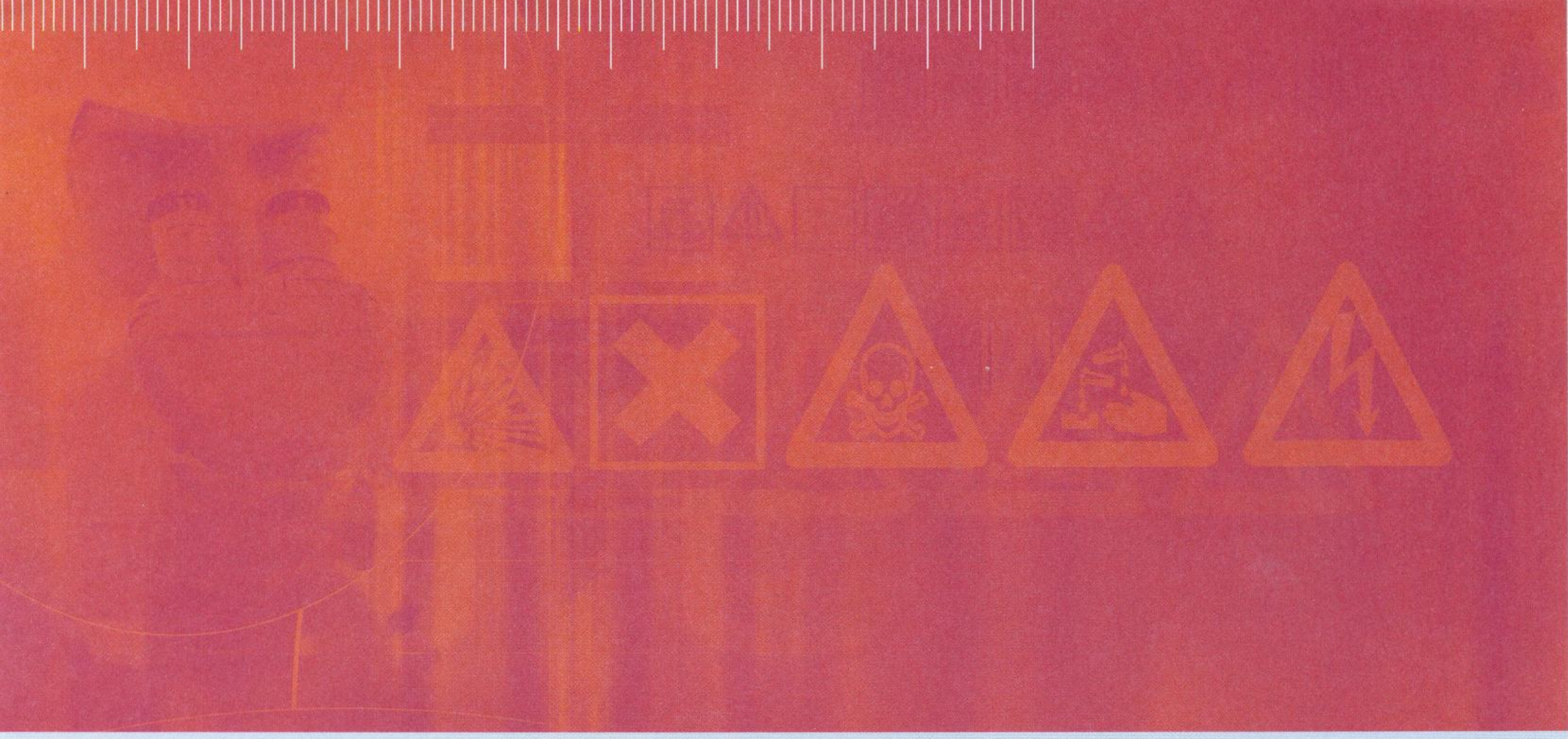

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N° DRC-07-81117-09289-C

Public health risk assessment of sludge landspreading

Final report

maîtriser le risque
pour un développement durable

Public health risk assessment of sludge landspreading

Final report

Customer : **European Federation for Agricultural Recycling (EFAR)**

This report n°DRC-07-81117-09289-C cancels and replaces the previous versions A and B.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

In Europe, most of the municipal and some industrial sludge are spread on land. The fertilising properties of these sludge have been recognised for many years and their application on agricultural lands for more than 30 years is considered as an environmental and economical sustainable practice. Because of the presence of chemical substances and pathogens in sludge, precaution measures have to be taken to guarantee food safety and the preservation of soils and other environmental compartments. The landspreading activity has to respect the 86/278 directive and specific member states regulation. Most of these texts include limits values for trace elements (heavy metals, organic compounds) concentration in the sludge.

The objective of this document is to propose a quantitative risk assessment methodology devoted to the specific case of sludge landspreading. This methodology is focused on chemical substances and adapted from the classical risk assessment methods.

The basic assumption in this work is that sludge landspreading is done in accordance with the regulatory aspects. The quantitative risk assessment is conducted with respect to a conservative approach. For example, all the considered concentrations of chemicals in the sludge correspond to the limit values we suggested.

Calculations using these assumptions show that the global risk levels are acceptable. It means that the suggested limit values are compatible with health regulations. These limit values correspond to the values from the appendix III of the document entitled « Proposal for a Directive of the European Parliament and of the Council on Spreading on Land» [CEC, 2003], except for DEHP (100 mg/kg DM) and lead (500 mg/kg DM).

Public health risk assessment appears as an effective method to evaluate the relevance of the limit values that have to be regulated in the context of sludge landspreading. If needed, this method could be applied to assess the accuracy of other sets of limit values. The quantitative results of this study allow us to determine these main points:

- the major exposure pathway is the ingestion of plant and animal products,
- the major substances are heavy metals (zinc, lead, cadmium, copper and nickel) for threshold effects and polycyclic aromatic hydrocarbons (PAHs) for non-threshold effects (and also to a certain extent polychlorobiphenyls (PCBs) for children and nickel for farmers),
- the contribution of sludge landspreading to the global risk is low in comparison with the contribution of the ingestion of food produced on non spread lands.

According to these results and to the assumptions made in the method, it is possible to suggest some improvements that could be taken into account for the sludge directive revision:

- benzo[a]pyren should be considered separately from other PAHs,
- some organic compounds like linear alkyl sulphonates, bis(2-ethylhexyl) phthalate, and nonylphenols do not contribute significantly to the global risk,
- a buffer zone between amended soils and rivers should be proposed in order to prevent any impact of sludge spreading on the quality of superficial waters.

GLOSSARY

AFSSA: French Food Safety Agency

ATSDR: Agency for Toxic Substances and Disease Registry

BAF: bio-accumulation factor

BCF: bio-concentration factor

CEC: commission of the European communities

CSAH: European Scientific Committee on Food

CSTEE: Scientific Committee on Toxicity, Ecotoxicity and the Environment

DED: daily exposure dose

DEHP: bis(2-ethylhexyl)phthalate

DM: dry matter

EFAR: European Federation for Agricultural Recycling

ER: excess of risk

FAO: Food and Agriculture Organisation

HQ: hazard quotient

HSDB: Hazardous Substances Data Bank

INERIS: French National Institute for Industrial Environment and Risks

INSEE: French National Institute for Statistics and Economic Studies

JECFA: Joint Expert Committee on Food Additives

LAS: linear alkyl sulphonates

NRC: Canadian National Research Council

NPE: nonylphenol and ethoxylated nonylphenols with one or two ethoxy groups

OEHHA: Office of Environmental Health Hazard Assessment

PAHs: polycyclic aromatic hydrocarbons

PCBs: polychlorobiphenyls

PCDD: polychlorodibenzodioxins

PCDF: polycholorodibenzofurans

RfD: reference dose

RIVM: Dutch National Institute for Public Health and the Environment

TEF: toxic equivalent factor

TRV: toxicological reference values

UR: unit risk

US EPA: United States Environmental Protection Agency

WHO: World Health Organisation

1. INTRODUCTION

In Europe, most of the municipal and some industrial sludge are spread on land. The fertilising properties of these sludge have been recognised for many years and their application on agricultural lands for more than 30 years is considered as an environmental and economical sustainable practice. Because of the presence of chemical substances and pathogens in sludge, precaution measures have to be taken to guarantee food safety and the preservation of soils and other environmental compartments. The landspreading activity has to respect the 86/278 directive and specific member states regulation. Most of these texts include threshold limits for trace elements (heavy metals, organic compounds) concentration in the sludge. Until now the level of these limit values was not clearly justified.

The objective of this document is to propose a quantitative risk assessment methodology devoted to the specific case of sludge landspreading. This methodology is focused on chemical substances and adapted from the classical risk assessment methods. Besides, the methodology gives insights to evaluate separately the risks associated to the exposure to the background concentration (due to substances present in daily food and present commonly in soils) and the risks directly linked to sludge spreading.

Four steps are classically considered for risk assessment:

- substances selection,
- toxicity evaluation,
- evaluation of the exposure,
- risk assessment.

The basic assumption in this work is that sludge landspreading is done in accordance with the regulatory aspects.

2. SUBSTANCE SELECTION

The substance selection is a key step of the quantitative risk assessment process.

Three criteria are defined to make an appropriate selection of a given substance:

- the presence in the source term (sludge),
- the occurrence of toxic effects and existence of corresponding toxicological reference values (see section 3.2),
- the possibility for this substance to be transferred to the human targets.

In the present approach, the selected substances come from drafts related to the revision of the Directive of the European Parliament and of the Council on Spreading on Land [CEC, 2000, 2003]. These substances are:

- cadmium,
- chromium,
- copper,
- mercury,

- nickel,
- lead,
- zinc,
- polycyclic aromatic hydrocarbons (PAHs) : acenapthen, phenanthren, benzo(b+j+k)fluoranthen, benzo(ghi)perylen, indeno(1, 2, 3-c, d)pyren, fluoren, fluoranthen, pyren,
- benzo[a]pyren, considered separately from other PAHs because of its higher toxicity,
- polychlorobiphenyls (PCBs) : 28, 52, 101, 118, 138, 153, 180,
- polychlorodibenzodioxins (PCDD) / polychlorodibenzofurans (PCDF),
- nonylphenol and nonylphenols ethoxylated with one or two ethoxy groups (NPE),
- bis(2-ethylhexyl)phthalate (DEHP),
- linear alkyl sulphonates (LAS).

3. TOXICITY EVALUATION

The toxicity evaluation phase of the human health risk assessment is divided in two steps:

- evaluation of the potential hazard of the substance,
- definition of the toxicological reference values (TRV).

Concerning this phase of the evaluation process, a distinction between threshold effect and non-threshold effect has to be done.

Threshold effects are defined as the effects for which a threshold of action exists and for which it is possible to find a range of dose without effect. Non-threshold effects are effects for which none threshold of action exists. For each dose, a probability of risk exists. These effects are generally genotoxic or carcinogenic.

A same substance can generate both effects.

For threshold effects, substance harmlessness is expressed by the notion of Reference Dose (RfD), which corresponds to the acceptable dose for an organism and for which none deleterious effect has been observed. The higher the RfD is, the less dangerous the substance is.

For non-threshold effect, the risk is expressed by the notion of Unit Risk (UR) whatever the exposure pathway. It represents the probability associated to one dose. Contrary to threshold effect, the higher the UR is, the more dangerous the substance is.

3.1 HAZARD IDENTIFICATION

For each substance, the identification of the potential hazard consists in defining the effects of each substance (both threshold and non-threshold effect) on the organs. Identification of these effects is done by international organisms and the description of these effects is available on corresponding databases.

3.2 TOXICOLOGICAL REFERENCE VALUE

TRV selected in the present study are detailed in table 1 to table 3.

Table 1: selected TRV for threshold effects by ingestion (except food ingestion) and inhalation exposure pathways.

	ingestion pathway (except food ingestion)		**inhalation pathway**	
	TRV in mg/kg.j	critical organ or effect	TRV in mg/m^3	critical organ or effect
cadmium	1×10^{-3} [US EPA, 1985]	kidney	2×10^{-5} [OEHHA, 2003]	kidney, respiratory
chromium III	1.5 [US EPA, 1998]		6×10^{-2} [RIVM, 2001]	respiratory
copper	0.14 [RIVM, 2001]	liver, kidney	10^{-3} [RIVM, 2001]	liver
inorganic mercury	nc		3×10^{-4} [US EPA, 1995]	nervous system
organic mercury	10^{-4} [US EPA, 2001]	neuropsychological development	nc	
nickel	2×10^{-2} [US EPA, 1996]	growth	5×10^{-5} [RIVM, 2001]	respiratory
lead	3.5×10^{-3} [WHO, 2004]	blood-lead level	5×10^{-4} [WHO, 2000]	blood-lead level
zinc	0.3 [US EPA, 1992]	blood	nc	
PCBs *	2×10^{-5} [WHO, 2003]	immune system, eye	0.5×10^{-3} [RIVM, 2001]	growth, liver
benzo[a] pyren	nc		nc	
other PAHs	4×10^{-2} ** [US EPA, 1993]	kidney, liver, blood	nc	
dioxins	1×10^{-9} [WHO, 2000]	neuropsychological development, immune system, reproduction	children: 1.8×10^{-9} adults: 3.2×10^{-9} (derived from WHO [2000])	reproduction
DEHP	2×10^{-2} [US EPA, 1987]	liver	nc	
NPE	4.5×10^{-2} [CSHPF, 2001]	kidney	nc	
LAS	4×10^{-2} [CSHPF, 2001]	growth	nc	

* PCBs 28, 52, 101, 118, 138, 153 and 180; ** based on the conservative value of fluoranthene;
nc : not concerned

Toxicological Reference Values (TRV) were selected from recognized international agencies:

- WHO (World Health Organisation), or joint committee as JECFA (Joint FAO/WHO Expert Committee on Food Additives),
- US EPA (United States Environmental Protection Agency),

- ATSDR (Agency for Toxic Substances and Disease Registry),
- RIVM (RijksInstituut voor Volksgezondheid en Milieu; Dutch National Institute for Public Health and the Environment),
- OEHHA (Office of Environmental Health Hazard Assessment),
- Health Canada,
- CSTEE (Scientific Committee on Toxicity, Ecotoxicity and the Environment).

Table 2: selected TRV for threshold effects by food ingestion.

		Cd	Cr III	Cu	Hg inorganic	Hg organic	Ni	Pb	Zn
adults	TRV in mg/kg.j	1.0×10^{-3}	1.4×10^{-2}	1.4×10^{-1}	7.1×10^{-4}	2.3×10^{-4}	8.6×10^{-3}	3.6×10^{-3}	2.1×10^{-1}
	reference	JECFA, 2003	CSAH, 2003	JECFA, 1982	JECFA, 2003	JECFA, 2003	AFSSA, 2001	JECFA, 2000	CSHPF, 1996
chlidren	TRV in mg/kg.j	1.0×10^{-3}	6.7×10^{-2}	6.7×10^{-1}	7.1×10^{-4}	2.3×10^{-4}	4.0×10^{-2}	3.6×10^{-3}	6.7×10^{-1}
	reference	JECFA, 2003	CSAH, 2003	JECFA, 1982	JECFA, 2003	JECFA, 2003	AFSSA, 2001	JECFA, 2000	CSAH, 2003
	critical effect or organ	kidney		liver, kidney	neuropsychological development		growth	blood-lead level	blood

Table 3: selected TRV for non-threshold effects.

	ingestion pathway	inhalation pathway
	TRV in $(mg/kg.j)^{-1}$	TRV in $(mg/m^3)^{-1}$
cadmium	pv	1.8 [US EPA, 1992]
chromium III	nc	nc
copper	nc	nc
inorganic mercury	nc	nc
organic mercury	nc	nc
nickel	pv	0.38 [OMS, 2000]
lead	nc	nc
zinc	nc	nc
PCBs *	Children : 2 Adults : 0.4 [US EPA, 1997]	nc
benzo[a]pyren	0.2 [RIVM, 2001]	1.1 [OEHHA, 2002]
other PAHs	0.02 [RIVM, 2001] + TEF of 0.1	0.11 [OEHHA, 2002] + TEF of 0.1
dioxins	nc	nc
DEHP	1.4×10^{-2} [US EPA, 1988]	nc
NPE	nc	nc
LAS	nc	nc

* PCBs 28, 52, 101, 118, 138, 153 et 180; nc: not concerned; TEF: toxic equivalence factor

4. EXPOSURE EVALUATION

Exposure of the identified human targets to the chemical substances depends on:

- their concentration and behaviour of each substance in the environment,
- the pathways and the levels of exposure of each person to these substances.

4.1 CONCEPTUAL SCHEME

A conceptual scheme is required to figure out the several transfer pathways that exist between the source (amended soils) and the human targets considered in the risk evaluation.

Three targets are considered in the methodology:

- the neighbours (who live next to the amended plots and consuming crop productions),
- the farmers (working on and living close to the amended soils and consuming products grown on amended soils),
- the general population (consumers of food crop production).

Both direct and indirect possible pathways are identified on the generic conceptual scheme below (see figure 1).

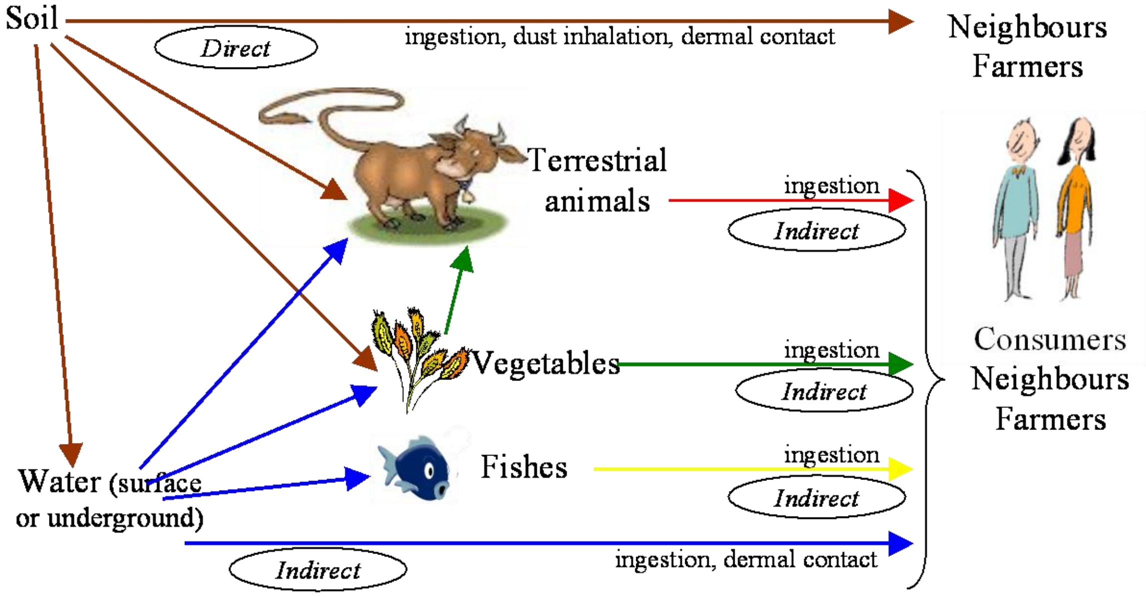

Figure 1: generic conceptual scheme of exposure pathways involved in sludge landspreading

As illustrated above, three direct exposure pathways can be considered: soil ingestion, dust inhalation and dermal contact. This latter was not considered in calculations due to the lack of valuable toxicological data regarding this pathway. The indirect pathways are linked to the consumption of food produced on amended soils (animal and vegetables) or to the exposure to water or fish in contact with water possibly impacted by sludge.

In the present study, the pathways involving waters (surface or underground) were not considered. Indeed, for the surface water, the buffer zone defined within the European member states regulation is supposed to minimise the impact on the quality of the adjacent rivers. Moreover, downward transfer of chemicals from amended soils to underground water was shown to be negligible [Wilson et al., 1996 ; Staples et al., 2001 ; Gove et al., 2001 ; Al-Subu et al., 2003 ; Schowanek et al., 2003].

4.2 CHEMICALS SOILS CONCENTRATIONS

4.2.1 SPECIATION OF MERCURY AND CHROMIUM

It was considered that 99% of mercury was present under its inorganic form and 1% under organic form [Gochfeld, 2003].

For chromium, this substance is considered under its reducing form which is the Chromium III due to soils reducing conditions [Bader et al., 1999 ; Kimbrough et al., 1999].

4.2.2 SLUDGE CONCENTRATIONS

In this report, we consider a theoretical sludge for which all the regulated compounds are present at their limit values. The selected concentrations in table 4 correspond to concentrations suggested by CEC [2003] at annex III, except for:

- DEHP for which the concentration comes from CEC [2000],
- lead for which we suggest a slight decrease from 750 to 500 mg/kg DM in order to reach an acceptable level of risk with 70 years of exposure and very conservative assumptions.

Table 4: compounds concentrations (mg/kg DM) considered in sludge

Substance	Concentrations considered in sludge
Cadmium	10
Chromium	1 000
Copper	1 000
Mercury	10
Nickel	300
Lead	500
Zinc	2 500
PCB	0.8
Benzo[a]pyren	2
Other PAHs	4
Dioxins	1×10^{-4}
DEHP	100
NPE	450
LAS	5 000

Once again the approach is very conservative in so far as we consider that the sludge landspreading will last 70 years and that any of its compounds at the maximum level allowed during all this time. Such an assumption is justified by the fact that we are considering regulated values, which have to guarantee food safety.

4.2.3 CONCENTRATION DUE TO SLUDGE INPUT OVER THE EXPOSURE TIME

The input concentration for a given substance is defined as the concentration to which the targets are exposed during their life. To calculate this concentration, the characteristics of the spreading operations (duration and frequency of sludge application) and the duration of the exposure should be considered as described below.

It is assumed that an average mass (3 tons of DM per ha and per year) of sludge is spread each year. It is a conservative quantity regarding actual European agricultural practices, which are closer to 2 tons of DM per ha and per year due mainly to the fertilising value of the sludge.

Over the entire frame of the exposure, the cumulative input of chemicals due to consecutive sludge inputs has to be considered.

For the substances that might be degraded in soils over the exposure time, a degradation factor is integrated. The degradation mechanism is supposed to fit an exponential law, modelled as following.

Concentration in year n (X_n) is linked to the concentration in the first year (year of spreading, X_1) by the following equation:

$$X_n = X_1 \text{ x } \exp [-\ln(2) \text{ x } (n-1) / T_{1/2}]$$

where $T_{1/2}$ is the half-life time of the substance is the soil considered in years.

Selected half-life times are shown in the table 5.

Table 5: half-life times selected for degradation.

Substance	Half-life time (year)	Source
Benzo[a]pyren	40.7	NRC, 2002
Other PAHs	8.6	NRC, 2002
Dioxins	12	HSDB, 2002
DEHP	1.0	NRC, 2002
NPE	0.41	Health Canada, 2001
LAS	0.082	Litz et al, 1987

PCBs and organic Hg were not considered to degrade in soils.

When the exposure time is lower than the duration of the spreading operation, it is considered that the exposure occurs during the last years of the spreading which corresponds to a conservative approach.

4.2.4 CONCENTRATION DUE TO BACKGROUND LEVEL

The background soil concentration is added to the cumulated concentration due to the sludge inputs as described above. This allows to consider the background soil chemicals concentration in the quantitative risk assessment. This concentration is supposed to be constant over the time.

Background values (table 6) are extracted from the database constituted with the help of EFAR members (around 30 000 data consulted for heavy metals). For organic compounds, values are issued from a literature review [McGrath, 1995;

ADEME, 1995, 2001; Perrono, 1999; CSHPF, 2001; AGHTM, 2002; Benfenati *et al*., 1992; Piqué, 2004; Motelay-Massei *et al*., 2004].

Table 6: considered background in soil (mg/kg DM).

Substance	Soil background concentration (mg/kg)
Cadmium	0.31
Chromium	34.6
Copper	19.1
Mercury	0.13
Nickel	21.1
Lead	23.0
Zinc	60.6
PCB	3.5×10^{-3}
Benzo[a]pyren	0.11
Other PAHs	0.94
Dioxins	10^{-6}
DEHP	0.04
NPE	0.02
LAS	5×10^{-5}

The background values for heavy metals are in coherence with other data in scientific articles.

4.3 TRANSFER PARAMETERS

The above calculated concentrations of the chemicals are used to estimate the transfer of the substances from the amended soils to direct or indirect exposure media such as food (plants and/or animals) defined by the conceptual scheme. This step of the quantitative risk assessment requires the utilisation of transfer parameters that depend on the different transfer media.

4.3.1 CROP TRANSFER PARAMETERS

It consists in the evaluation of a substance concentration using scientific knowledge and particularly field experiments or by modelling. The approach requires either a direct utilisation of transfer factors (bio-concentration factors (BCF) for plants and bio-accumulation factors (BAF) for animals) or empirical modelling of the substance concentration in the media.

4.3.1.1 TYPES OF CROPS CULTIVATED

Five types of crops are taken into account. The theoretical repartition is described in table 7. According to EFAR, these crops are representative of the practices of European member states. Maize, rape and grazing are used for forage and silage and enter animal food.

Table 7: types of crops and repartition.

Type of crop	Part (%)	Type of crop	Part (%)
Grassland	10	Root crops (beet…)	20
Maize	10	Potatoes	10
Cereals (wheat and rape)	50		

4.3.1.2 BIO-CONCENTRATION FACTORS

It is possible to figure substance transfer by using Bio-Concentration Factor notion (BCF). This factor is specific to each substance and to each culture. This factor represents the ratio between concentration of the substance in plant and concentration of the same substance in the soil: that's why the BCF is dimensionless. The BCF in fresh matter are detailed in table 8.

Table 8: BCF values, expressed in fresh matter.

Substance	Grass land	Corn	Cereals	Root crops	Potatoes
Cadmium	6.5×10^{-1} [a,d]	2.0×10^{-1} [f]	1.5×10^{-1} [d,h]	2.0×10^{-1} [i]	4.3×10^{-2} [k]
Chromium	1.2×10^{-2} [b,d]	2.2×10^{-2} [f]	3.4×10^{-3} [d,h]	1.5×10^{-3} [i]	9.9×10^{-4} [l]
Copper	1.3×10^{-1} [a,e]	$1.5 \times 10^{+0}$ [f]	5.3×10^{-1} [d,h]	3.8×10^{-2} [i]	5.2×10^{-2} [l]
Inorganic mercury	1.1×10^{-4} [b]	1.0×10^{-3} [b]	9.6×10^{-4} [b]	8.1×10^{-6} [b]	1.4×10^{-5} [b]
Organic mercury	4.0×10^{-1} [c]	5.7×10^{-1} [f]	1.7×10^{-2} [d,h]	4.7×10^{-1} [i]	8.5×10^{-1} [c]
Nickel	1.4×10^{-1} [a,e]	1.0×10^{-1} [f]	6.4×10^{-3} [d,h]	8.3×10^{-3} [i]	4.5×10^{-3} [l]
Lead	1.5×10^{-2} [a,d]	4.1×10^{-2} [f]	5.7×10^{-3} [d,h]	5.9×10^{-3} [i]	3.4×10^{-4} [k]
Zinc	2.3×10^{-1} [a,e]	$1.1 \times 10^{+0}$ [f]	2.9×10^{-1} [d,h]	3.7×10^{-2} [i]	1.9×10^{-2} [k]
Dioxins	5.6×10^{-4} [c]	4.0×10^{-3} [c]	5.0×10^{-3} [c]	5.8×10^{-4} [c]	9.6×10^{-4} [c]
PCBs	1.4×10^{-3} [c]	9.5×10^{-3} [g]	1.2×10^{-2} [c]	5.2×10^{-3} [j]	2.7×10^{-3} [c]
Benzo[a]pyren	1.3×10^{-3} [c]	8.9×10^{-3} [c]	1.2×10^{-2} [c]	1.5×10^{-3} [c]	1.9×10^{-4} [l]
other PAHs	2.7×10^{-3} [c]	1.8×10^{-2} [c]	2.4×10^{-2} [c]	3.3×10^{-3} [c]	3.4×10^{-4} [l]
DEHP	2.9×10^{-4} [c]	2.2×10^{-3} [c]	2.6×10^{-3} [c]	2.4×10^{-4} [c]	4.0×10^{-4} [c]
NPE	2.0×10^{-3} [c]	1.4×10^{-2} [c]	1.8×10^{-2} [c]	2.5×10^{-3} [c]	4.1×10^{-3} [c]
LAS	2.8×10^{-2} [c]	1.8×10^{-1} [c]	2.5×10^{-1} [c]	3.6×10^{-2} [c]	5.9×10^{-2} [c]

a: Baxter *et al*. [1980], b: Baes [1982], c: Versluijs *et al*. [1998], d: Pinet *et al*. [2003], e: Davis [1979], f: Heffron *et al*. [1980], g: Webber *et al*. [1994], h: Toullec [2003], i: Colombé [1999], j: Weber *et al*. [1981], k: Dudka *et al*. [1996], l: Samsøë-Petersen *et al*. [2002]

4.3.2 ANIMAL PRODUCTS TRANSFER PARAMETERS

4.3.2.1 TYPES OF ANIMAL PRODUCTS

Three categories of animal products are considered:

- beef, veal, and horse,
- sheep and lamb,
- pork.

4.3.2.2 BIO-ACCUMULATION FACTORS

It's possible to figure substance transfer by using Bio-Accumulation Factor notion (BAF). This factor is specific to each substance and to each culture.

This factor represents the ratio between concentration of the substance in the animal (more especially in the muscle because it's the part consumed) and concentration of the same substance in the diet ingested, that's why the BAF is dimensionless.

The BAF values used in this study are detailed in table 10.

On base of Laurent et al. [2003] studies, we consider that an animal ingests:

- 4% of soil,
- 48% of forage/grazing,
- 48% of silage (maize and rape).

As for plant products, we need the values in fresh matter. The dry matter contents were selected from US EPA [1997]: 28.4% for beef, 30% for pork, 26,6% for sheep.

4.3.2.3 BAF USED IN THE CALCULATION

It's possible to calculate a global BAF which is determined by this manner:

$$BAF_{global} = 0.04 \times BAF_{soil} + 0.48 \times BCF_{forage} \times BAF_{forage} + 0.48 \times BCF_{silage} \times BAF_{silage}$$

The BAF values are given in table 9.

Table 9: global BAF values, in fresh matter.

Substance	Beef, veal, horse	Sheep, lamb	Pork
Cadmium	4.0×10^{-6}	3.7×10^{-6}	1.7×10^{-6}
Chromium	4.4×10^{-7}	nv	nv
Copper	5.0×10^{-6}	nv	2.1×10^{-1}
Mercury inorganic	nv	nv	nv
Mercury organic	7.2×10^{-7}	7.6×10^{-7}	6.7×10^{-7}
Nickel	4.0×10^{-6}	6.4×10^{-6}	nv
Lead	2.2×10^{-6}	nv	2.3×10^{-3}
Zinc	3.4×10^{-4}	1.6×10^{-4}	7.6×10^{-1}
Dioxins	2.5×10^{-3}	2.7×10^{-3}	2.4×10^{-3}
PCB	4.7×10^{-4}	5.0×10^{-4}	4.4×10^{-4}
benzo[a]pyren	5.0×10^{-4}	5.3×10^{-4}	4.7×10^{-4}
other HAP	1.7×10^{-4}	nv	1.5×10^{-4}
DEHP	1.1×10^{-2}	nv	1.0×10^{-2}
NPE	2.5×10^{-4}	nv	2.3×10^{-4}
LAS	1.1×10^{-5}	nv	1.0×10^{-5}

nv: no value

Table 10: detailed BAF Values, in fresh matter.

Substance	Beef, veal, horse				Pork				Sheep, Lamb			
	soil	grassland	cereals	reference	soil	grassland	cereals	reference	soil	grassland	cereals	reference
Cadmium	nv	$1.1x10^{-5}$	$4.4x10^{-6}$	Laurent et al., 2002	nv	nv	$3.8x10^{-5}$	Laurent et al., 2002	$4.0x10^{-6}$	$5.3x10^{-6}$	$4.1x10^{-9}$	Laurent et al., 2002
Chromium	nv	$7.4x10^{-5}$	nv	Laurent et al., 2002	nv	nv	nv		$4.4x10^{-7}$	nv	nv	
Copper	nv	$2.8x10^{-5}$	$4.4x10^{-6}$	Laurent et al., 2002	nv	nv	nv		$5.0x10^{-6}$	$3.2x10^{+0}$	$4.9x10^{-5}$	Laurent et al., 2002 + Liu, 2003
Mercury inorganic	nv	nv	nv		nv	nv	nv		nv	nv	nv	
Mercury organic	$3.0x10^{-7}$	$3.0x10^{-6}$	$4.6x10^{-7}$	Travis and Arms, 1988	$3.2x10^{-7}$	$3.2x10^{-6}$	$4.8x10^{-7}$	Travis and Arms, 1988	$7.1x10^{-7}$	$2.8x10^{-6}$	$4.3x10^{-7}$	
Nickel	nv	$3.7x10^{-5}$	$3.0x10^{-5}$	Laurent et al., 2002	nv	nv	$1.3x10^{-4}$	Laurent et al., 2002	$4.0x10^{-6}$	nv	nv	
Lead	nv	$2.8x10^{-4}$	$4.4x10^{-6}$	Laurent et al., 2002	nv	nv	nv		$2.2x10^{-6}$	$3.1x10^{-1}$	$6.5x10^{-5}$	Laurent et al., 2002 + Liu, 2003
Zinc	nv	$3.6x10^{-4}$	$5.5x10^{-4}$	Laurent et al., 2002	nv	nv	$2.9x10^{-4}$	Laurent et al., 2002	$3.4x10^{-4}$	$7.0x10^{+0}$	$1.6x10^{-6}$	Laurent et al., 2002 + Liu, 2003
dioxins	$5.5x10^{-2}$	$5.5x10^{-1}$	$8.5x10^{-2}$	Travis and Arms, 1988	$5.8x10^{-2}$	$5.8x10^{-1}$	$9.0x10^{-2}$	Travis and Arms, 1988	$2.5x10^{-3}$	$5.2x10^{-1}$	$7.9x10^{-2}$	
PCB	$8.9x10^{-3}$	$8.9x10^{-2}$	$1.4x10^{-2}$	Travis and Arms, 1988	$9.4x10^{-3}$	$9.4x10^{-2}$	$1.4x10^{-2}$	Travis and Arms, 1988	$4.7x10^{-4}$	$8.3x10^{-2}$	$1.3x10^{-2}$	
benzo[a]pyren	$9.5x10^{-3}$	$9.5x10^{-2}$	$1.5x10^{-2}$	Travis and Arms, 1988	$1.0x10^{-2}$	$1.0x10^{-1}$	$1.5x10^{-2}$	Travis and Arms, 1988	$5.0x10^{-4}$	$8.9x10^{-2}$	$1.4x10^{-2}$	
other HAP	$2.5x10^{-3}$	$2.5x10^{-2}$	$3.8x10^{-3}$	Travis and Arms, 1988	nv	nv	nv		$1.7x10^{-4}$	$2.3x10^{-2}$	$3.6x10^{-3}$	
DEHP	$2.6x10^{-1}$	$2.6x10^{+0}$	$4.0x10^{-1}$	Travis and Arms, 1988	nv	nv	nv		$1.1x10^{-2}$	$2.4x10^{+0}$	$3.7x10^{-1}$	
NPE	$4.1x10^{-3}$	$4.1x10^{-2}$	$6.3x10^{-3}$	Travis and Arms, 1988	nv	nv	nv		$2.5x10^{-4}$	$3.9x10^{-2}$	$5.9x10^{-3}$	
LAS	$3.5x10^{-5}$	$3.5x10^{-4}$	$5.3x10^{-5}$	Travis and Arms, 1988	nv	nv	nv		$1.1x10^{-5}$	$3.2x10^{-4}$	$5.0x10^{-5}$	

nv: no value

4.4 EXPOSURE PARAMETERS

The exposure parameters aim to describe the physiological characteristics and the comportment of the targets considered in the quantitative risk assessment. The parameters vary according to the age (e.g. children are considered distinctly from adults) and to the activity of the targets (e.g. consumers are considered distinctly from farmers)

4.4.1 EXPOSURE AND SPREADING TERMS

A sludge spreading term of 70 years is taken because it corresponds to the entire life term usually considered in health risk assessment.

In a equivalent way as what it can be done in health risk assessment, the sensitive character of children is taken during the six first years of their life. After, they are taken considered as adults. The exposure durations are 6 years for children, 64 years for adults and 40 years for farmers which correspond to their professional activities.

To be as conservative as possible, the years of exposure correspond to the end of the spreading, it means to the years where the accumulation is maximum. For each year, it's possible to calculate an exposure concentration. Then, an average exposure concentration is calculated for each target population over the entire exposure frame.

4.4.2 PHYSIOLOGICAL PARAMETERS

The physiological parameters are resumed in table 11.

Table 11: physiological parameters.

Parameter	Adult value (6-70 years)	Child value (0-6 years)	Source
Body mass	70 kg	15 kg	[US EPA, 1997]
Body surface	1.815 m²	0.656 m²	[US EPA, 1997, 2004]
Breath volume	20 m^3/day	7.6 m^3/day	[Veerkamp and ten Berge, 1994]

4.4.3 SOIL INGESTION

Table 12: daily quantity of ingested soils for the different targets.

Target	Child	Adult	Farmer
Soil mass ingested (mg/d)	150	50	215
Reference	Conventional values used in health risk assessment		Cf calculation below

Caillaud [2002] figured the quantity of dust breath by a farmer was 18 mg/m^3. Based of a inhalation rate for physic activities of 1.5 m^3/h [US EPA, 1997] and daily work time of 8 hours, we can consider a quantity of soil ingested of almost 215 mg/d.

4.4.4 DUST INHALATION

This transfer from soils to inhaled dust is evaluated using the conservative RIVM approach. Quantity of dust inhaled (table 13) is figured out dust concentration in air and retention factor in lung.

Table 13: exposure parameters.

Target	Child neighbour	Adult neighbour	Farmer
Dust concentration in inhaled air (kg/m^3)	7×10^{-8}	7×10^{-8}	2×10^{-5}
Retention factor in lung (-)	0.75	0.75	0.1
Source	Veerkamp and ten Berge [1994]		Caillaud [2002]

We consider that the half of dust concentration originates from amended soil [Veerkamp and ten Berge, 1994].

4.4.5 FREQUENCY AND DURATION OF EXPOSURE

Farmer exposure duration is based on data from the « Bureau de Coordination du Machinisme Agricole » (july 2001). Data available is relative to the number of hectares realized by operation type and by crop type. That's why it's possible to build an hour rate by type of culture. The data are the following:

- standing crop (roots: 0.8 hectares per hour, potatoes: 0.3 hectares per hour, cereals: 2 hectares per hour, maize: 1.5 hectares per hour),
- culture maintenance (only for potatoes): 0.4 hectares per hour,
- agricultural fertilizers spreading (whatever the culture): 3 hectares per hour,
- sowing (whatever the culture): 1 hectare per hour,
- cultivation after cereals: 1.5 hectares per hour.

The crop that needs the most important time is potatoes, its hour-rate is 7.2 hours per hectare. To be conservative, we considered that the average farm surface is of 100 ha and that a farmer will spend 800 hours for the cultivation of his parcels.

For the other targets, frequency and duration of exposure (table 14) are based on conservative assumptions. For example, a child neighbour is supposed to play 2 hours a day, 92 days a year, near the amended plots.

Table 14: frequency and duration of exposure.

Target	Child neighbour	Adult neighbour	Farmer
Daily time exposure outside (hour/day)	2	1	800 hours/year
Exposure day per year outside (day/year)	92	26	
Exposure frequency outside (-)	3.0×10^{-3}	2.1×10^{-2}	9.1×10^{-2}

4.4.6 ANIMAL AND PLANT PRODUCTS CONSUMPTION

Data about animal and plant product consumption (table 15) are extracted from a database called CIBLEX [2003], which used data from INSEE (a French institute specialized in France demography and habits).

Table 15: quantities of animal and plant products consumed by the different target population in g/day.

Type of food	Child	Adult
Cereals	106	187
Roots	18	31
Potatoes	56	78
Beef, veal, horse	32	43
Pork	37	77
Sheep, lamb	15	27

Preliminary calculations showed that exposure via food ingestion was the major exposure pathway (more than 95% of the global risk level for some targets). Due to that, it was decided in the methodology to consider both the ingestion of food produced on amended and non-amended soils. Regarding the quantities of sludge spread on land throughout Europe, it was considered than 5% of food crop production were concerned by sludge spreading.

Including the self-sufficiency productions, table 16 gives the percentage of products concerned by sludge spreading. For animal products and for the potatoes of the farmer, we make a distinction between:

- the consumption values at a national level which are used for child and adult consumers: agricultural production concerned by sludge spreading is equal to 5% at European level,
- the consumption values at the local level which are used for child and adult neighbours and farmers: they traduced the fact that this type of population will have tendency to consume the products produced in self-sufficiency.

Table 16: percentage of products concerned by sludge spreading.

Type of food	Consumers (national level)	Neighbours (specific values)	Farmers (specific values)
Cereals	5%	5%	5%
Roots	5%	5%	5%
Potatoes	5%	5%	81.7%
Beef, veal, horse	5%	7.8%	41.5%
Pork	5%	9.4%	48.5%
Sheep, lamb	5%	8.7%	34.2%

4.5 EXPOSURE EQUATIONS

Table 17 gives equation for different direct or indirect exposure pathways. These equations use the different transfer or exposure parameters described above, and allow the calculation of a daily exposure dose (DED).

Table 17: equations to evaluate targets exposure.

DED by soil ingestion	
$\frac{M_{\text{ingested soil}} C_i \times F}{BW}$	$M_{\text{soil ingested}}$: soil ingested mass C_i : i Substance concentration F : Exposure concentration BW :body weight
DED by dermal contact	
$\frac{M_{\text{soil on skin}} \times S_{\text{body}} \times \tau_{\text{i dermal}} \times C_i \times F}{BW \times \tau_{\text{i oral}}}$	$M_{\text{soil on skin}}$: Soil mass by skin surface unit S_{body} : Body Surface $\tau_{\text{i dermal}}$: Dermal absorption rate of i substance $\tau_{\text{i oral}}$: Oral absorption rate of i substance
DED by dust inhalation	
$[Part]_{air} \times f \times C_i \times F \times Retention$	$[Part]_{air}$: Dust concentration in outside air f : Soil Particles fraction in outside air (0,5) R : retention factor in lung
DED by plant products ingestion	
$\frac{C_i \times \sum_k (Cons_k \times BCF_{ik})}{BW}$	$Cons_k$: Daily consumption of food k category BCF_{ik} : Bio-Concentration factor of the substance i in food k category
DED by animal products ingestion	
$\frac{C_i \times \sum_k (Cons_k \times BAF_{ik})}{BW}$	BAF_{ik} : Bio-Accumulation factor of the substance i in food k category

5. RISK CALCULATION

From the exposure and the toxicological reference values, the risks are quantified for both the threshold and non-threshold effects.

5.1 THRESHOLD EFFECTS

For threshold effects, assessment is based on the calculation of a hazard quotient (HQ) which is determined as following:

$$HQ = \frac{\text{daily exposure dose (DED)}}{\text{toxicological reference value (TRV)}}$$

When HQ is lower than one, none adverse effect is expected for the population, even for sensible population. Beyond the reference value of one, deleterious effect can appear. For threshold effect, the sum of each hazard quotient must be done when toxic effect affects the same organ by the same action mechanism.

5.2 NON-THRESHOLD EFFECTS

For non-threshold effect, i.e. carcinogenic effects, evaluation is based on the calculation of an excess of risk (ER) which is determined as following :

ER = daily exposure dose (DED) $\times$ toxicological reference value (TRV)

The acceptable reference level usually varies from 10^{-6} to 10^{-4}. As the background soil concentrations highly influence the global risk levels, a reference level of 10^{-5} is considered here. For non-threshold effects, ER sum is systematic and is based on an independence of carcinogenic effects of the substances.

5.3 RESULTS

5.3.1 CUMULATIVE THRESHOLD EFFECTS

As illustrated in table 18, with the selected concentrations in sludge (see table 4), all the hazard quotients are less than one, and we can consider that the risks associated to the threshold effects are acceptable. The most important hazard quotient concerns the effects on kidney for children, which is slightly less than one: 0.99. This closeness with the acceptable limit of one may be considered relevant as:

- the main assumptions lead to a conservative approach,
- this report suggests some limit values for compounds present in sludge,
- these global results take into account the exposure both to the sludge and to the background. The section 5.3.3.1 will detail these two exposures and will focus on the contribution of sludge landspreading.

Table 18: cumulated hazard quotients by organ or effect.

Organs or effects	consumer		neighbours		farmer
	Adult	Child	Adult	Child	adult
respiratory	nc	nc	5.2×10^{-5}	4.7×10^{-4}	6.8×10^{-2}
growth	6.9×10^{-2}	5.1×10^{-2}	6.9×10^{-2}	5.2×10^{-2}	8.2×10^{-2}
neuropsychologic development	1.6×10^{-1}	4.3×10^{-1}	1.6×10^{-1}	4.4×10^{-1}	1.9×10^{-1}
liver	2.3×10^{-1}	1.4×10^{-1}	2.3×10^{-1}	1.5×10^{-1}	2.7×10^{-1}
eye	9.6×10^{-3}	3.2×10^{-2}	9.6×10^{-3}	3.2×10^{-2}	1.6×10^{-2}
blood-lead level	1.3×10^{-1}	3.5×10^{-1}	1.3×10^{-1}	3.5×10^{-1}	1.4×10^{-1}
kidney	5.3×10^{-1}	9.9×10^{-1}	5.3×10^{-1}	9.9×10^{-1}	6.1×10^{-1}
reproduction	2.1×10^{-2}	5.6×10^{-2}	2.1×10^{-2}	5.7×10^{-2}	2.5×10^{-2}
blood	3.4×10^{-1}	3.1×10^{-1}	3.5×10^{-1}	3.1×10^{-1}	4.3×10^{-1}
immune system	1.6×10^{-1}	4.4×10^{-1}	1.6×10^{-1}	4.4×10^{-1}	1.9×10^{-1}
peripheric nervous system	1.3×10^{-1}	3.5×10^{-1}	1.3×10^{-1}	3.5×10^{-1}	1.5×10^{-1}

nc : non concerned

In all the cases, plants product consumption is the major way of exposure: more than 90% for farmers and more than 95% for other targets. The second way of exposure is the animal products consumption.

Several substances contribute to these results. As illustrated in figure 2, lead, cadmium, and copper contribute mainly to the threshold effects for children neighbours.

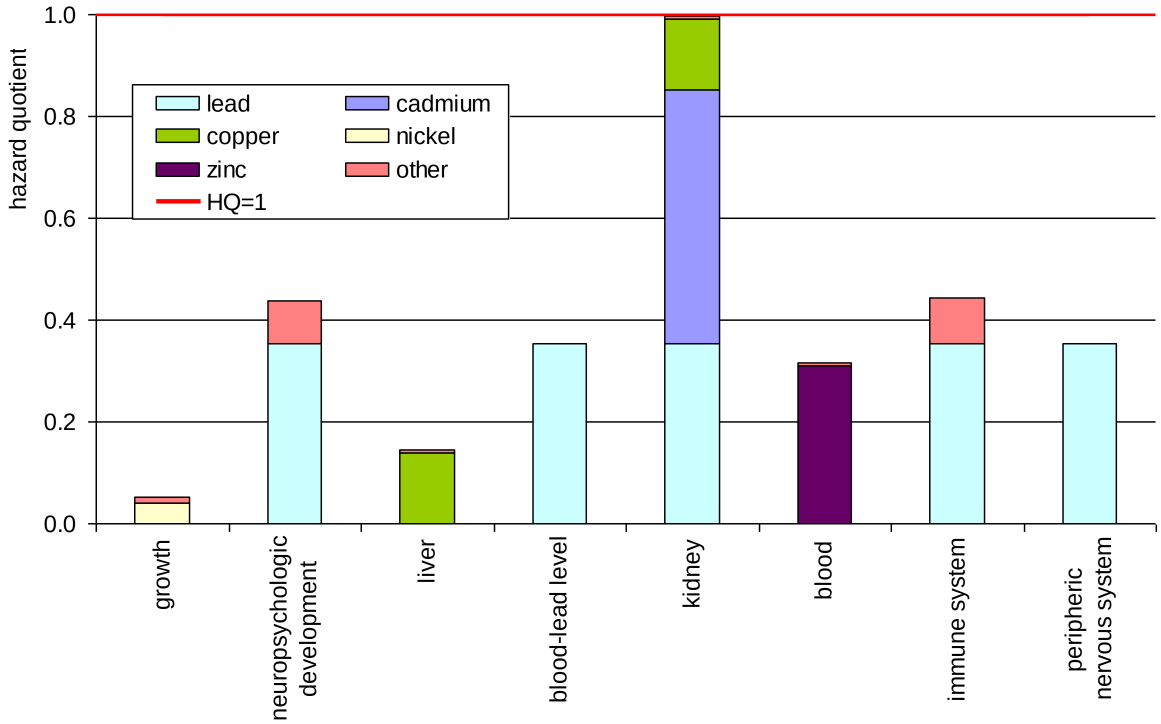

Figure 2: contribution of substances for the threshold effects of children neighbours.

5.3.2 CUMULATIVE NON-THRESHOLD EFFECTS

Non threshold effects are presented in table 19 for each concerned substance. Specific adult and child scenarios are considered. Besides, cumulative scenarios are also considered. For the farmers, the cumulative scenario integrates:

- 6 years as a neighbour child,
- 40 years as an adult farmer,
- 24 years as an adult neighbour.

Table 19: cumulated excesses of risk by target.

	Consumers			**Neighbours**			**Farmers**	
	adult	child	cumul	adult	child	cumul	adult	cumul
Cadmium	nc	nc	nc	8.5×10^{-11}	7.9×10^{-11}	1.6×10^{-10}	7.2×10^{-08}	7.3×10^{-08}
Nickel	nc	nc	nc	8.6×10^{-10}	7.1×10^{-10}	1.6×10^{-09}	7.0×10^{-07}	7.0×10^{-07}
PCBs	7.0×10^{-08}	1.1×10^{-07}	1.8×10^{-07}	7.0×10^{-08}	1.1×10^{-07}	1.8×10^{-07}	7.2×10^{-08}	2.1×10^{-07}
Benzo[a]pyren	7.0×10^{-07}	1.8×10^{-07}	8.8×10^{-07}	7.0×10^{-07}	1.8×10^{-07}	8.8×10^{-07}	4.6×10^{-07}	9.0×10^{-07}
Other PAHs	1.1×10^{-06}	2.8×10^{-07}	1.4×10^{-06}	1.1×10^{-06}	2.8×10^{-07}	1.4×10^{-06}	7.2×10^{-07}	1.4×10^{-06}
DEHP	9.3×10^{-09}	2.7×10^{-09}	1.2×10^{-08}	9.8×10^{-09}	2.9×10^{-09}	1.3×10^{-08}	1.1×10^{-08}	1.7×10^{-08}
Sum	1.9×10^{-6}	5.7×10^{-7}	2.5×10^{-6}	1.9×10^{-6}	5.8×10^{-7}	2.5×10^{-6}	2.0×10^{-6}	3.3×10^{-6}

nc: non concerned; non-mentioned substances do not present non-treshold effects

In all the cases, the global risks for non-threshold effects are acceptable. The most important excess of risk concerns the entire-life farmer: 3.3×10^{-6}.

As illustrated in figure 3, PAHs are the major substances for all the targets: more than 95% for adults, more than 80% for children and almost 70% for entire-life farmers. For children, PCBs contribute for 19% of the risk levels. For adult farmers, nickel contributes for 34% of risk levels.

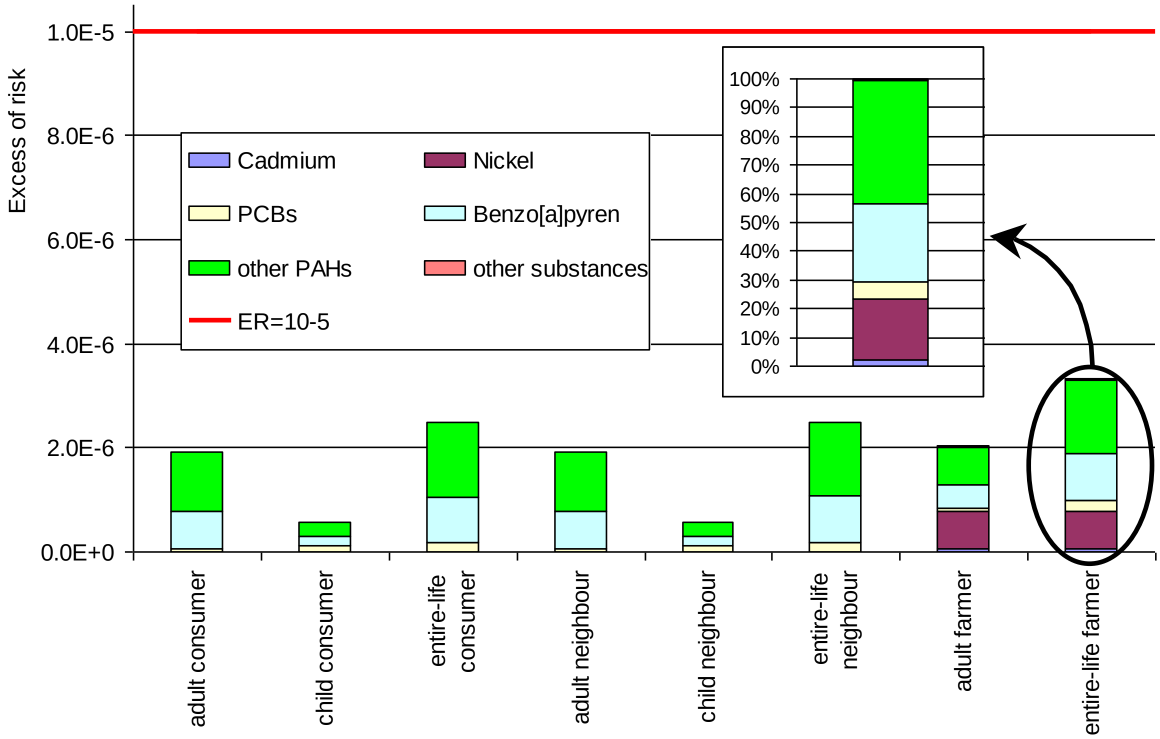

Figure 3: relative contributions of substances for non-threshold effects.

In all the cases, plants product consumption is the major way of exposure: more than 60% for adult farmers and more than 97% for other targets. The second way of exposure is the dust inhalation for the farmers and the animal products consumption for other targets.

5.3.3 Discussion

To put the results into perspective, we have:

- calculated the contribution of background exposure,
- simulated an exposure to an “average” sludge,
- made the assessment of the conservative assumptions.

5.3.3.1 Background contributions

The figure 4 presents for each threshold effect on the children neighbours the contribution of the background exposure (substances in soils and food) and the sludge contribution itself. This figure shows that the main contributor to the global risk level for threshold effects are the background levels in chemicals. The sludge contribution ranges from 7% to 27% of the global risks level depending on the considered effect.

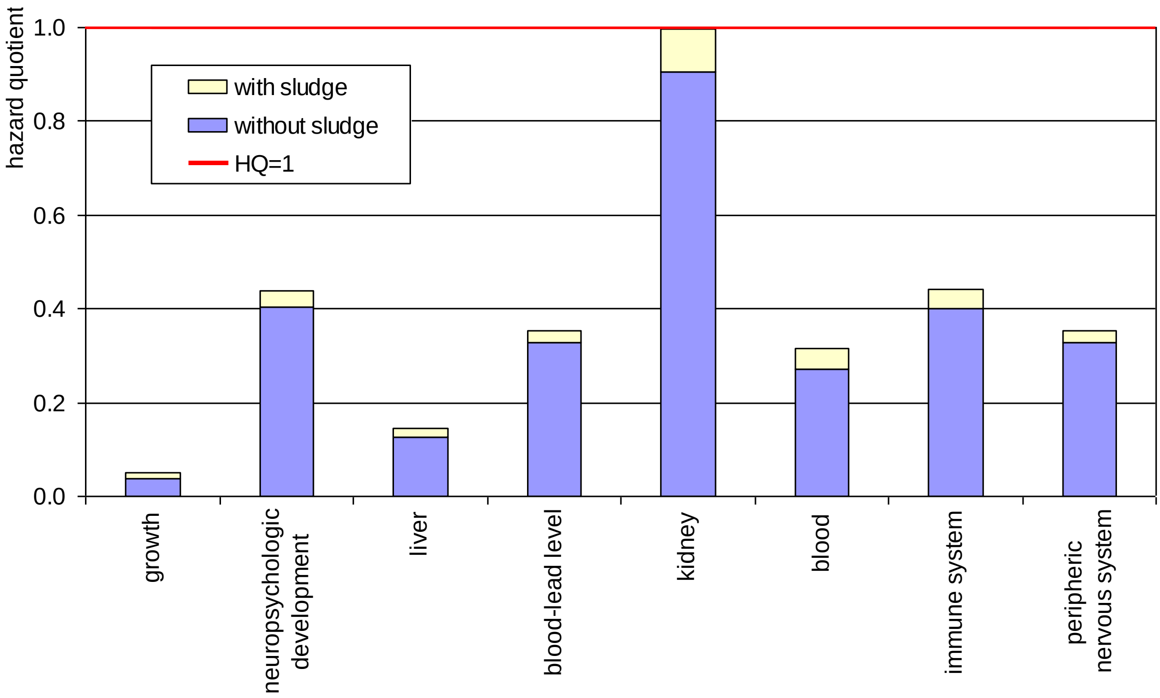

Figure 4: respective background and sludge landspreading contributions for threshold effects on children neighbours.

The figure 5 presents for each target the contribution of the background exposure (substances in soils and food) and the sludge contribution itself for non-threshold effects. As previously, this figure shows that the main contributor to the global risk level for non-threshold effects is the chemicals found in the background. The sludge contribution ranges from 2% to 20% of the global risks level depending on the considered target.

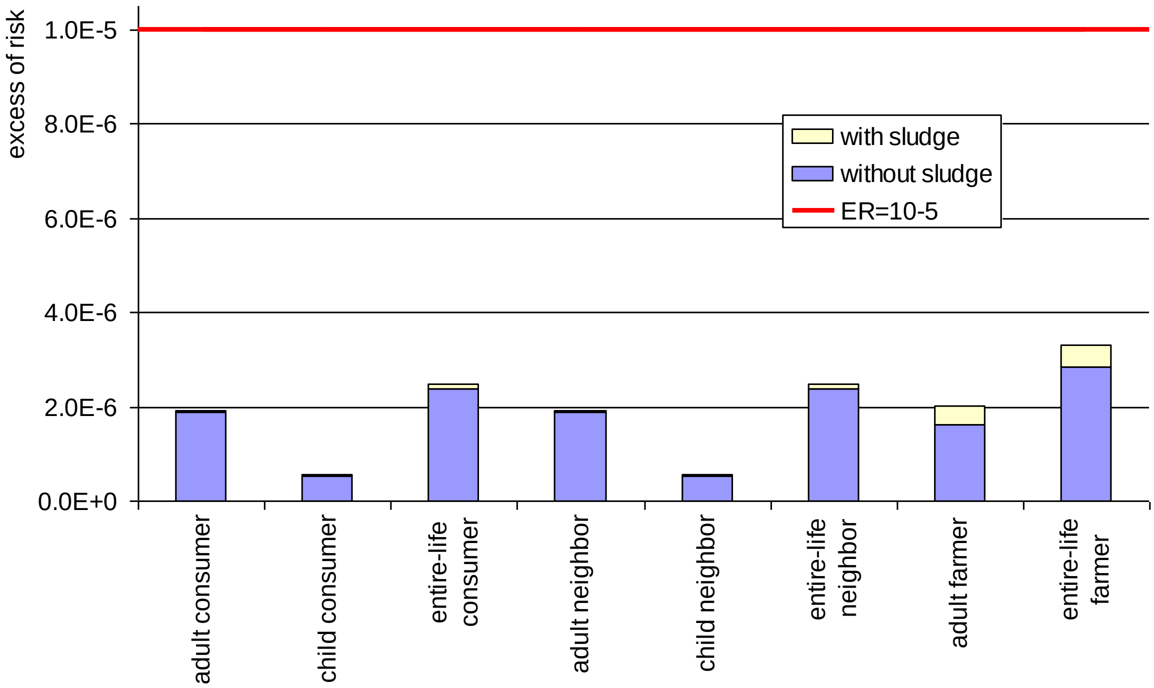

Figure 5: respective background and sludge landspreading contributions for non-threshold effects.

Without the contribution of the background, the exposure to sludge lead to widely acceptable risks both for threshold and non-threshold effects: the most important hazard quotient is 0.11 for the threshold effects on blood for farmers, and the most important excess of risk is 4.6×10^{-7} for the entire-life farmer.

5.3.3.2 EXPOSURE TO AN "AVERAGE" SLUDGE

In order to compare the results with the limit values, we have calculated the risks related to an exposure to an "average" sludge. The considered concentrations in such an "average" sludge are described in table 20, and come from a study of AGHTM [2002].

Table 20: compounds concentrations (mg/kg DM) in an "average" sludge

Substance	Concentration in sludge (mg/kg)	Substance	Concentration in sludge (mg/kg)
Cadmium	2.6	PCB	0.12
Chromium	49	Benzo[a]pyren	0.28
Copper	293	Other PAHs	2.0
Mercury	2.2	Dioxins	1.1×10^{-5}
Nickel	28	DEHP	42
Lead	68	NPE	145
Zinc	813	LAS	2018

With these concentrations, the risks remain acceptable. The most important hazard quotient is 0.91 for the cumulative threshold effects on kidney for children, and the most important cumulative excess of risk is 2.9×10^{-6} for the entire-life farmer. If we consider only the contribution of the spread sludge, the most important hazard quotient is 0.02 for the cumulative threshold effects on kidney for children, and the most important cumulative excess of risk is 6.1×10^{-8} for the entire-life farmer.

In the case of an "average" sludge, the main contribution is due to the exposure to background concentrations as illustrated by figure 6. The sludge contribution for threshold effects ranges from 1% to 12% of the global risks level depending on the considered effect. The sludge contribution for non-threshold effects ranges from 0.4% to 3% of the global risks level depending on the considered target.

5.3.3.3 SYNTHESIS OF CONSERVATIVE ASSUMPTIONS

The most important conservative assumption is to consider the exposure during all the life (70 years) to the spreading, at a rate of 3 tons of DM per ha and per year, of a theoretical sludge for which all the regulated compounds are present at their limit values.

Concerning the toxicity evaluation, the following conservative assumptions may be underlined:

- the TRV are calculated by recognised agencies to be protective for sensible population (e.g. children),
- for the non-threshold effects of PAHs, we applied a TEF of 0.1 for all the other PAHs than benzo[a]pyren even if the TEF range from 0.001 to 0.1.

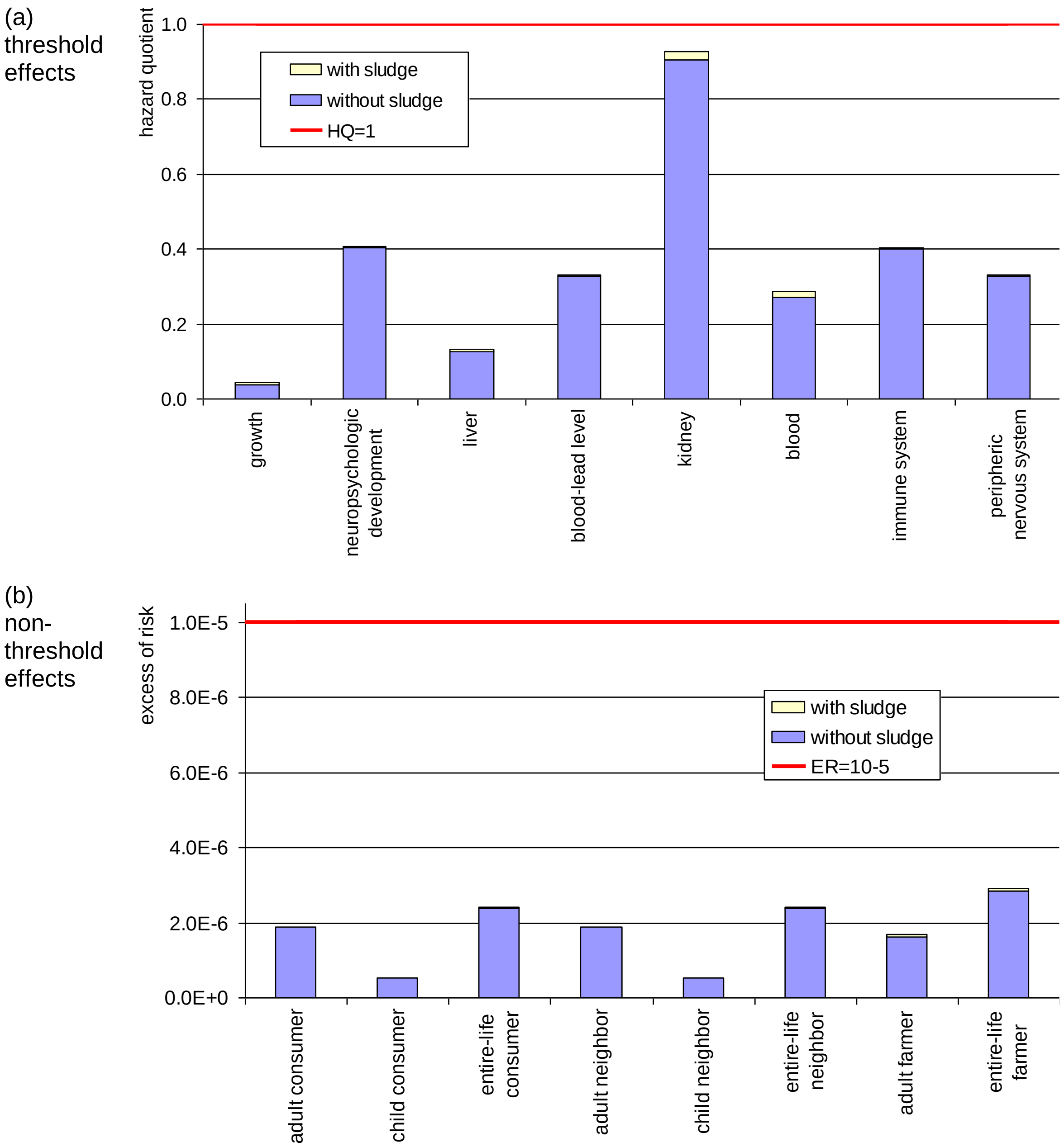

Figure 6: respective background and "average" sludge landspreading contributions for threshold effects on children neighbours (a) and non-threshold effects (b).

Concerning the transfer parameters (BCF and BAF), the following conservative assumptions may be underlined:

- BCF and BAF for inorganic compounds are generally specific and based on literature review: when several values are available, the most conservative has been chosen,
- BCF and BAF for organic compounds are generally calculated by empirical equations, which leads to over-estimated transfer factors,
- BCF and BAF are always considered on raw aliments, even if the population consumes prepared aliments.

Concerning the exposure parameters, the following conservative assumptions may be underlined:

- the exposure of children has been considered over the last 6 years of spreading, when the concentrations in soils are the highest,
- frequencies and duration of exposure correspond to worse case scenarios,
- parameters for soil ingestion and dust inhalation have been chosen between the most conservative values,
- we have supposed that 100% of all compounds would be bioavailable, even if only one part (actually non quantifiable) of the exposure quantities is metabolised to lead to the adverse effects.

5.4 QUALITATIVE UNCERTAINTY ANALYSIS

An uncertainty analysis is required in the quantitative risk assessment procedure. This analysis should mention and recall any hypothesis, uncertainty factors and their impact on the risk calculation. This step concerns all the phases of the evaluation process.

In this particular case, the quantitative risk assessment is generic as calculations are done on the values based on the European Directive project. The uncertainty analysis is more adapted to a specific case scenario. From a general point of view, following points can be discussed.

Uncertainties in the exposure evaluation are associated to three levels:

- targets and uses,
- models used,
- parameters definition.

Concerning the targets and uses in this generic case, the exposure associated to underground and surface water was not taken into account in the quantitative risk assessment calculation.

Concerning definition of the parameters, soil-plant BCF values have to be estimated very carefully as the plant ingestion is the pathway which mostly contribute to the risk levels.

Adapted to specific cases, the BCF selection could be improved by selection of values adapted to the specific soil and sludge properties.

6. CONCLUSIONS AND PERSPECTIVES

The quantitative risk assessment is conducted with respect to a conservative approach. For example, all the considered concentrations of chemicals in the sludge correspond to the limit values we suggested. Calculations using these assumptions show that the global risk levels are acceptable. It means that the suggested limit values are compatible with health regulations.

These limit values correspond to:

- the values from the appendix III of the document entitled « Proposal for a Directive of the European Parliament and of the Council on Spreading on Land» [CEC, 2003],

- except for DEHP (which is not included in this document), for which we suggest to consider 100 mg/kg DM [CEC, 2000],
- except for lead for which we suggest a slight decrease from 750 to 500 mg/kg DM in order to reach an acceptable level of risk with 70 years of exposure and very conservative assumptions.

Public health risk assessment appears as an effective method to evaluate the relevance of the limit values that have to be regulated in the context of sludge landspreading. If needed, this method could be applied to assess the accuracy of other sets of limit values.

The quantitative results of this study allow us to determine these main points:

- the major exposure pathway is the ingestion of plant and animal products,
- the major substances are heavy metals (zinc, lead, cadmium, copper and nickel) for threshold effects and PAHs for non-threshold effects (and also to a certain extent PCBs for children and nickel for farmers),
- the contribution of sludge landspreading to the global risk is low in comparison with the contribution of the ingestion of food produced on non spread lands.

According to these results and to the assumptions made in the method, it is possible to suggest some improvements that could be taken into account for the sludge directive revision:

- benzo[a]pyren should be considered separately from other PAHs,
- some organic compounds like DEHP, LAS and NPE do not contribute significantly to the global risk,
- a buffer zone between amended soils and rivers should be proposed in order to prevent any impact of sludge spreading on the quality of superficial waters.

As all risk assessment, developing specific studies on the following aspects could refine this method: bioconcentration factors for organic compounds, bioaccumulation factors for animals for all compounds, speciation of chromium and mercury in soils, bioavailability of substances.

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Appendix: spreadsheets

Substances

Substances	orga-nic ?	log Kow	Kow	Kd	source	taux d'absorption dermique (/24h)	source	demi-vie (an)	source
Cadmium	non			2.1E+2		0.010	US EPA, 1992		
Chromium III	non					0.001	US EPA, 2000		
Copper	non			2.7E+0	fiches de	0.001	US EPA, 2000		
Mercury inorganic	non			6.0E+4	données	0.001	US EPA, 2000		
Mercury organic	oui	1.7	5.0E+1	6.7E+3	toxicologiques	0.010	US EPA, 2000		pas de dégradation
Nickel	non			3.6E+1	et environne-	0.001	US EPA, 2000		
Lead	non			7.0E+0	mentales de	0.001	US EPA, 2000		
Zinc	non			2.0E+0	l'INERIS	0.001	US EPA, 2000		
Dioxins	oui	6.8	6.3E+6	9.6E+5		0.030	US EPA, 2004	12.0	HSDB, 2002
PCBs	oui	6.0	1.1E+6			0.140	US EPA, 2004		pas de dégradation
Benzo[a]pyren	oui	6.1	1.1E+6		fiches toxicologi-	0.130	US EPA, 2004	40.7	NCR, 2002
other PAHs	oui	5.5	3.2E+5		ques et environ-	0.130	US EPA, 2004	8.6	NCR, 2002
DEHP	oui	7.45	2.8E+7		Ellebaek Laursen et	0.010	US EPA, 2000	1.0	NCR, 2002
NPE	oui	5.7	5.1E+5		HSDB, 2003	0.010	US EPA, 2000	0.4	Santé Canada, 2001
LAS	oui	3.7	5.0E+3		AGHTM, 2002	0.010	US EPA, 2000	0.1	Litz et al., 1987

Targets

		1a - Consomma-teurs adulte	1b - Consomma-teurs enfant	2a - Riverain adulte	2b - Riverain enfant	3a - Agriculteur adulte	Source biblio
âge	ans	06 - 70	0 - 6	06 - 70	0 - 6	06 - 70	convention en EQRS
durée d'exposition	ans	64	6	64	6	40	convention en EQRS
masse corporelle	kg	70	15	70	15	70	US EPA, 1997
volume d'air inhalé	m3/j	20	7.6	20	7.6	20	Veerkamp and ten Berge, 1994
masse de sol ingéré (extérieur)	mg/j			50	150	216	cf. guide méthodologique
surface corporelle totale	m2			1.815	0.656	1.815	US EPA, 1997, 2004
quantité de sol sur la peau	kg/m2			0.003	0.005	0.004	US EPA, 2004 ; Shell, 1995 ;
concentration inhalée en poussières (extérieur)	kg/m3			7.0E-8	7.0E-8	2.0E-5	Veerkamp and ten Berge, 1994 ;
concentration inhalée en poussières (intérieur)	kg/m3						Caillaud, 2002
facteur de rétention des particules dans les poumons	-			0.75	0.75	0.1	Veerkamp and ten Berge, 1994 ; Caillaud, 2002
durée journalière d'exposition (extérieur)	h/j			1.0	2.0	8.0	choix définis spécifiquement dans
jours d'exposition (extérieur)	j/an			26	92	100	le cadre de ce rapport
fréquence d'exposition (extérieur)	-			0.003	0.021	0.091	calculs
rapport T/Tm pour les effets sans seuil	-	0.914	0.086	0.914	0.086	0.571	calculs
ingestion de sol (extérieur)	exposition chronique			oui	oui	oui	
contact cutané (extérieur)							choix effectués dans le cadre des
inhalation de poussières (extérieur)				oui	oui	oui	scénarios définis spécifiquement
consommation de végétaux		oui	oui	oui	oui	oui	pour ce rapport
consommation d'animaux		oui	oui	oui	oui	oui	
Ratio plan d'épandage considéré / SAU		5.000%	5.000%	5.000%	5.000%	5.000%	
consommation de vég1 - céréales	kg/j	0.187	0.106	0.187	0.106	0.187	CIBLEX, 2003
fraction produite sur plan d'épandage	-	5.000%	5.000%	5.000%	5.000%	5.000%	expertise + CIBLEX, 2003
consommation de vég2 - légumes feuilles	kg/j	0.044	0.020	0.044	0.020	0.044	CIBLEX, 2003
fraction produite sur plan d'épandage	-	5.000%	5.000%	5.000%	5.000%	5.000%	expertise + CIBLEX, 2003
consommation de vég3 - légumes fruits	kg/j	0.181	0.115	0.181	0.115	0.181	CIBLEX, 2003
fraction produite sur plan d'épandage	-	5.000%	5.000%	5.000%	5.000%	5.000%	expertise + CIBLEX, 2003
consommation de vég4 - légumes racines	kg/j	0.031	0.018	0.031	0.018	0.031	CIBLEX, 2003
fraction produite sur plan d'épandage	-	5.000%	5.000%	5.000%	5.000%	5.000%	expertise + CIBLEX, 2003
consommation de vég5 - pommes de terre	kg/j	0.078	0.056	0.078	0.056	0.078	CIBLEX, 2003
fraction produite sur plan d'épandage	-	5.000%	5.000%	5.000%	5.000%	81.700%	expertise + CIBLEX, 2003
consommation de bœuf, veau, cheval	kg/j	0.043	0.032	0.043	0.032	0.043	CIBLEX, 2003
fraction produite sur plan d'épandage	-	5.000%	5.000%	7.800%	7.800%	41.490%	expertise + CIBLEX, 2003
consommation de mouton, agneau	kg/j	0.027	0.015	0.027	0.015	0.027	CIBLEX, 2003
fraction produite sur plan d'épandage	-	5.000%	5.000%	9.360%	9.360%	48.460%	expertise + CIBLEX, 2003
consommation de porc	kg/j	0.077	0.037	0.077	0.037	0.077	CIBLEX, 2003
fraction produite sur plan d'épandage	-	5.000%	5.000%	8.660%	8.660%	34.230%	expertise + CIBLEX, 2003

Plots

Surface agricole utile (SAU)	ha	2 000
Surface agricole amendée en France	ha	
Surface du plan d'épandage considéré	ha	100.0
Quantité de boues apportées sur l'ensemble du plan d'épandage (MS)	t/an	300.0

Pourcentage de SAU amendée en France	
Ratio plan d'épandage considéré / SAU	5.0%
Quantité moyenne de boues épandues par hectare sur le plan d'épandage considéré	3.0 t/ha.an

		Moyenne pondérée par surface	source biblio	type de culture								
type de culture mise en place	-			betterave sucrière	blé	chicorée	colza	maïs	orge	pomme de terre	prairie	RGI
superficie de sol amendé	ha			20.0	33.3		16.7	10.0		10.0	5.0	5.0
quantité de boues apportées à la parcelle par épandage	t		calculs	60	100		50	30		30	15	15
profondeur d'enfouissement des boues	cm	25.0	expertise	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
volume de sol amendé	m3		calculs	50 000	83 333		41 667	25 000		25 000	12 500	12 500
densité du sol sec amendé	t/m3	1.30	expertise	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
masse de sol sec amendé	t		calculs	65 000	108 333		54 167	32 500		32 500	16 250	16 250
facteur de dilution des boues à chaque apport	-	0.09%	calculs	0.09%	0.09%		0.09%	0.09%		0.09%	0.09%	0.09%
fraction de sol dans les particules dans l'air extérieur	-	0.50	Veerkamp and ten Berge, 1994	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50

		Sol 1			**Sol 2**		
surface	ha	50.0			50.0		
caractéristiques générales	-	sols de type argilo-limoneux avec présence significative de calcaire			sols de type limoneux		
		Moyenne pondérée par surface	minimum	maximum	Moyenne pondérée par surface	minimum	maximum
pH du sol amendé	-	7.6	6.7	8.1	7.6	6.7	8.1
matières organiques du sol	g/kg	21.4	18.0	34.0	21.4	18.0	34.0
fraction argileuse	-	16.1%	10.8%	26.9%	16.1%	10.8%	26.9%
fraction limoneuse fine	-	27.1%	16.5%	32.6%	27.1%	16.5%	32.6%
fraction limoneuse grossière	-	41.7%	25.5%	51.9%	41.7%	25.5%	51.9%
fraction sableuse fine	-	8.9%	5.0%	22.5%	8.9%	5.0%	22.5%
fraction sableuse grossière	-	3.6%	0.7%	12.2%	3.6%	0.7%	12.2%

Concentrations in soils and sludges

Concentrations		Sols						Boues					
		bruit de fond moyen au niveau national	1a - Consommateurs adulte	1b - Consommateurs enfant	2a - Riverain adulte	2b - Riverain enfant	3a - Agriculteur adulte	concentration moyenne au niveau national	1a - Consommateurs adulte	1b - Consommateurs enfant	2a - Riverain adulte	2b - Riverain enfant	3a - Agriculteur adulte
Cadmium	mg/kg	3.1E-1	6.6E-1	9.3E-1	6.6E-1	9.3E-1	7.7E-1	1.0E+1	3.6E-1	6.2E-1	3.6E-1	6.2E-1	4.7E-1
Chromium III	mg/kg	3.5E+1	7.0E+1	9.7E+1	7.0E+1	9.7E+1	8.1E+1	1.0E+3	3.6E+1	6.2E+1	3.6E+1	6.2E+1	4.7E+1
Copper	mg/kg	1.9E+1	5.5E+1	8.1E+1	5.5E+1	8.1E+1	6.6E+1	1.0E+3	3.6E+1	6.2E+1	3.6E+1	6.2E+1	4.7E+1
Mercury inorganic	mg/kg	1.3E-1	4.8E-1	7.5E-1	4.8E-1	7.5E-1	5.9E-1	1.0E+1	3.6E-1	6.2E-1	3.6E-1	6.2E-1	4.7E-1
Mercury organic	mg/kg	1.3E-3	4.8E-3	7.5E-3	4.8E-3	7.5E-3	5.9E-3	1.0E-1	3.6E-3	6.2E-3	3.6E-3	6.2E-3	4.7E-3
Nickel	mg/kg	2.1E+1	3.2E+1	4.0E+1	3.2E+1	4.0E+1	3.5E+1	3.0E+2	1.1E+1	1.9E+1	1.1E+1	1.9E+1	1.4E+1
Lead	mg/kg	2.3E+1	4.1E+1	5.4E+1	4.1E+1	5.4E+1	4.6E+1	5.0E+2	1.8E+1	3.1E+1	1.8E+1	3.1E+1	2.3E+1
Zinc	mg/kg	6.1E+1	1.5E+2	2.2E+2	1.5E+2	2.2E+2	1.8E+2	2.5E+3	8.9E+1	1.6E+2	8.9E+1	1.6E+2	1.2E+2
Dioxins	mg/kg	1.0E-6	2.3E-6	2.6E-6	2.3E-6	2.6E-6	2.5E-6	1.0E-4	1.3E-6	1.6E-6	1.3E-6	1.6E-6	1.5E-6
PCBs	mg/kg	3.5E-3	3.2E-2	5.3E-2	3.2E-2	5.3E-2	4.1E-2	8.0E-1	2.8E-2	5.0E-2	2.8E-2	5.0E-2	3.7E-2
Benzo[a]pyren	mg/kg	1.1E-1	1.6E-1	1.9E-1	1.6E-1	1.9E-1	1.7E-1	2.0E+0	5.0E-2	7.5E-2	5.0E-2	7.5E-2	6.2E-2
other PAHs	mg/kg	9.4E-1	9.8E-1	9.9E-1	9.8E-1	9.9E-1	9.9E-1	4.0E+0	4.2E-2	4.7E-2	4.2E-2	4.7E-2	4.6E-2
DEHP	mg/kg	4.0E-2	2.2E-1	2.2E-1	2.2E-1	2.2E-1	2.2E-1	1.0E+2	1.8E-1	1.8E-1	1.8E-1	1.8E-1	1.8E-1
NPE	mg/kg	2.0E-2	5.3E-1	5.3E-1	5.3E-1	5.3E-1	5.3E-1	4.5E+2	5.1E-1	5.1E-1	5.1E-1	5.1E-1	5.1E-1
LAS	mg/kg	5.0E-5	4.6E+0	4.6E+0	4.6E+0	4.6E+0	4.6E+0	5.0E+3	4.6E+0	4.6E+0	4.6E+0	4.6E+0	4.6E+0

durée d'un plan d'épandage
70 ans

Bioconcentration factors (BCF) 1/8

prise en compte des dépôts atmosphériques: oui; nombre de végétaux: 10	vég1 - céréales	vég2 - légumes feuilles	vég3 - légumes fruits	vég4 - légumes racines	vég5 - pommes de terre	vég6 - fruits	vég7 - ensilage	vég8 - fourrage	
surfaces (ha)	33.3333			20	10		26.6667	10	
rendement (kg/m2)	0.30	0.38	0.11	0.11	0.11	0.11	0.20	0.30	
période de croisance (j)	180	100	180	180	180	180	180	180	
fraction interceptée (-)	0.4	0.4	0.4			0.4	0.4	0.4	
taux de déposition (mg/m2.j)	60	60	60			60	60	60	
constante climatique (j-1)	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	
facteur de déposition (mg poussière / kg plante MS)	2017	1355	5308			5308	3026	2017	
BCF (en matières fraîches) pondérés par surfaces cultivées avec prise en compte des dépôts atmosphériques	1.5E-1			2.0E-1	4.3E-2		2.0E-1	6.5E-1	Cadmium
	3.4E-3			1.5E-3	9.9E-4		2.2E-2	1.2E-2	Chromium III
	5.3E-1			3.8E-2	5.2E-2		1.5E+0	1.3E-1	Copper
	9.6E-4			8.1E-6	1.4E-5		1.0E-3	1.1E-4	Mercury inorganic
	1.7E-2			4.7E-1	8.5E-1		5.7E-1	4.0E-1	Mercury organic
	6.4E-3			8.3E-3	4.5E-3		1.0E-1	1.4E-1	Nickel
	5.7E-3			5.9E-3	3.4E-4		4.1E-2	1.5E-2	Lead
	2.9E-1			3.7E-2	1.9E-2		1.1E+0	2.3E-1	Zinc
	5.0E-3			5.8E-4	9.6E-4		4.0E-3	5.6E-4	Dioxins
	1.2E-2			5.2E-3	2.7E-3		9.5E-3	1.4E-3	PCBs
	1.2E-2			1.5E-3	1.9E-4		8.9E-3	1.3E-3	Benzo[a]pyren
	2.4E-2			3.3E-3	3.4E-4		1.8E-2	2.7E-3	other PAHs
	2.6E-3			2.4E-4	4.0E-4		2.2E-3	2.9E-4	DEHP
	1.8E-2			2.5E-3	4.1E-3		1.4E-2	2.0E-3	NPE
	2.5E-1			3.6E-2	5.9E-2		1.8E-1	2.8E-2	LAS

Bioconcentration factors (BCF) 2/8

culture	betterave sucrière							
surface (ha)	20.0							
teneur en MS (-)	0.127 (US EPA, 1997)							
type d'aliment	vég4 - légumes racines							
facteur de déposition (kg sol/kg plante MF)								
Type de sol	Sol 1			Sol 2			BCF calculé racine + aérien (MF)	BCF retenu (MF)
BCF bruts	expéri-mental	poids sec ?	source biblio	expéri-mental	poids sec ?	source biblio		
Cadmium	1.6E+0	oui	Colombé, 1999	1.6E+0	oui	Colombé, 1999	4.6E-3	2.0E-1
Chromium III	1.2E-2	oui	Colombé, 1999	1.2E-2	oui	Colombé, 1999		1.5E-3
Copper	3.0E-1	oui	Colombé, 1999	3.0E-1	oui	Colombé, 1999	6.0E-1	3.8E-2
Mercury inorganic							8.1E-6	8.1E-6
Mercury organic	3.7E+0	oui	Colombé, 1999	3.7E+0	oui	Colombé, 1999	5.1E-1	4.7E-1
Nickel	6.5E-2	oui	Colombé, 1999	6.5E-2	oui	Colombé, 1999	3.3E-2	8.3E-3
Lead	4.6E-2	oui	Colombé, 1999	4.6E-2	oui	Colombé, 1999	2.1E-1	5.9E-3
Zinc	2.9E-1	oui	Colombé, 1999	2.9E-1	oui	Colombé, 1999	8.4E-1	3.7E-2
Dioxins							5.8E-4	5.8E-4
PCBs	4.1E-2	oui	Weber et al., 1981	4.1E-2	oui	Weber et al., 1981	1.6E-3	5.2E-3
Benzo[a]pyren							1.5E-3	1.5E-3
other PAHs							3.3E-3	3.3E-3
DEHP							2.4E-4	2.4E-4
NPE							2.5E-3	2.5E-3
LAS							3.6E-2	3.6E-2

Bioconcentration factors (BCF) 3/8

culture	blé							
surface (ha)	33.3							
teneur en MS (-)	0.897 (US EPA, 1997)							
type d'aliment	vég1 - céréales							
facteur de déposition (kg sol/kg plante MF)	9.05E-04							
Type de sol	Sol 1			Sol 2			BCF calculé racine + aérien (MF)	BCF retenu (MF)
BCF bruts	expéri-mental	poids sec ?	source biblio	expéri-mental	poids sec ?	source biblio		
Cadmium	1.7E-1	oui	Toullec, 2003	1.7E-1	oui	Toullec, 2003	3.3E-2	1.5E-1
Chromium III	3.8E-3	oui	Toullec, 2003	3.8E-3	oui	Toullec, 2003	9.1E-4	3.4E-3
Copper	5.9E-1	oui	Toullec, 2003	5.9E-1	oui	Toullec, 2003	4.3E+0	5.3E-1
Mercury inorganic							9.6E-4	9.6E-4
Mercury organic	2.0E-2	oui	Toullec, 2003	2.0E-2	oui	Toullec, 2003	3.6E+0	1.7E-2
Nickel	7.1E-3	oui	Toullec, 2003	7.1E-3	oui	Toullec, 2003	2.3E-1	6.4E-3
Lead	6.3E-3	oui	Toullec, 2003	6.3E-3	oui	Toullec, 2003	1.5E+0	5.7E-3
Zinc	3.3E-1	oui	Toullec, 2003	3.3E-1	oui	Toullec, 2003	6.0E+0	2.9E-1
Dioxins							5.0E-3	5.0E-3
PCBs							1.2E-2	1.2E-2
Benzo[a]pyren							1.2E-2	1.2E-2
other PAHs							2.4E-2	2.4E-2
DEHP							2.6E-3	2.6E-3
NPE							1.8E-2	1.8E-2
LAS							2.5E-1	2.5E-1

Bioconcentration factors (BCF) 4/8

culture	colza							
surface (ha)	16.7							
teneur en MS (-)	0.900 (US EPA, 1997 + expertise)							
type d'aliment	vég7 - ensilage							
facteur de déposition (kg sol/kg plante MF)	1.36E-03							
Type de sol	Sol 1			Sol 2			BCF calculé racine + aérien (MF)	BCF retenu (MF)
BCF bruts	expéri-mental	poids sec ?	source biblio	expéri-mental	poids sec ?	source biblio		
Cadmium	2.1E-1	oui	Pinet et al., 2003	2.1E-1	oui	Pinet et al., 2003	3.4E-2	1.9E-1
Chromium III	3.7E-2	oui	Pinet et al., 2003	3.7E-2	oui	Pinet et al., 2003	1.4E-3	3.3E-2
Copper	2.6E+0	oui	Pinet et al., 2003	2.6E+0	oui	Pinet et al., 2003	4.3E+0	2.4E+0
Mercury inorganic							1.4E-3	1.4E-3
Mercury organic	9.0E-1	oui	Pinet et al., 2003	9.0E-1	oui	Pinet et al., 2003	3.6E+0	8.1E-1
Nickel	1.8E-1	oui	Pinet et al., 2003	1.8E-1	oui	Pinet et al., 2003	2.4E-1	1.6E-1
Lead	5.2E-2	oui	Pinet et al., 2003	5.2E-2	oui	Pinet et al., 2003	1.5E+0	4.7E-2
Zinc	2.0E+0	oui	Pinet et al., 2003	2.0E+0	oui	Pinet et al., 2003	6.0E+0	1.8E+0
Dioxins							5.5E-3	5.5E-3
PCBs							1.3E-2	1.3E-2
Benzo[a]pyren							1.2E-2	1.2E-2
other PAHs							2.4E-2	2.4E-2
DEHP							3.1E-3	3.1E-3
NPE							1.9E-2	1.9E-2
LAS							2.5E-1	2.5E-1

Bioconcentration factors (BCF) 5/8

culture	maïs							
surface (ha)	10.0							
teneur en MS (-)	0.240 (US EPA, 1997)							
type d'aliment	vég7 - ensilage							
facteur de déposition (kg sol/kg plante MF)	3.64E-04							
Type de sol	Sol 1			Sol 2			BCF calculé racine + aérien (MF)	BCF retenu (MF)
BCF bruts	expéri-mental	poids sec ?	source biblio	expéri-mental	poids sec ?	source biblio		
Cadmium	8.9E-1	oui	Heffron et al., 1980	8.9E-1	oui	Heffron et al., 1980	9.1E-3	2.2E-1
Chromium III	1.9E-2	oui	Heffron et al., 1980	1.9E-2	oui	Heffron et al., 1980	3.6E-4	4.7E-3
Copper	3.7E-1	oui	Heffron et al., 1980	3.7E-1	oui	Heffron et al., 1980	1.1E+0	8.9E-2
Mercury inorganic							3.8E-4	3.8E-4
Mercury organic	7.5E-1	oui	Heffron et al., 1980	7.5E-1	oui	Heffron et al., 1980	9.7E-1	1.8E-1
Nickel	1.9E-2	oui	Heffron et al., 1980	1.9E-2	oui	Heffron et al., 1980	6.3E-2	4.4E-3
Lead	1.3E-1	oui	Heffron et al., 1980	1.3E-1	oui	Heffron et al., 1980	3.9E-1	3.1E-2
Zinc	4.7E-1	oui	Heffron et al., 1980	4.7E-1	oui	Heffron et al., 1980	1.6E+0	1.1E-1
Dioxins							1.5E-3	1.5E-3
PCBs	1.6E-2	oui	Webber et al., 1994	1.6E-2	oui	Webber et al., 1994	3.4E-3	3.9E-3
Benzo[a]pyren							3.3E-3	3.3E-3
other PAHs							6.5E-3	6.5E-3
DEHP							8.2E-4	8.2E-4
NPE							5.0E-3	5.0E-3
LAS							6.8E-2	6.8E-2

Bioconcentration factors (BCF) 6/8

culture	**pomme de terre**							
surface (ha)	10.0							
teneur en MS (-)	0.210 (US EPA, 1997)							
type d'aliment	vég5 - pommes de terre							
facteur de déposition (kg sol/kg plante MF)								
Type de sol	Sol 1			Sol 2			BCF calculé racine + aérien (MF)	BCF retenu (MF)
BCF bruts	expéri-mental	poids sec ?	source biblio	expéri-mental	poids sec ?	source biblio		
Cadmium	2.0E-1	oui	Dudka et al., 1996	2.0E-1	oui	Dudka et al., 1996	7.6E-3	4.3E-2
Chromium III	4.7E-3	oui	Samsoe-Petersen et al, 2002	4.7E-3	oui	Samsoe-Petersen et al, 2002		9.9E-4
Copper	2.5E-1	oui	Samsoe-Petersen et al, 2002	2.5E-1	oui	Samsoe-Petersen et al, 2002	1.0E+0	5.2E-2
Mercury inorganic							1.4E-5	1.4E-5
Mercury organic							8.5E-1	8.5E-1
Nickel	2.1E-2	oui	Samsoe-Petersen et al, 2002	2.1E-2	oui	Samsoe-Petersen et al, 2002	5.5E-2	4.5E-3
Lead	1.6E-3	oui	Dudka et al., 1996	1.6E-3	oui	Dudka et al., 1996	3.4E-1	3.4E-4
Zinc	9.0E-2	oui	Dudka et al., 1996	9.0E-2	oui	Dudka et al., 1996	1.4E+0	1.9E-2
Dioxins							9.6E-4	9.6E-4
PCBs							2.7E-3	2.7E-3
Benzo[a]pyren	9.1E-4	oui	Samsoe-Petersen et al, 2002	9.1E-4	oui	Samsoe-Petersen et al, 2002	2.6E-3	1.9E-4
other PAHs	1.6E-3	oui	Samsoe-Petersen et al, 2002	1.6E-3	oui	Samsoe-Petersen et al, 2002	5.4E-3	3.4E-4
DEHP							4.0E-4	4.0E-4
NPE							4.1E-3	4.1E-3
LAS							5.9E-2	5.9E-2

Bioconcentration factors (BCF) 7/8

culture	prairie							
surface (ha)	5.0							
teneur en MS (-)	0.100 (expertise)							
type d'aliment	vég8 - fourrage							
facteur de déposition (kg sol/kg plante MF)	1.01E-04							
Type de sol	Sol 1			Sol 2			BCF calculé racine + aérien (MF)	BCF retenu (MF)
BCF bruts	expéri-mental	poids sec ?	source biblio	expéri-mental	poids sec ?	source biblio		
Cadmium	8.6E+0	oui	Baxter et al., 1980	8.6E+0	oui	Baxter et al., 1980	3.7E-3	8.6E-1
Chromium III							1.0E-4	1.0E-4
Copper	2.6E+0	oui	Baxter et al., 1980	2.6E+0	oui	Baxter et al., 1980	4.7E-1	2.6E-1
Mercury inorganic							1.1E-4	1.1E-4
Mercury organic							4.0E-1	4.0E-1
Nickel	2.6E+0	oui	Baxter et al., 1980	2.6E+0	oui	Baxter et al., 1980	2.6E-2	2.6E-1
Lead	2.8E-1	oui	Baxter et al., 1980	2.8E-1	oui	Baxter et al., 1980	1.6E-1	2.8E-2
Zinc	3.8E+0	oui	Baxter et al., 1980	3.8E+0	oui	Baxter et al., 1980	6.6E-1	3.8E-1
Dioxins							5.6E-4	5.6E-4
PCBs							1.4E-3	1.4E-3
Benzo[a]pyren							1.3E-3	1.3E-3
other PAHs							2.7E-3	2.7E-3
DEHP							2.9E-4	2.9E-4
NPE							2.0E-3	2.0E-3
LAS							2.8E-2	2.8E-2

Bioconcentration factors (BCF) 8/8

culture	RGI							
surface (ha)	5.0							
teneur en MS (-)	0.100 (expertise)							
type d'aliment	vég8 - fourrage							
facteur de déposition (kg sol/kg plante MF)	1.01E-04							
Type de sol	Sol 1			Sol 2			BCF calculé racine + aérien (MF)	BCF retenu (MF)
BCF bruts	expéri-mental	poids sec ?	source biblio	expéri-mental	poids sec ?	source biblio		
Cadmium	4.5E+0	oui	Pinet et al., 2003	4.5E+0	oui	Pinet et al., 2003	3.7E-3	4.5E-1
Chromium III	2.5E-1	oui	Pinet et al., 2003	2.5E-1	oui	Pinet et al., 2003	1.0E-4	2.5E-2
Copper	1.4E-1	oui	Davis, 1979	1.4E-1	oui	Davis, 1979	4.7E-1	1.4E-2
Mercury inorganic							1.1E-4	1.1E-4
Mercury organic							4.0E-1	4.0E-1
Nickel	2.9E-1	oui	Davis, 1979	2.9E-1	oui	Davis, 1979	2.6E-2	2.9E-2
Lead	2.5E-2	oui	Pinet et al., 2003	2.5E-2	oui	Pinet et al., 2003	1.6E-1	2.5E-3
Zinc	6.9E-1	oui	Davis, 1979	6.9E-1	oui	Davis, 1979	6.6E-1	6.9E-2
Dioxins							5.6E-4	5.6E-4
PCBs							1.4E-3	1.4E-3
Benzo[a]pyren							1.3E-3	1.3E-3
other PAHs							2.7E-3	2.7E-3
DEHP							2.9E-4	2.9E-4
NPE							2.0E-3	2.0E-3
LAS							2.8E-2	2.8E-2

Bioaccumulation factors (BAF) 1/3

	bœuf, veau, cheval																	
teneur en MS animal	0.284 (US EPA, 1997)																	BAF pondérés par la ration alimentaire
types d'aliment	sol					vég8 - fourrage						vég7 - ensilage						
part dans l'alimentation	0.04					0.48						0.48						
teneur en MS aliment	non concerné					0.100						0.653						
BAF	expéri-mental	poids sec ?	source biblio	calculé (MF)	retenu (MF)	expéri-mental	poids sec ?		source biblio	calculé (MF)	retenu (MF)	expéri-mental	poids sec ? animal	végétal	source biblio	calculé (MF)	retenu (MF)	
Cadmium						4.0E-6	oui	oui	Laurent et al., 2002		1.1E-5	1.0E-5	oui	oui	Laurent et al., 2002		4.4E-6	4.0E-6
Chromium III						2.6E-5	oui	oui	Laurent et al., 2002		7.4E-5							4.4E-7
Copper						1.0E-5	oui	oui	Laurent et al., 2002		2.8E-5	1.0E-5	oui	oui	Laurent et al., 2002		4.4E-6	5.0E-6
Mercury inorganic																		
Mercury organic				3.0E-7	3.0E-7					3.0E-6	3.0E-6					4.6E-7	4.6E-7	7.1E-7
Nickel						1.3E-5	oui	oui	Laurent et al., 2002		3.7E-5	7.0E-5	oui	oui	Laurent et al., 2002		3.0E-5	4.0E-6
Lead						1.0E-4	oui	oui	Laurent et al., 2002		2.8E-4	1.0E-5	oui	oui	Laurent et al., 2002		4.4E-6	2.2E-6
Zinc						1.3E-4	oui	oui	Laurent et al., 2002		3.6E-4	1.3E-3	oui	oui	Laurent et al., 2002		5.5E-4	3.4E-4
Dioxins				5.5E-2	5.5E-2					5.5E-1	5.5E-1					8.5E-2	8.5E-2	2.5E-3
PCBs				8.9E-3	8.9E-3					8.9E-2	8.9E-2					1.4E-2	1.4E-2	4.7E-4
Benzo[a]pyren				9.5E-3	9.5E-3					9.5E-2	9.5E-2					1.5E-2	1.5E-2	5.0E-4
other PAHs				2.5E-3	2.5E-3					2.5E-2	2.5E-2					3.8E-3	3.8E-3	1.7E-4
DEHP				2.6E-1	2.6E-1					2.6E+0	2.6E+0					4.0E-1	4.0E-1	1.1E-2
NPE				4.1E-3	4.1E-3					4.1E-2	4.1E-2					6.3E-3	6.3E-3	2.5E-4
LAS				3.5E-5	3.5E-5					3.5E-4	3.5E-4					5.3E-5	5.3E-5	1.1E-5

Bioaccumulation factors (BAF) 2/3

	mouton, agneau																
teneur en MS animal	0.266 (US EPA, 1997)																
types d'aliment	sol					vég8 - fourrage						vég7 - ensilage					
part dans l'alimentation	0.04					0.48						0.48					
teneur en MS aliment	non concerné					0.100						0.653					
BAF	expéri-mental	poids sec ?	source biblio	calculé (MF)	retenu (MF)	expéri-mental	poids sec ? animal	poids sec ? végétal	source biblio	calculé (MF)	retenu (MF)	expéri-mental	poids sec ? animal	poids sec ? végétal	source biblio	calculé (MF)	retenu (MF)
Cadmium					4.0E-6	2.00E-6	oui	oui	Laurent et al., 2002		5.32E-6	1.00E-8	oui	oui	Laurent et al., 2002		4.07E-9
Chromium III					4.4E-7												
Copper					5.0E-6	3.20E-1		oui	Liu, 2003 + expertise		3.20E+0	1.20E-4	oui	oui	Laurent et al., 2002		4.89E-5
Mercury inorganic																	
Mercury organic				2.79E-7	7.1E-7					2.79E-6	2.79E-6					4.28E-7	4.28E-7
Nickel					4.0E-6												
Lead					2.2E-6	3.10E-2		oui	Liu, 2003 + expertise		3.10E-1	1.60E-4	oui	oui	Laurent et al., 2002		6.52E-5
Zinc					3.4E-4	7.00E-1		oui	Liu, 2003 + expertise		7.00E+0	3.90E-6	oui	oui	Laurent et al., 2002		1.59E-6
Dioxins				5.18E-2	2.5E-3					5.18E-1	5.18E-1					7.93E-2	7.93E-2
PCBs				8.29E-3	4.7E-4					8.29E-2	8.29E-2					1.27E-2	1.27E-2
Benzo[a]pyren				8.90E-3	5.0E-4					8.90E-2	8.90E-2					1.36E-2	1.36E-2
other PAHs				2.3E-3	1.7E-4					2.3E-2	2.3E-2					3.6E-3	3.6E-3
DEHP				2.4E-1	1.1E-2					2.4E+0	2.4E+0					3.7E-1	3.7E-1
NPE				3.9E-3	2.5E-4					3.9E-2	3.9E-2					5.9E-3	5.9E-3
LAS				3.2E-5	1.1E-5					3.2E-4	3.2E-4					5.0E-5	5.0E-5

Bioaccumulation factors (BAF) 3/3

	porc																
teneur en MS animal	0.300 (US EPA, 1997)																
types d'aliment	sol					vég8 - fourrage						vég7 - ensilage					
part dans l'alimentation	0.04					0.48						0.48					
teneur en MS aliment	non concerné					0.100						0.653					
BAF	expéri-mental	poids sec ?	source biblio	calculé (MF)	retenu (MF)	expéri-mental	poids sec ? animal	poids sec ? végétal	source biblio	calculé (MF)	retenu (MF)	expéri-mental	poids sec ? animal	poids sec ? végétal	source biblio	calculé (MF)	retenu (MF)
Cadmium												8.30E-5	oui	oui	Laurent et al., 2002		3.82E-5
Chromium III																	
Copper																	
Mercury inorganic																	
Mercury organic				3.15E-7	3.15E-7					3.15E-6	3.15E-6					4.83E-7	4.83E-7
Nickel												2.85E-4	oui	oui	Laurent et al., 2002		1.31E-4
Lead																	
Zinc												6.24E-4	oui	oui	Laurent et al., 2002		2.87E-4
Dioxins				5.84E-2	5.84E-2					5.84E-1	5.84E-1					8.95E-2	8.95E-2
PCBs				9.36E-3	9.36E-3					9.36E-2	9.36E-2					1.43E-2	1.43E-2
Benzo[a]pyren				1.00E-2	1.00E-2					1.00E-1	1.00E-1					1.54E-2	1.54E-2
other PAHs																	
DEHP																	
NPE																	
LAS																	

Toxicological reference values (TRV) 1/5

	effet à seuil par voie orale						
	taux d'absorption		source biblio	DJTo (mg/kg.j)		effet critique	source biblio ou calculs
	adulte	enfant		adulte	enfant		
Cadmium	5.0%	5.0%	INERIS, 2005b	1.0E-3	1.0E-3	rein	US EPA, 1985
Chromium III	0.5%	0.5%	INERIS, 2005c	1.5E+0	1.5E+0	ingestion de chrome	US EPA, 1998
Copper	15.0%	15.0%	INERIS, 2005d	1.4E-1	1.4E-1	foie	RIVM, 2001
Mercury inorganic	15.0%	15.0%	INERIS, 2005e				
Mercury organic	95.0%	95.0%	INERIS, 2005e	1.0E-4	1.0E-4	développement neuropsychologique	US EPA, 2001
Nickel	0.7%	0.7%	INERIS, 2005f	2.0E-2	2.0E-2	croissance	US EPA, 1996
Lead	5.0%	20.0%	INERIS, 2005g	3.5E-3	3.5E-3	plombémie	OMS, 2004
Zinc	8.0%	8.0%	INERIS, 2005h	3.0E-1	3.0E-1	sang	US EPA, 1992
Dioxins	90.0%	90.0%	INERIS, 2005i	1.0E-9	1.0E-9	système immunitaire	OMS, 2000
PCBs	80.0%	80.0%	INERIS, 2005j	2.0E-5	2.0E-5	système immunitaire	OMS, 2003
Benzo[a]pyren	20.0%	20.0%	INERIS, 2005m				
other PAHs	100.0%	100.0%	par défaut	3.0E-2	3.0E-2	rein	US EPA, 1993
DEHP	50.0%	100.0%	Ellebaek Laursen et al., 2003	2.0E-02	2.0E-2	foie	US EPA, 1987
NPE	100.0%	100.0%	par défaut	4.5E-2	4.5E-2	rein	CSHPF, 2001
LAS	100.0%	100.0%	par défaut	4.0E-2	4.0E-2	croissance	CSHPF, 2001

Toxicological reference values (TRV) 2/5

	effet à seuil par voie alimentaire						
	taux d'absorption		source biblio	DJTa (mg/kg.j)		effet critique	source biblio ou calculs
	adulte	enfant		adulte	enfant		
Cadmium	5.0%	5.0%	INERIS, 2005b	1.0E-3	1.0E-3	rein	JECFA, 2003
Chromium III	0.5%	0.5%	INERIS, 2005c	1.4E-2	6.7E-2	ingestion de chrome	CSAH, 2003
Copper	15.0%	15.0%	INERIS, 2005d	1.4E-1	6.7E-1	foie	JECFA, 1982
Mercury inorganic	15.0%	15.0%	INERIS, 2005e	7.1E-4	7.1E-4	développement neuropsychologique	JECFA, 2003
Mercury organic	95.0%	95.0%	INERIS, 2005e	2.3E-4	2.3E-4	développement neuropsychologique	JECFA, 2003
Nickel	0.7%	0.7%	INERIS, 2005f	8.6E-3	4.0E-2	croissance	AFSSA, 2001
Lead	5.0%	20.0%	INERIS, 2005g	3.6E-3	3.6E-3	plombémie	JECFA, 2000
Zinc	8.0%	8.0%	INERIS, 2005h	2.1E-1	6.7E-1	sang	CSHPF, 1996
Dioxins	90.0%	90.0%	INERIS, 2005i	1.0E-9	1.0E-9	système immunitaire	OMS, 2000
PCBs	80.0%	80.0%	INERIS, 2005j	2.0E-5	2.0E-5	système immunitaire	OMS, 2003
Benzo[a]pyren	20.0%	20.0%	INERIS, 2005m				
other PAHs	100.0%	100.0%	par défaut	3.0E-2	3.0E-2	rein	US EPA, 1993
DEHP	50.0%	100.0%	Ellebaek Laursen et al., 2003	2.0E-2	2.0E-2	foie	US EPA, 1987
NPE	100.0%	100.0%	par défaut	4.5E-2	4.5E-2	rein	CSHPF, 2001
LAS	100.0%	100.0%	par défaut	4.0E-2	4.0E-2	croissance	CSHPF, 2001

Toxicological reference values (TRV) 3/5

	effet à seuil par voie inhalation						
	taux d'absorption		source biblio	CT (mg/m3)		effet critique	source biblio ou calculs
	adulte	enfant		adulte	enfant		
Cadmium	100.0%	100.0%	INERIS, 2005b	2.0E-5	2.0E-5	rein	OEHHA, 2003
Chromium III	30.0%	30.0%	INERIS, 2005c	6.0E-2	6.0E-2	appareil respiratoire	RIVM, 2001
Copper				1.0E-3	1.0E-3	foie	RIVM, 2001
Mercury inorganic	85.0%	85.0%	INERIS, 2005e	3.0E-4	3.0E-4	système nerveux	US EPA, 1995
Mercury organic							
Nickel	35.0%	35.0%	INERIS, 2005f	5.0E-5	5.0E-5	appareil respiratoire	RIVM, 2001
Lead	30.0%	30.0%	INERIS, 2005g	5.0E-4	5.0E-4	plombémie	OMS, 2000
Zinc							pas de dérivation
Dioxins	100.0%	100.0%	par défaut	3.2E-9	1.8E-9	reproduction	dérivation
PCBs	80.0%	80.0%	INERIS, 2005j	5.0E-4	5.0E-4	croissance	RIVM, 2001
Benzo[a]pyren							
other PAHs							
DEHP							pas de dérivation
NPE							
LAS							

Toxicological reference values (TRV) 4/5

	effet sans seuil par voie orale					
	taux d'absorption		source biblio	ERUo (mg/kg.j)-1		source biblio ou calculs
	adulte	enfant		adulte	enfant	
Cadmium	5.0%	5.0%	INERIS, 2005b			pas de dérivation
Chromium III	0.5%	0.5%	INERIS, 2005c			
Copper	15.0%	15.0%	INERIS, 2005d			
Mercury inorganic	15.0%	15.0%	INERIS, 2005e			
Mercury organic	95.0%	95.0%	INERIS, 2005e			
Nickel	0.7%	0.7%	INERIS, 2005f			pas de dérivation
Lead	5.0%	20.0%	INERIS, 2005g			
Zinc	8.0%	8.0%	INERIS, 2005h			
Dioxins	90.0%	90.0%	INERIS, 2005i			pas de valeur
PCBs	80.0%	80.0%	INERIS, 2005j	4.0E-1	2.0E+0	US EPA, 1997
Benzo[a]pyren	20.0%	20.0%	INERIS, 2005m	2.0E-1	2.0E-1	RIVM, 2001
other PAHs	100.0%	100.0%	par défaut	2.0E-2	2.0E-2	FET = 0,1
DEHP	50.0%	100.0%	Ellebaek Laursen et al., 2003	1.4E-02	1.4E-2	US EPA, 1988
NPE	100.0%	100.0%	par défaut			
LAS	100.0%	100.0%	par défaut			

Toxicological reference values (TRV) 5/5

	effet sans seuil par voie inhalation					
	taux d'absorption		source biblio	ERUi (mg/m3)-1		source biblio ou calculs
	adulte	enfant		adulte	enfant	
Cadmium	100.0%	100.0%	INERIS, 2005b	1.8E+0	1.8E+0	US EPA, 1992
Chromium III	30.0%	30.0%	INERIS, 2005c			
Copper						
Mercury inorganic	85.0%	85.0%	INERIS, 2005e			
Mercury organic						
Nickel	35.0%	35.0%	INERIS, 2005f	3.8E-1	3.8E-1	OMS, 2000
Lead	30.0%	30.0%	INERIS, 2005g			
Zinc						
Dioxins	100.0%	100.0%	par défaut			pas de valeur
PCBs	80.0%	80.0%	INERIS, 2005j	1.1E-1	1.0E+0	dérivation
Benzo[a]pyren				1.1E+0	1.1E+0	OEHHA, 2002
other PAHs				1.1E-1	1.1E-1	FET = 0,1
DEHP						pas de dérivation
NPE						
LAS						

Daily exposure doses (DED) 1/2

	ingestion de sol (extérieur)	ingestion de sol (extérieur) (mg/kg.j)					inhalation de poussières (extérieur)	inhalation de poussières (extérieur) (mg/m3)				
		1a - Consommateurs adulte	1b - Consommateurs enfant	2a - Riverain adulte	2b - Riverain enfant	3a - Agriculteur adulte		1a - Consommateurs adulte	1b - Consommateurs enfant	2a - Riverain adulte	2b - Riverain enfant	3a - Agriculteur adulte
Cadmium				1.4E-09	1.9E-07	2.2E-07				5.1E-11	5.1E-10	7.0E-08
Chromium III				1.5E-07	2.0E-05	2.3E-05				5.5E-09	5.3E-08	7.4E-06
Copper				1.2E-07	1.7E-05	1.9E-05				4.3E-09	4.5E-08	6.0E-06
Mercury inorganic				1.0E-09	1.6E-07	1.7E-07				3.8E-11	4.1E-10	5.4E-08
Mercury organic				1.0E-11	1.6E-09	1.7E-09				3.8E-13	4.1E-12	5.4E-10
Nickel				6.7E-08	8.4E-06	9.9E-06				2.5E-09	2.2E-08	3.2E-06
Lead				8.6E-08	1.1E-05	1.3E-05				3.2E-09	3.0E-08	4.2E-06
Zinc				3.2E-07	4.5E-05	5.0E-05				1.2E-08	1.2E-07	1.6E-05
Dioxins				5.0E-15	5.5E-13	7.1E-13				1.8E-16	1.4E-15	2.3E-13
PCBs				6.8E-11	1.1E-08	1.1E-08				2.5E-12	2.9E-11	3.7E-09
Benzo[a]pyren				3.4E-10	3.9E-08	4.9E-08				1.3E-11	1.0E-10	1.6E-08
other PAHs				2.1E-09	2.1E-07	2.8E-07				7.7E-11	5.4E-10	9.0E-08
DEHP				4.8E-10	4.7E-08	6.3E-08				1.7E-11	1.2E-10	2.1E-08
NPE				1.1E-09	1.1E-07	1.5E-07				4.1E-11	2.9E-10	4.8E-08
LAS				9.8E-09	9.7E-07	1.3E-06				3.6E-10	2.5E-09	4.2E-07

Daily exposure doses (DED) 2/2

	consommation de végétaux	consommation de végétaux (mg/kg.j)					consommation d'animaux	consommation d'animaux (mg/kg.j)				
		1a - Consommateurs adulte	1b - Consommateurs enfant	2a - Riverain adulte	2b - Riverain enfant	3a - Agriculteur adulte		1a - Consommateurs adulte	1b - Consommateurs enfant	2a - Riverain adulte	2b - Riverain enfant	3a - Agriculteur adulte
Cadmium		1.8E-04	5.0E-04	1.8E-04	5.0E-04	2.0E-04		2.3E-09	6.5E-09	2.4E-09	6.9E-09	3.5E-09
Chromium III		3.9E-04	1.1E-03	3.9E-04	1.1E-03	4.4E-04		1.0E-08	3.6E-08	1.0E-08	3.8E-08	1.5E-08
Copper		3.1E-02	8.8E-02	3.1E-02	8.8E-02	3.4E-02		1.7E-03	4.6E-03	1.8E-03	5.2E-03	3.4E-03
Mercury inorganic		3.7E-07	1.1E-06	3.7E-07	1.1E-06	3.9E-07						
Mercury organic		1.7E-06	6.1E-06	1.7E-06	6.1E-06	5.2E-06		2.2E-12	6.4E-12	2.4E-12	7.3E-12	4.7E-12
Nickel		5.5E-04	1.6E-03	5.5E-04	1.6E-03	6.1E-04		2.1E-07	5.4E-07	2.1E-07	5.5E-07	2.5E-07
Lead		4.3E-04	1.2E-03	4.3E-04	1.2E-03	4.4E-04		2.1E-05	5.6E-05	2.2E-05	5.9E-05	3.1E-05
Zinc		5.3E-02	1.5E-01	5.3E-02	1.5E-01	5.6E-02		1.9E-02	5.2E-02	2.0E-02	5.7E-02	3.5E-02
Dioxins		1.6E-11	4.3E-11	1.6E-11	4.3E-11	1.7E-11		4.9E-12	1.3E-11	5.1E-12	1.4E-11	7.2E-12
PCBs		1.9E-07	6.2E-07	1.9E-07	6.2E-07	2.9E-07		4.4E-09	1.4E-08	5.2E-09	1.8E-08	1.6E-08
Benzo[a]pyren		3.7E-06	1.0E-05	3.7E-06	1.0E-05	3.8E-06		1.1E-07	2.9E-07	1.1E-07	3.0E-07	1.3E-07
other PAHs		6.2E-05	1.6E-04	6.2E-05	1.6E-04	6.2E-05		1.2E-07	4.0E-07	1.2E-07	4.0E-07	1.2E-07
DEHP		3.7E-07	1.0E-06	3.7E-07	1.0E-06	4.4E-07		3.6E-07	1.2E-06	4.0E-07	1.4E-06	8.5E-07
NPE		2.5E-06	6.7E-06	2.5E-06	6.7E-06	4.3E-06		8.4E-09	2.8E-08	1.1E-08	3.7E-08	4.4E-08
LAS		1.8E-04	4.8E-04	1.8E-04	4.8E-04	4.1E-04		2.4E-09	7.5E-09	3.9E-09	1.2E-08	2.1E-08

Threshold effects 1/3

	ingestion de sol (extérieur)	ingestion de sol (extérieur)					inhalation de poussières (extérieur)	inhalation de poussières (extérieur)				
		1a - Consommateurs adulte	1b - Consommateurs enfant	2a - Riverain adulte	2b - Riverain enfant	3a - Agriculteur adulte		1a - Consommateurs adulte	1b - Consommateurs enfant	2a - Riverain adulte	2b - Riverain enfant	3a - Agriculteur adulte
Cadmium				1.4E-6	1.9E-4	2.2E-4				2.6E-6	2.6E-5	3.5E-3
Chromium III				9.9E-8	1.4E-5	1.5E-5				9.1E-8	8.9E-7	1.2E-4
Copper				8.3E-7	1.2E-4	1.3E-4				4.3E-6	4.5E-5	6.0E-3
Mercury inorganic										1.3E-7	1.4E-6	1.8E-4
Mercury organic				1.0E-7	1.6E-5	1.7E-5						
Nickel				3.4E-6	4.2E-4	4.9E-4				4.9E-5	4.4E-4	6.4E-2
Lead				2.5E-5	3.2E-3	3.7E-3				6.4E-6	6.0E-5	8.5E-3
Zinc				1.1E-6	1.5E-4	1.7E-4						
Dioxins				5.0E-6	5.5E-4	7.1E-4				5.8E-8	8.1E-7	7.3E-5
PCBs				3.4E-6	5.6E-4	5.7E-4				5.0E-9	5.9E-8	7.4E-6
Benzo[a]pyren												
other PAHs				6.9E-8	6.9E-6	9.3E-6						
DEHP				2.4E-8	2.4E-6	3.2E-6						
NPE				2.5E-8	2.5E-6	3.3E-6						
LAS				2.4E-7	2.4E-5	3.3E-5						

Threshold effects 2/3

	consommation de végétaux	consommation de végétaux					consommation d'animaux	consommation d'animaux				
		1a - Consommateurs adulte	1b - Consommateurs enfant	2a - Riverain adulte	2b - Riverain enfant	3a - Agriculteur adulte		1a - Consommateurs adulte	1b - Consommateurs enfant	2a - Riverain adulte	2b - Riverain enfant	3a - Agriculteur adulte
Cadmium		1.8E-1	5.0E-1	1.8E-1	5.0E-1	2.0E-1		2.3E-6	6.5E-6	2.4E-6	6.9E-6	3.5E-6
Chromium III		2.8E-2	1.7E-2	2.8E-2	1.7E-2	3.1E-2		7.0E-7	5.4E-7	7.2E-7	5.7E-7	1.0E-6
Copper		2.2E-1	1.3E-1	2.2E-1	1.3E-1	2.4E-1		1.2E-2	6.9E-3	1.3E-2	7.7E-3	2.4E-2
Mercury inorganic		5.2E-4	1.5E-3	5.2E-4	1.5E-3	5.5E-4						
Mercury organic		7.6E-3	2.7E-2	7.6E-3	2.7E-2	2.3E-2		9.7E-9	2.8E-8	1.1E-8	3.2E-8	2.1E-8
Nickel		6.5E-2	4.0E-2	6.5E-2	4.0E-2	7.1E-2		2.4E-5	1.3E-5	2.4E-5	1.4E-5	2.9E-5
Lead		1.2E-1	3.3E-1	1.2E-1	3.3E-1	1.2E-1		6.0E-3	1.6E-2	6.2E-3	1.7E-2	8.6E-3
Zinc		2.5E-1	2.2E-1	2.5E-1	2.2E-1	2.6E-1		9.0E-2	7.8E-2	9.6E-2	8.5E-2	1.6E-1
Dioxins		1.6E-2	4.3E-2	1.6E-2	4.3E-2	1.7E-2		4.9E-3	1.3E-2	5.1E-3	1.4E-2	7.2E-3
PCBs		9.3E-3	3.1E-2	9.3E-3	3.1E-2	1.4E-2		2.2E-4	7.1E-4	2.6E-4	9.1E-4	7.8E-4
Benzo[a]pyren other PAHs		2.1E-3	5.5E-3	2.1E-3	5.5E-3	2.1E-3		4.0E-6	1.3E-5	4.0E-6	1.3E-5	4.1E-6
DEHP		1.9E-5	5.0E-5	1.9E-5	5.0E-5	2.2E-5		1.8E-5	6.2E-5	2.0E-5	6.8E-5	4.3E-5
NPE		5.5E-5	1.5E-4	5.5E-5	1.5E-4	9.5E-5		1.9E-7	6.2E-7	2.5E-7	8.3E-7	9.8E-7
LAS		4.4E-3	1.2E-2	4.4E-3	1.2E-2	1.0E-2		5.9E-8	1.9E-7	9.8E-8	3.1E-7	5.2E-7

Threshold effects 3/3

	Sommations	1a - Consommateurs adulte	1b - Consommateurs enfant	2a - Riverain adulte	2b - Riverain enfant	3a - Agriculteur adulte
Cadmium		1.8E-1	5.0E-1	1.8E-1	5.0E-1	2.0E-1
Chromium III		2.8E-2	1.7E-2	2.8E-2	1.7E-2	3.1E-2
Copper		2.3E-1	1.4E-1	2.3E-1	1.4E-1	2.7E-1
Mercury inorganic		5.2E-4	1.5E-3	5.2E-4	1.5E-3	7.3E-4
Mercury organic		7.6E-3	2.7E-2	7.6E-3	2.7E-2	2.3E-2
Nickel		6.5E-2	4.0E-2	6.5E-2	4.0E-2	1.4E-1
Lead		1.3E-1	3.5E-1	1.3E-1	3.5E-1	1.4E-1
Zinc		3.4E-1	3.0E-1	3.4E-1	3.1E-1	4.2E-1
Dioxins		2.1E-2	5.6E-2	2.1E-2	5.7E-2	2.5E-2
PCBs		9.6E-3	3.2E-2	9.6E-3	3.2E-2	1.6E-2
Benzo[a]pyren						
other PAHs		2.1E-3	5.5E-3	2.1E-3	5.5E-3	2.1E-3
DEHP		3.6E-5	1.1E-4	3.8E-5	1.2E-4	6.8E-5
NPE		5.5E-5	1.5E-4	5.5E-5	1.5E-4	9.9E-5
LAS		4.4E-3	1.2E-2	4.4E-3	1.2E-2	1.0E-2

synthèse		1a - Consommateurs adulte	1b - Consommateurs enfant	2a - Riverain adulte	2b - Riverain enfant	3a - Agriculteur adulte
	appareil respiratoire			5.2E-5	4.7E-4	6.8E-2
	croissance	6.9E-2	5.1E-2	6.9E-2	5.2E-2	8.2E-2
	développement neuropsychologique	1.6E-1	4.3E-1	1.6E-1	4.4E-1	1.9E-1
	foie	2.3E-1	1.4E-1	2.3E-1	1.5E-1	2.7E-1
	œil	9.6E-3	3.2E-2	9.6E-3	3.2E-2	1.6E-2
	plombémie	1.3E-1	3.5E-1	1.3E-1	3.5E-1	1.4E-1
	rein	5.3E-1	9.9E-1	5.3E-1	1.0E+0	6.1E-1
	reproduction	2.1E-2	5.6E-2	2.1E-2	5.7E-2	2.5E-2
	sang	3.4E-1	3.1E-1	3.5E-1	3.1E-1	4.3E-1
	système immunitaire	1.6E-1	4.4E-1	1.6E-1	4.4E-1	1.9E-1
	système nerveux périphérique	1.3E-1	3.5E-1	1.3E-1	3.5E-1	1.5E-1

Non-threshold effects 1/3

		ingestion de sol (extérieur)									**inhalation de poussières (extérieur)**							
	ingestion de sol (extérieur)	1a - Consommateurs adulte	1b - Consommateurs enfant	1c - Consommateur cumul	2a - Riverain adulte	2b - Riverain enfant	2c - Riverain cumul	3a - Agriculteur adulte	3c - Agriculteur cumul	inhalation de poussières (extérieur)	1a - Consommateurs adulte	1b - Consommateurs enfant	1c - Consommateur cumul	2a - Riverain adulte	2b - Riverain enfant	2c - Riverain cumul	3a - Agriculteur adulte	3c - Agriculteur cumul
Cadmium														8.5E-11	7.9E-11	1.6E-10	7.2E-08	7.3E-08
Chromium III																		
Copper																		
Mercury inorganic																		
Mercury organic																		
Nickel														8.6E-10	7.1E-10	1.6E-09	7.0E-07	7.0E-07
Lead																		
Zinc																		
Dioxins																		
PCBs					2.5E-11	1.9E-09	1.9E-09	2.6E-09	4.6E-09					2.6E-13	2.6E-12	2.8E-12	2.4E-10	2.5E-10
Benzo[a]pyren					6.3E-11	6.8E-10	7.4E-10	5.6E-09	6.3E-09					1.3E-11	9.7E-12	2.2E-11	1.0E-08	1.0E-08
other PAHs					3.8E-11	3.6E-10	3.9E-10	3.2E-09	3.5E-09					7.7E-12	5.1E-12	1.3E-11	5.7E-09	5.7E-09
DEHP					6.1E-12	5.7E-11	6.3E-11	5.1E-10	5.7E-10									
NPE																		
LAS																		
Sommations	1.5E-8				1.3E-10	3.0E-9	3.1E-9	1.2E-8	1.5E-8	7.9E-7				9.7E-10	8.1E-10	1.8E-9	7.8E-7	7.9E-7
Contributions	0.5%				0.0%	0.5%	0.1%	0.6%	0.5%	23.6%				0.1%	0.1%	0.1%	38.6%	23.6%

Non-threshold effects 2/3

		consommation de végétaux									consommation d'animaux							
	consommation de végétaux	1a - Consommateurs adulte	1b - Consommateurs enfant	1c - Consommateur cumul	2a - Riverain adulte	2b - Riverain enfant	2c - Riverain cumul	3a - Agriculteur adulte	3c - Agriculteur cumul	consommation d'animaux	1a - Consommateurs adulte	1b - Consommateurs enfant	1c - Consommateur cumul	2a - Riverain adulte	2b - Riverain enfant	2c - Riverain cumul	3a - Agriculteur adulte	3c - Agriculteur cumul
Cadmium																		
Chromium III																		
Copper																		
Mercury inorganic																		
Mercury organic																		
Nickel																		
Lead																		
Zinc																		
Dioxins																		
PCBs		6.8E-08	1.1E-07	1.7E-07	6.8E-08	1.1E-07	1.7E-07	6.6E-08	2.0E-07		1.6E-09	2.4E-09	4.0E-09	1.9E-09	3.1E-09	5.0E-09	3.5E-09	7.4E-09
Benzo[a]pyren		6.8E-07	1.7E-07	8.6E-07	6.8E-07	1.7E-07	8.6E-07	4.3E-07	8.6E-07		2.0E-08	5.0E-09	2.5E-08	2.0E-08	5.1E-09	2.5E-08	1.5E-08	2.7E-08
other PAHs		1.1E-06	2.8E-07	1.4E-06	1.1E-06	2.8E-07	1.4E-06	7.1E-07	1.4E-06		2.2E-09	6.8E-10	2.9E-09	2.2E-09	6.8E-10	2.9E-09	1.4E-09	2.9E-09
DEHP		4.8E-09	1.2E-09	6.0E-09	4.8E-09	1.2E-09	6.0E-09	3.5E-09	6.5E-09		4.6E-09	1.5E-09	6.1E-09	5.1E-09	1.6E-09	6.7E-09	6.8E-09	1.0E-08
NPE																		
LAS																		
Sommations	2.5E-6	1.9E-6	5.6E-7	2.4E-6	1.9E-6	5.6E-7	2.4E-6	1.2E-6	2.5E-6	4.8E-8	2.8E-8	9.6E-9	3.8E-8	2.9E-8	1.1E-8	4.0E-8	2.6E-8	4.8E-8
Contributions	74.5%	98.5%	98.3%	98.5%	98.4%	97.5%	98.2%	59.5%	74.5%	1.4%	1.5%	1.7%	1.5%	1.5%	1.8%	1.6%	1.3%	1.4%

Non-threshold effects 3/3

	Sommations	Sommations: 1a - Consommateurs adulte	1b - Consommateurs enfant	1c - Consommateur cumul	2a - Riverain adulte	2b - Riverain enfant	2c - Riverain cumul	3a - Agriculteur adulte	3c - Agriculteur cumul	Contributions détaillées	Contributions: 1a - Consommateurs adulte	1b - Consommateurs enfant	1c - Consommateur cumul	2a - Riverain adulte	2b - Riverain enfant	2c - Riverain cumul	3a - Agriculteur adulte	3c - Agriculteur cumul
Cadmium					8.5E-11	7.9E-11	1.6E-10	7.2E-08	7.3E-08					0.0%	0.0%	0.0%	3.6%	2.2%
Chromium III																		
Copper																		
Mercury inorganic																		
Mercury organic																		
Nickel					8.6E-10	7.1E-10	1.6E-09	7.0E-07	7.0E-07					0.0%	0.1%	0.1%	34.3%	21.0%
Lead																		
Zinc																		
Dioxins																		
PCBs		7.0E-08	1.1E-07	1.8E-07	7.0E-08	1.1E-07	1.8E-07	7.2E-08	2.1E-07		3.6%	18.9%	7.2%	3.7%	19.2%	7.3%	3.6%	6.3%
Benzo[a]pyren		7.0E-07	1.8E-07	8.8E-07	7.0E-07	1.8E-07	8.8E-07	4.6E-07	9.0E-07		36.7%	31.1%	35.4%	36.7%	31.0%	35.4%	22.7%	27.2%
other PAHs		1.1E-06	2.8E-07	1.4E-06	1.1E-06	2.8E-07	1.4E-06	7.2E-07	1.4E-06		59.1%	49.5%	56.9%	59.1%	49.2%	56.8%	35.3%	42.9%
DEHP		9.3E-09	2.7E-09	1.2E-08	9.8E-09	2.9E-09	1.3E-08	1.1E-08	1.7E-08		0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
NPE																		
LAS																		
Sommations		1.9E-6	5.7E-7	2.5E-6	1.9E-6	5.8E-7	2.5E-6	2.0E-6	3.3E-6									