < 5 µg Pb/kg and < 5 µg Hg/kg (COKZ, 2002). Total Hg concentrations mostly do not exceed 5E-4 mg/l (International Dairy Federation, 1992). These values correspond to the concentrations found by MAFF (1999).

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[1] The dry matter intake of 15.6 kg/d represents the average grass consumption (15 kg/d) and the adhering soil (0.6 kg/d) of unlimited grazing without roughage supplement (van Hooft, 1995).

There was not enough information to allow an accurate estimate for Ni. Metals added as a component in sludge (mainly Pb, As and Cd) did not lead to a significant elevation of the concentration in milk. It is suggested that metals in sludge are less bioavailable for lactating cows than metal salts (Stevens, 1991). The bioavailability of trace elements in soil is about 1.5 times lower than in feed (van Hooft, 1995).

It is not clear whether addition of Cu to the diet leads to an elevation of the Cu content in milk. A substantial elevation of the Cu content of milk is probably due to contamination after milking (van Hooft, 1995). Miller (1975) reports that the excretion via milk is a homeostatic process in ruminants, although less important. The concentrations of Cu in uncontaminated milk are about 0.02 – 0.05 mg/l (International Dairy Federation, 1992; MAFF, 1999).

Miller (1975) reports that the excretion of Zn with milk is an important homeostatic regulation process. According to the International Dairy Federation (1992) however, the Zn concentration in milk will hardly raise if Zn is added to the diet. Zn concentrations of 4.2, 6.7 and 8.0 mg/l in milk are reported at concentrations of 44, 372 and 692 mg Zn/kg dw in the feed. Further raising of the Zn concentration in the food up to 1279 mg/kg dw did not lead to a further raise in the concentration in milk (Neathery et al., 1972). This means a non-linear transfer of Zn to milk. MAFF reports a Zn concentration in milk of 3.9 mg/l (MAFF, 1999).

5.3.4.4 Recommendations to calculate the transfer

- *Transfer to meat (muscular tissue)*

The available data are the transfer factors collected by Stevens (1992) and the BTFs used in the models of IAEA (1994, 2001) and Spadaro-Rabl (2002).

- *Cd*

The calculated BTFs of Stevens (1992) for cadmium correspond with IAEA (1994, 2001) and Spadaro-Rabl (2002). Accumulation occurs predominantly in kidney, followed by liver and muscular tissues.

- *Cr*

The BTF values of Stevens (1992) for chromium are based on less reliable data. The BTF for transfer to kidney is smaller than the BTF for transfer to the liver. This is in conflict with the data of Anke et al. (1971). It is unclear how the speciation of Cr affects the BTF_{muscle} presented by Stevens (1992). The studies of IAEA do not account for speciation. A comparison of the BTFs is therefore difficult.

- *Pb*

The BTFs calculated by Stevens (1992) for Pb correspond with IAEA (1994, 2001) and Spadaro-Rabl (2002). Accumulation occurs mainly in kidney and liver and less in muscular tissue. Accumulation in bone also takes place. A BTF equal to the average of Stevens and IAEA (1994) is proposed if a single value has to be used (BTF = $2.3\ 10^{-4}$ d/kg ww).

- *Ni*

Stevens (1992) does not give BTFs for Ni because of lack of data. A BCF for muscular tissue is proposed from an other study and transformed to a BTF.

- *As*

According to Stevens (1991) the BTFs for the different tissues are of the same order of magnitude, the BTFs for liver and kidney are about twice the BTF for muscular tissue. This is also reflected in the data of Alonso et al. (2000), although here highest concentrations are found in the kidney rather than in the liver. The difference with the conservative BTF of IAEA (2001) is one order of magnitude.

- *Hg*

In spite of the less reliable results for the calculation of a BTF, the values of Stevens (1992) correspond with the other literature data. Accumulation takes mainly place in liver and kidney, followed by muscular tissue. The transfer factor calculated with the Vlier-humaan equation and the default excretion factor of 1, is situated between the value of Stevens (1992) and the value of IAEA (2001).

- *Cu*

Copper mainly accumulates in the liver. The transfer factor of IAEA (1994) is preferred.

- *Zn*

Van Hooft (1995) reports that Zn does not accumulate in liver and kidney. Alonso et al. (2000) indicates that highest concentrations are found in muscular tissue and in liver (comparable levels). The BTF of IAEA is therefore preferred.

- *Transfer to milk*

- *Cr*

It is proposed to calculate the transfer of Cr(III) and Cr(VI) and Cr total with the BTF of IAEA (2001; $BTF_{milk} = 2\ 10^{-4}$ d/l), as:

- Stevens (1991) only gives a BTF for Cr(VI);
- IAEA (1994, 2001) give no indication of the species;
- there are too little data to compare the excretion of Cr(III), Cr(VI) and Cr total, which justifies a conservative estimate;
- a smaller BTF than for meat is calculated; this corresponds with the data.

- *Hg*

The BTF_{milk} proposed by Stevens (1992) and IAEA (1994) is considered as the best estimate ($BTF_{milk} = 5.7\ 10^{-6}$ d/l).

- *Ni*

As the literature data indicate that the concentration in milk is some orders of magnitude lower than in meat, the BTF_{milk} of Stevens (1991) is proposed as the best estimate (maximum 2.7 10^{-5} d/l).

- *As*

It is proposed to use the BTF of IAEA (2001; BTF_{milk}: 1 10^{-4} d/l) as:

- the transfer factor of Stevens (1991) is valid for As(III):
- IAEA (2001) gives no indication on the As speciation
- even considering the conservatism in the IAEA (2001) BTF, the value is smaller than the BTF for meat; this corresponds with the measured concentrations.

- *Cd*

The BTF_{milk} exceeds the BTF_{meat}.

As the concentration in milk approaches the concentration in meat (Table A. 7), the BTF_{meat} is proposed as a conservative BTF_{milk}.

- *Pb*

The value of IAEA is recommended (2001).

- *Cu*

The proposed BTF_{meat} is the value of IAEA (1994) and equals 9 10^{-3} d/kg ww. The BTF_{milk} of IAEA (2001) equals 2 10^{-3} d/l. Taking into account the concentrations of Cu in meat and milk, a BTF_{milk} is estimated that is about 1 – 2 orders of magnitude smaller thant the BTF_{meat}. If the effective ratio C_{mi}/C_{me} from the literature data is used, a BTF_{milk} of 3.5 10^{-4} d/l is calculated (1/26 of the BTF_{meat}). It should be remarked that this is only an estimate as the concentrations in meat and milk are not necessarily linked to the same concentrations in feed (data are taken from a total diet study) and that excretion from milk and deposition in tissue are considered as homeostatic processes according to Miller (1975).

- *Zn*

The same methdology can be adopted for Zn. The BTF_{meat} of IAEA (1994; 1 10^{-1} d/kg ww) is considered the best estimate for transfer to meat. The BTF_{milk} of IAEA (2001) equals 1 10^{-2} d/l and is proposed as the best estimate for transfer to milk, as the ratio between C_{mi}/C_{me} is about 1/10.

5.3.5 Proportion of contaminated offal in total oral intake from food

When calculating human exposure from consumption of animal products, exposure via muscular tissue and milk, as well as exposure via offal (liver, kidney, organs) needs to be taken into account. To assess the proportation of contaminated offal in total oral intake from food, Belgian consumption data for these products and the legally enforced maximum concentrations of contaminants in animal products are used. Table A. 12 shows the maximal doses for an adult based on consumption data and maximum concentrations for lead, cadmium and mercury. From this estimate, exposure results mostly from consumption of meat. The exposure from consumption of offal are 14 times, 7 – 3.5 and 7 times smaller for Pb, Cd and Hg, respectively.

There is little evidence that maximum concentrations are exceeded. Because the ratios between the legally enforced maximum concentrations in meat and offal not necessarily reflect the ratios in meat and offal, an estimate is made of real exposure. Based on Table A. 6 to Table A. 11 with concentrations, ratios for muscular tissue/liver and muscular tissue/kidney are calculated for each reference (or for each cattle species mentioned). Average ratios are calculated for each metal (Cd, Pb and Hg only). Based on the average concentration in muscular tissue and the average ratios the concentrations in liver and kidney were estimated. These concentrations were combined with the consumption data. For liver and kidney the consumption is considered as being the consumption of offal. The results are given in Table A. 13. There were not enough data to calculate exposure from milk.

Table A. 12: Comparison of maximum daily dose of Pb, Cd and Hg from intake of meat, offal and milk

Daily consumption* [kg ww/pers.d]	**Contaminant**					
	Pb		**Cd**		**Hg**	
	MTC [mg/kg ww]	**DMC [mg/pers.d]**	**MTC [mg/kg ww]**	**DMC [mg/pers.d]**	**MTC [mg/kg ww]**	**DMC [mg/pers.d]**
meat 0.255	$1\ 10^{-1}$	$2.55\ 10^{-2}$	$5\ 10^{-2}$	$1.28\ 10^{-2}$	$5\ 10^{-2}$	$1.28\ 10^{-2}$
offal 0.0036	$5\ 10^{-1}$	$1.8\ 10^{-3}$	$5\ 10^{-1}$ – 1.10^{0}	$1.8\ 10^{-3}$-$3.6\ 10^{-3}$	$5\ 10^{-2}$	$1.8\ 10^{-3}$
milk 0.190	$2\ 10^{-2}$	$3.8\ 10^{-3}$	$5\ 10^{-3}$	$1\ 10^{-4}$	$1\ 10^{-2}$	$1.9\ 10^{-3}$

*: from EC (1996);
MTC: maximal allowed concentration;
DMC: maximal daily exposure = daily consumption x MTC.

From this estimate, exposure results mostly from consumption of meat. The exposure from consumption of offal are 14 times, 7 – 3.5 and 7 times smaller for Pb, Cd and Hg, respectively.

There is little evidence that maximum concentrations are exceeded. Because the ratios between the legally enforced maximum concentrations in meat and offal not necessarily reflect the ratios in meat and offal, an estimate is made of real exposure. Based on Table A. 6 to Table A. 11 with concentrations, ratios for muscular tissue/liver and muscular tissue/kidney are calculated for each reference (or for each cattle species mentioned). Average ratios are calculated for each metal (Cd, Pb and Hg only). Based on the average concentration in muscular tissue and the average ratios the concentrations in liver and kidney were estimated. These concentrations were combined with the consumption data. For liver and kidney the consumption is considered as being the consumption of offal. The results are given in Table A. 13. There were not enough data to calculate exposure from milk.

Table A. 13: Estimation of the daily intake of Pb, Cd and Hg from meat, offal and milk

Daily consumption* [kg ww/pers.d]	**Contaminant**					
	Pb		**Cd**		**Hg**	
	conc. (1) **[mg/kg ww]**	**DC** **[mg/pers.d]**	**conc. (2)** **[mg/kg ww]**	**DC** **[mg/pers.d]**	**conc. (3)** **[mg/kg ww]**	**DC** **[mg/pers.d]**
Meat 0.255	$3.4\ 10^{-2}$	$8.7\ 10^{-3}$	$9.2\ 10^{-3}$	$2.3\ 10^{-3}$	$2.8\ 10^{-3}$	$7.1\ 10^{-4}$
Liver (Offal) 0.0036	$1.4\ 10^{-1}$	$5\ 10^{-4}$	$1.4\ 10^{-1}$	$5\ 10^{-4}$	$7.4\ 10^{-3}$	$2.7\ 10^{-5}$
Kidney (Offal) 0.0036	$1.8\ 10^{-1}$	$6.5\ 10^{-4}$	$3.6\ 10^{-1}$	$1.3\ 10^{-3}$	$1.9\ 10^{-2}$	$6.8\ 10^{-5}$

*: from EC (1996);
(1): average ratio conc. meat/conc. liver: $2.4\ 10^{-1}$; average ratio conc. meat/conc. kidney: $1.9\ 10^{-1}$;
(2): average ratio conc. meat/conc. liver: $6.8\ 10^{-2}$; average ratio conc. meat/conc. kidney: $2.5\ 10^{-2}$;
(3): average ratio conc. meat/conc. liver: $3.8\ 10^{-2}$; average ratio conc. meat/conc. kidney: $1.4\ 10^{-1}$;
DC: daily intake of contaminant = daily consumption x concentration.

Above calculations show that the intake from consumption of offal is 13 – 17, 1.8 – 5 and 10 – 26 times for Pb, Cd and Hg respectively than the intake from consumption of meat. For cadmium, the intake from consumption of kidneys seems to be rather high. This scenario can, however, be considered as rather worst-case as offal is not constituted of kidney alone, but also covers liver, heart, tongue and brains, but it shows that for cadmium, consumption of offal could be a point of attention.

5.3.6 Transfer of organic chemicals in cattle

An overview of biotransfer factors for organic chemicals is given in Table A. 14 . The transfer factors depend on:
-the source (soil, grass, soluble form, bolus, secondary contamination…)
-the animal (sex, age, weight, lactation state, …)
-housing (open environment, closed environment,
-time of exposure (steady-state, non steady state, …)
-surface area for foraging and number of animals per unit area (chickens)
The selection of the pertinent transfer factors and appropriate transfer models for use in this project will be made in the second working year.

Table A. 14: Database of transfer factors of organic chemicals in cattle

Chemical	Source	Matrix	BCF*	Dimension BCF	BTF*	Dimension BTF	COR*	ABS*	Animal	Duration experiment (days)	Contaminant supply	Reference
PCB 153	diet	milk					0.78		1 Simmenthal cow, 4 years old, 650 kg	114	background contamination fodder, secondary contamination by grass ropes	McLachlan, 1993
PCB 138							0.63					
PCB 180							0.63					
γ-HCH							0.04					
α-HCH							0.21					
HCH							0.79					
p,p'-DDE							0.80					
p,p'-DDT							0.04					
PCB 52	diet	milk fat	0.10	kg diet/kg milk fat						60	dosing Arochlor 1260, and mono- and dichloro-PCB congeners	Tuinstra et al., 1992
PCB 7			0.10									
PCB 15			0.40									
PCB 101			0.40									
PCB 149			0.40									
PCB 151			0.40									
PCB 95			0.50									
PCB 141			0.50									
PCB 187			1.00									
PCB 198			1.40									
PCB 52			1.80									
PCB 138			3.50									
PCB 170			3.60									
PCB 194			3.70									
PCB 180			4.00									
PCB 206			4.00									
PCB 128			4.10									
PCB 153			4.50									

*parameter	abbr	dimension	
bioconcentration factor	BCF	(concentration in matrix)/(concentration in source)	
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	**Source**	**Matrix**	**BCF***	**Dimension BCF**	**BTF***	**Dimension BTF**	**COR***	**ABS***	**Animal**	**Duration experiment (days)**	**Contaminant supply**	**Reference**
2,3,7,8-TCDD	diet	kidney /back	11.30	(pg/g FW)/(ng/kg diet)			0.53		4 male calves, 220-262 kg	120	250g/d mais supply containing dioxins, furans and PCBs dissolved in acetone, secondary contamination PCP by wood protection products	Feil et al., 2000
2,3,7,8-TCDF	diet	kidney /back	0.20				0.01					
1,2,3,7,8-PeCDD	diet	kidney /back	7.60				0.37					
2,3,4,7,8-PeCDF	diet	kidney /back	8.90				0.43					
2,3,7,8-TCDD	diet	liver	0.90									
2,3,7,8-TCDF	diet	liver	0.01									
1,2,3,7,8-PeCDD	diet	liver	2.20									
2,3,4,7,8-PeCDF	diet	liver	3.30									
2,3,7,8-TCDD	diet	bone	0.30									
2,3,7,8-TCDF	diet	bone	0.00									
1,2,3,7,8-PeCDD	diet	bone	0.10									
2,3,4,7,8-PeCDF	diet	bone	0.10									

*parameter	abbr	dimension	
bioconcentration factor		BCF	(concentration in matrix)/(concentration in source)
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	**Source**	**Matrix**	**BCF ***	**Dimension BCF**	**BTF ***	**Dimension BTF**	**COR***	**ABS***	**Animal**	**Duration experiment (days)**	**Contaminant supply**	**Reference**
2,3,7,8-TCDD	soil	egg fat	1.20	g soil/g egg fat					13 chickens open air 250 m^2	one sample	surroundings of an aluminium recycling plant	Schuler et al., 1997
1,2,3,7,8-PeCDD			2.40									
1,2,3,4,7,8-HxCDD			1.50									
1,2,3,6,7,8-HxCDD			1.60									
1,2,3,7,8,9-HxCDD			0.80									
1,2,3,4,6,7,8-HpCDD			0.40									
OCDD			0.10									
2,3,7,8-TCDF			3.30									
1,2,3,7,8-PeCDF			4.40									
2,3,4,7,8-PeCDF			0.80									
1,2,3,4,7,8-HxCDF			0.90									
1,2,3,6,7,8-HxCDF			1.00									
1,2,3,7,8,9-HxCDF			0.10									
2,3,4,6,7,8-HxCDF			0.60									
1,2,3,4,6,7,8-HpCDF			0.20									
1,2,3,4,7,8,9-HpCDF			0.10									
OCDF			0.10									

*parameter	abbr	dimension	
bioconcentration factor		BCF	(concentration in matrix)/(concentration in source)
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	Source	Matrix	BCF *	Dimension BCF	BTF *	Dimension BTF	COR*	ABS*	Animal	Duration experiment (days)	Contaminant supply	Reference
2,3,7,8-TCDD	soil	egg fat	2.52	g soil/g egg fat					300 chickens open air 50 m2	one sample	surroundings production unit chlorinated chemicals	Schuler et al., 1997
1,2,3,7,8-PeCDD			0.49									
1,2,3,4,7,8-HxCDD			0.37									
1,2,3,6,7,8-HxCDD			0.53									
1,2,3,7,8,9-HxCDD			0.23									
1,2,3,4,6,7,8-HpCDD			0.11									
OCDD			0.05									
2,3,7,8-TCDF			0.40									
1,2,3,7,8-PeCDF			0.53									
2,3,4,7,8-PeCDF			0.22									
1,2,3,4,7,8-HxCDF			0.17									
1,2,3,6,7,8-HxCDF			0.17									
1,2,3,7,8,9-HxCDF			0.20									
2,3,4,6,7,8-HxCDF			0.34									
1,2,3,4,6,7,8-HpCDF			0.08									
1,2,3,4,7,8,9-HpCDF			0.05									
OCDF			0.02									

*parameter	abbr	dimension	
bioconcentration factor		BCF	(concentration in matrix)/(concentration in source)
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	**Source**	**Matrix**	**BCF ***	**Dimension BCF**	**BTF ***	**Dimension BTF**	**COR***	**ABS***	**Animal**	**Duration experiment (days)**	**Contaminant supply**	**Reference**
2,3,7,8-TCDD	soil	egg fat	5.04	g soil/g egg fat					70 chickens open air 40 m2	one sample	rural area	Schuler et al., 1997
1,2,3,7,8-PeCDD			1.91									
1,2,3,4,7,8-HxCDD			0.79									
1,2,3,6,7,8-HxCDD			0.27									
1,2,3,7,8,9-HxCDD			0.28									
1,2,3,4,6,7,8-HpCDD			0.01									
OCDD			0.30									
2,3,7,8-TCDF			2.97									
1,2,3,7,8-PeCDF			1.99									
2,3,4,7,8-PeCDF			0.95									
1,2,3,4,7,8-HxCDF			0.63									
1,2,3,6,7,8-HxCDF			0.39									
1,2,3,7,8,9-HxCDF			0.78									
2,3,4,6,7,8-HxCDF			0.41									
1,2,3,4,6,7,8-HpCDF			0.02									
1,2,3,4,7,8,9-HpCDF			0.14									
OCDF			0.17									

*parameter	abbr	dimension	
bioconcentration factor		BCF	(concentration in matrix)/(concentration in source)
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	**Source**	**Matrix**	**BCF***	**Dimension BCF**	**BTF***	**Dimension BTF**	**COR***	**ABS***	**Animal**	**Duration experiment (days)**	**Contaminant supply**	**Reference**
2,3,7,8-TCDD	soil	egg fat	4.47	g soil/g egg fat					15 chickens open air 40m2	one sample	rural area	Schuler et al., 1997
1,2,3,7,8-PeCDD			2.60									
1,2,3,4,7,8-HxCDD			3.05									
1,2,3,6,7,8-HxCDD			2.75									
1,2,3,7,8,9-HxCDD			1.73									
1,2,3,4,6,7,8-HpCDD			0.10									
OCDD			-0.07									
2,3,7,8-TCDF			10.39									
1,2,3,7,8-PeCDF			4.72									
2,3,4,7,8-PeCDF			4.48									
1,2,3,4,7,8-HxCDF			3.40									
1,2,3,6,7,8-HxCDF			1.93									
1,2,3,7,8,9-HxCDF			#N/A									
2,3,4,6,7,8-HxCDF			2.48									
1,2,3,4,6,7,8-HpCDF			0.43									
1,2,3,4,7,8,9-HpCDF			0.27									
OCDF			0.94									

*parameter	abbr	dimension	
bioconcentration factor		BCF	(concentration in matrix)/(concentration in source)
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	Source	Matrix	BCF*	Dimension BCF	BTF*	Dimension BTF	COR*	ABS*	Animal	Duration experiment (days)	Contaminant supply	Reference
2,3,7,8-TCDD	soil	egg fat	10.50	g soil/g egg fat					180 chickens unlimited foraging area	one sample	rural area	Schuler et al., 1997
1,2,3,7,8-PeCDD			0.77									
1,2,3,4,7,8-HxCDD			0.93									
1,2,3,6,7,8-HxCDD			0.24									
1,2,3,7,8,9-HxCDD			0.68									
1,2,3,4,6,7,8-HpCDD			0.10									
OCDD			0.02									
2,3,7,8-TCDF			11.00									
1,2,3,7,8-PeCDF			4.07									
2,3,4,7,8-PeCDF			1.29									
1,2,3,4,7,8-HxCDF			0.98									
1,2,3,6,7,8-HxCDF			0.46									
1,2,3,7,8,9-HxCDF			-0.80									
2,3,4,6,7,8-HxCDF			0.70									
1,2,3,4,6,7,8-HpCDF			0.11									
1,2,3,4,7,8,9-HpCDF			0.10									
OCDF			-0.05									

*parameter	abbr	dimension	
bioconcentration factor		BCF	(concentration in matrix)/(concentration in source)
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	**Source**	**Matrix**	**BCF***	**Dimension BCF**	**BTF***	**Dimension BTF**	**COR***	**ABS***	**Animal**	**Duration experiment (days)**	**Contaminant supply**	**Reference**
2,3,7,8-TCDD	deposition (Bergerhoff)	milk fat					0.03		41 cows on 35 ha	one sample	dairy farm in the vicinity of houshold waste burning installation	Schuler et al., 1995
1,2,3,7,8-PeCDD							0.02					
1,2,3,4,7,8-HxCDD							0.02					
1,2,3,6,7,8-HxCDD							0.04					
1,2,3,7,8,9-HxCDD							0.01					
1,2,3,4,6,7,8-HpCDD							0.00					
OCDD							0.00					
2,3,7,8-TCDF							0.00					
1,2,3,7,8-PeCDF							0.01					
2,3,4,7,8-PeCDF							0.05					
1,2,3,4,7,8-HxCDF							0.02					
1,2,3,6,7,8-HxCDF							0.02					
1,2,3,7,8,9-HxCDF							#N/A					
2,3,4,6,7,8-HxCDF							0.03					
1,2,3,4,6,7,8-HpCDF							0.00					
1,2,3,4,7,8,9-HpCDF							0.00					
OCDF							0.01					

*parameter	abbr	dimension	
bioconcentration factor	BCF	(concentration in matrix)/(concentration in source)	
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	**Source**	**Matrix**	**BCF***	**Dimension BCF**	**BTF***	**Dimension BTF**	**COR***	**ABS***	**Animal**	**Duration experiment (days)**	**Contaminant supply**	**Reference**
2,3,7,8-TCDD	diet	milk					#N/A		4 Holstein cows, 43-73 months	58	backgroundconcentration fodder	Fries et al., 1999
1,2,3,7,8-PeCDD							#N/A					
1,2,3,4,7,8-HxCDD							0.18					
1,2,3,6,7,8-HxCDD							0.16					
1,2,3,7,8,9-HxCDD							0.12					
1,2,3,4,6,7,8-HpCDD							0.02					
OCDD							0.00					
2,3,7,8-TCDF							#N/A					
1,2,3,7,8-PeCDF							#N/A					
2,3,4,7,8-PeCDF							0.18					
1,2,3,4,7,8-HxCDF							0.06					
1,2,3,6,7,8-HxCDF							0.11					
1,2,3,7,8,9-HxCDF							#N/A					
2,3,4,6,7,8-HxCDF							0.08					
1,2,3,4,6,7,8-HpCDF							0.01					
1,2,3,4,7,8,9-HpCDF							#N/A					
OCDF							0.00					

*parameter	abbr	dimension	
bioconcentration factor		BCF	(concentration in matrix)/(concentration in source)
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	**Source**	**Matrix**	**BCF***	**Dimension BCF**	**BTF***	**Dimension BTF**	**COR***	**ABS***	**Animal**	**Duration experiment (days)**	**Contaminant supply**	**Reference**
2,3,7,8-TCDD	diet	milk					0.35		1 Simmenthal cow,4 yr, 650 kg	35	background concentration fodder	McLachlan et al., 1990
1,2,3,7,8-PeCDD							0.33					
1,2,3,4,7,8-HxCDD							0.17					
1,2,3,6,7,8-HxCDD							0.14					
1,2,3,7,8,9-HxCDD							0.18					
1,2,3,4,6,7,9-HpCDD							0.01					
1,2,3,4,6,7,8-HpCDD							0.03					
OCDD							0.04					
2,3,7,8-TCDF							0.07					
1,2,3,7,8-PeCDF							0.06					
2,3,4,7,8-PeCDF							0.25					
1,2,3,4,7,8-HxCDF							0.19					
1,2,3,6,7,8-HxCDF							0.16					
1,2,3,7,8,9-HxCDF							#N/A					
2,3,4,6,7,8-HxCDF							0.14					
1,2,3,4,6,7,8-HpCDF							0.03					
1,2,3,4,7,8,9-HpCDF							0.08					
OCDF							0.01					

*parameter	abbr	dimension	
bioconcentration factor		BCF	(concentration in matrix)/(concentration in source)
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	**Source**	**Matrix**	**BCF***	**Dimension BCF**	**BTF***	**Dimension BTF**	**COR***	**ABS***	**Animal**	**Duration experiment (days)**	**Contaminant supply**	**Reference**
2,3,7,8-TCDD	diet	milk					0.30		4 cows		dosing 13C labeled PCDD/Fs	Olling et al., 1991
1,2,3,7,8-PeCDD							0.28					
1,2,3,4,7,8-HxCDD							#N/A					
1,2,3,6,7,8-HxCDD							0.27					
1,2,3,7,8,9-HxCDD							#N/A					
1,2,3,4,6,7,8-HpCDD							0.02					
OCDD							#N/A					
2,3,7,8-TCDF							#N/A					
1,2,3,7,8-PeCDF							#N/A					
2,3,4,7,8-PeCDF							0.36					
1,2,3,4,7,8-HxCDF							0.18					
1,2,3,6,7,8-HxCDF							#N/A					
1,2,3,7,8,9-HxCDF							#N/A					
2,3,4,6,7,8-HxCDF							#N/A					
1,2,3,4,6,7,8-HpCDF							0.02					
1,2,3,4,7,8,9-HpCDF							#N/A					
OCDF							#N/A					

*parameter	abbr	dimension	
bioconcentration factor		BCF	(concentration in matrix)/(concentration in source)
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	**Source**	**Matrix**	**BCF***	**Dimension BCF**	**BTF***	**Dimension BTF**	**COR***	**ABS***	**Animal**	**Duration experiment (days)**	**Contaminant supply**	**Reference**
2,3,7,8-TCDD	diet	milk					0.15		composite milk sample of dairy farm	60	dairy farm in the vicnity of houshold waste burning facility	Slob et al., 1995
1,2,3,7,8-PeCDD	diet	milk					0.10					
1,2,3,4,7,8-HxCDD	diet	milk					0.06					
1,2,3,6,7,8-HxCDD	diet	milk					0.06					
1,2,3,7,8,9-HxCDD	diet	milk					0.03					
1,2,3,4,6,7,8-HpCDD	diet	milk					0.01					
OCDD	diet	milk					0.00					
2,3,7,8-TCDF	diet	milk					0.01					
1,2,3,7,8-PeCDF	diet	milk					0.01					
2,3,4,7,8-PeCDF	diet	milk					0.12					
1,2,3,4,7,8-HxCDF	diet	milk					0.04					
1,2,3,6,7,8-HxCDF	diet	milk					0.04					
1,2,3,7,8,9-HxCDF	diet	milk					#N/A					
2,3,4,6,7,8-HxCDF	diet	milk					0.04					
1,2,3,4,6,7,8-HpCDF	diet	milk					0.00					
1,2,3,4,7,8,9-HpCDF	diet	milk					0.01					
OCDF	diet	milk					#N/A					

*parameter	abbr	dimension	
bioconcentration factor		BCF	(concentration in matrix)/(concentration in source)
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	**Source**	**Matrix**	**BCF***	**Dimension BCF**	**BTF***	**Dimension BTF**	**COR***	**ABS***	**Animal**	**Duration experiment (days)**	**Contaminant supply**	**Reference**
2,3,7,8-TCDD	diet	milk					0.34		1 cow	100	dosing	Tuinstra et al., 1992
1,2,3,7,8-PeCDD							0.55					
1,2,3,4,7,8-HxCDD							0.28					
1,2,3,6,7,8-HxCDD							0.37					
1,2,3,7,8,9-HxCDD							0.12					
1,2,3,4,6,7,8-HpCDD							0.03					
OCDD							0.01					
2,3,7,8-TCDF							#N/A					
1,2,3,7,8-PeCDF							#N/A					
2,3,4,7,8-PeCDF							0.24					
1,2,3,4,7,8-HxCDF							0.26					
1,2,3,6,7,8-HxCDF							0.30					
1,2,3,7,8,9-HxCDF							#N/A					
2,3,4,6,7,8-HxCDF							0.25					
1,2,3,4,6,7,8-HpCDF							0.02					
1,2,3,4,7,8,9-HpCDF							#N/A					
OCDF							#N/A					

*parameter	abbr	dimension	
bioconcentration factor		BCF	(concentration in matrix)/(concentration in source)
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	Source	Matrix	BCF *	Dimension BCF	BTF *	Dimension BTF	COR*	ABS*	Animal	Duration experiment (days)	Contaminant supply	Reference
PCB 18							0.02		5 milk cows	120	background contamination fodder	Thomas et al., 1999
PCB 47							0.23					
PCB 52							0.00					
PCB 74							0.37					
PCB 87							0.00					
PCB 101							0.04					
PCB 105							0.00					
PCB 110							0.02					
PCB 118							0.94					
PCB 128							0.61					
PCB 138							0.74					
PCB 149							0.04					
PCB 151							0.00					
PCB 153							0.75					
PCB 170							0.58					
PCB 180							0.63					
PCB 183							0.64					
PCB 187							0.09					
PCB 194							0.00					

*parameter	abbr	dimension	
bioconcentration factor	BCF	(concentration in matrix)/(concentration in source)	
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	**Source**	**Matrix**	**BCF***	**Dimension BCF**	**BTF***	**Dimension BTF**	**COR***	**ABS***	**Animal**	**Duration experiment (days)**	**Contaminant supply**	**Reference**
PCB 47	diet	milk	10.00	g DW/g milk fat			0.48		11 farms, Holstein/Friesian cows	sampling campagne	background contamination fodder	Thomas et al., 1998
PCB 66			8.50				0.39					
PCB 74			2.80				0.13					
PCB 105			8.40				0.37					
PCB 118			20.00				0.88					
PCB 128			#N/A				#N/A					
PCB 138			33.00				1.40					
PCB 153			18.00				0.84					
PCB 170			17.00				0.74					
PCB 180			21.00				0.93					
PCB 183			18.00				0.76					
PCB 187			2.80				0.12					
PCB 47			11.00				0.37					
PCB 66			1.70				0.07					
PCB 74			8.00				0.31					
PCB 105			10.00				0.37					
PCB 118			17.00				0.66					
PCB 128			17.00				0.66					
PCB 138			15.00				0.57					
PCB 153			16.00				0.63					
PCB 170			20.00				0.78					

PCB 180	20.00	0.80
PCB 183	23.00	0.92
PCB 187	1.80	0.07

*parameter	abbr	dimension	
bioconcentration factor		BCF	(concentration in matrix)/(concentration in source)
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	Source	Matrix	BCF*	Dimension BCF	BTF*	Dimension BTF	COR*	ABS*	Animal	Duration experiment (days)	Contaminant supply	Reference
PCB 18	diet	milk	0.30	g DW/g milk fat			0.00		1 farm, Holstein/Friesian cows	monitoring during growth season (april-october)	background concentration	Thomas et al., 1998
PCB 28			0.20	g DW/g milk fat			0.01					
PCB 66			2.00	g DW/g milk fat			0.08					
PCB 74			9.80	g DW/g milk fat			0.34					
PCB 101			0.40	g DW/g milk fat			0.02					
PCB 110			0.20	g DW/g milk fat			0.00					
PCB 118			21.20	g DW/g milk fat			0.74					
PCB 138			13.80	g DW/g milk fat			0.48					
PCB 149			0.50	g DW/g milk fat			0.02					
PCB 153			13.00	g DW/g milk fat			0.46					
PCB 170			8.90	g DW/g milk fat			0.31					
PCB 180			7.60	g DW/g milk fat			0.27					
PCB 183			11.70	g DW/g milk fat			0.41					
PCB 187			0.60	g DW/g milk fat			0.02					

*parameter	abbr	dimension	
bioconcentration factor	BCF	(concentration in matrix)/(concentration in source)	
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	**Source**	**Matrix**	**BCF ***	**Dimension BCF**	**BTF ***	**Dimension BTF**	**COR***	**ABS***	**Animal**	**Duration experiment (days)**	**Contaminant supply**	**Reference**
2,3,7,8-TCDD	grass	milk					0.30		1 dairy farm, 41 cows on 35 ha	4 harvest periods in 1994-1995 (july 1994-sept 1994-june 1995-oct 1995)	background concentration	Schuler et al., 1997
1,2,3,7,8-PeCDD							0.20					
1,2,3,4,7,8-HxCDD							0.08					
1,2,3,4,6,7,8-HpCDD							0.02					
OCDD							0.01					
2,3,7,8-TCDF							0.02					
1,2,3,7,8-PeCDF							0.04					
2,3,4,7,8-PeCDF							0.50					
1,2,3,4,7,8-HxCDF							0.07					
1,2,3,4,6,7,8-HpCDF							0.01					
OCDF							0.01					

*parameter	abbr	dimension	
bioconcentration factor	BCF	(concentration in matrix)/(concentration in source)	
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)

Chemical	**Source**	**Matrix**	**BCF***	**Dimension BCF**	**BTF***	**Dimension BTF**	**COR***	**ABS***	**Animal**	**Duration experiment (days)**	**Contaminant supply**	**Reference**
2,3,7,8-TCDD	diet	milk					0.24		4 milk cows	3 samplings (juli-nov)	background	Lorber et al., 2000
1,2,3,7,8-PeCDD							0.29					
1,2,3,4,7,8-HxCDD							0.31					
1,2,3,6,7,8-HxCDD							0.39					
1,2,3,7,8,9-HxCDD							0.24					
1,2,3,4,6,7,8-HpCDD							0.06					
OCDD							0.01					
2,3,7,8-TCDF							0.17					
1,2,3,7,8-PeCDF							0.24					
2,3,4,7,8-PeCDF							0.40					
1,2,3,4,7,8-HxCDF							0.36					
1,2,3,6,7,8-HxCDF							0.34					
1,2,3,7,8,9-HxCDF							0.24					
2,3,4,6,7,8-HxCDF							0.29					
1,2,3,4,6,7,8-HpCDF							0.06					
1,2,3,4,7,8,9-HpCDF							0.12					
OCDF							0.03					

*parameter	abbr	dimension	
bioconcentration factor		BCF	(concentration in matrix)/(concentration in source)
biotransferfactor	BTF	(concentration in matrix)/(flux in source)	
carry-over rate	COR	(flux in matrix)/(flux in source)	
net-absorption	ABS	(flux in source-flux in faeces)/(flux in source)	ABS=COR for persistent compounds (no metabolism)