Short-range transport of contaminants released from an e-waste recycling site in South China

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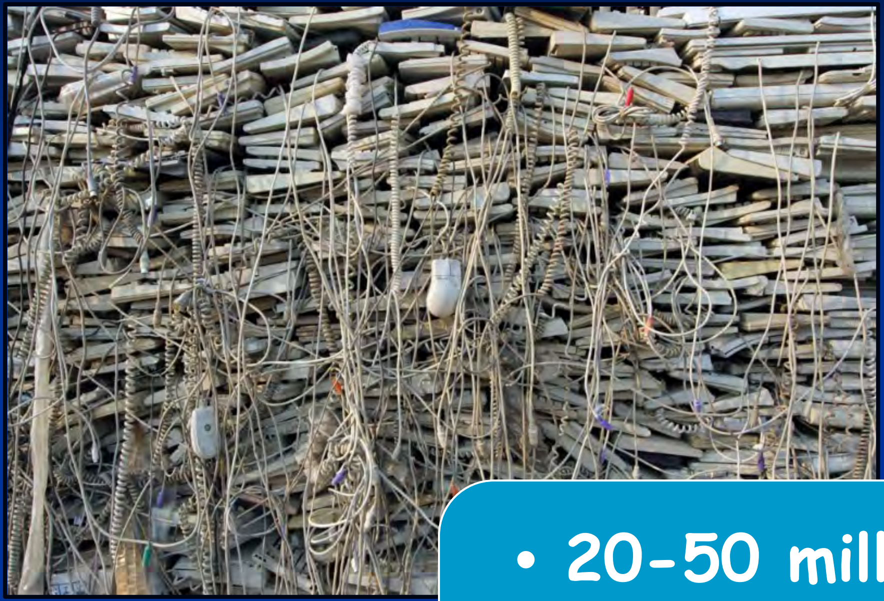
- Introduction
- Short-range transport study
- perspectives

Electronic waste (E-waste)



- 20-50 million tons/year
- About 5% of the municipal solid waste

E-waste Management

- Most of e-waste goes to landfill and incinerators (86.4%, USEPA, 2007)

- Most recyclers don't recycle, but export (50-80%)

- Prison recycling: high tech chain gang

http://www.electronicstakeback.com/resources/problem-overview/

E-waste in China

Of the e-waste imported into Asia, 90% ended up in China (~14-35 million tons/year)

China generates about 1.1 million tons of e-waste annually (The PRD accounts for ~45%)

From: *http://*www.vitalgraphics.net/waste/

Major e-waste recycling sites in China

Ni & Zeng, *ES&T*, 2009

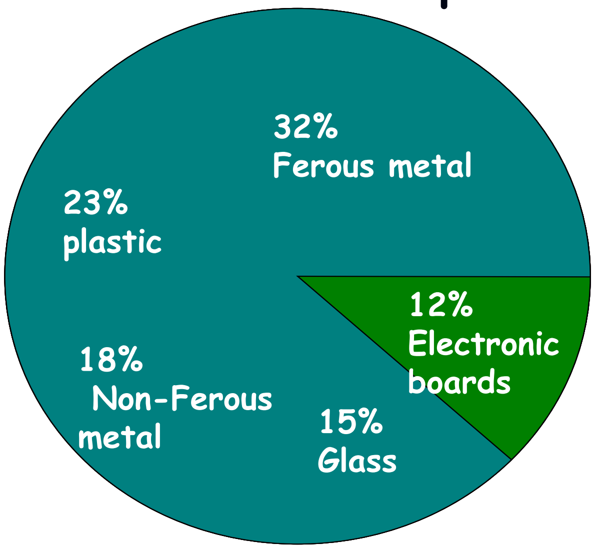
Informal E-waste recycling operations



Open burning, plastic peeling and melting, acid leaching......


Benefits & Problems

What's in a computer?



Recycling →

- Recovery of valuable metals
- Recovery of plastics
- Employments

↓

POPs (PAHs, PBDEs, PCBs, PCDD/PCDFs etc.), heavy metals

Air, water, soil, sediment, organism and human

Contaminants in air

	PBDEs (ng/m^3)	PCDD/Fs (pg/m^3)	Reference
Guiyu	11.7		Chen et al. 2009
Control-Chendian	0.38		Chen et al. 2009
Guiyu	21.5		Deng et al. 2007
Control-Hongkong	0.15		…07
Control-Guangzhou	0.29		…007
Guiyu		64.9-2365	Zhao et al. 2007
Control-Chendian		7.12-461	Zhao et al. 2007

30 times

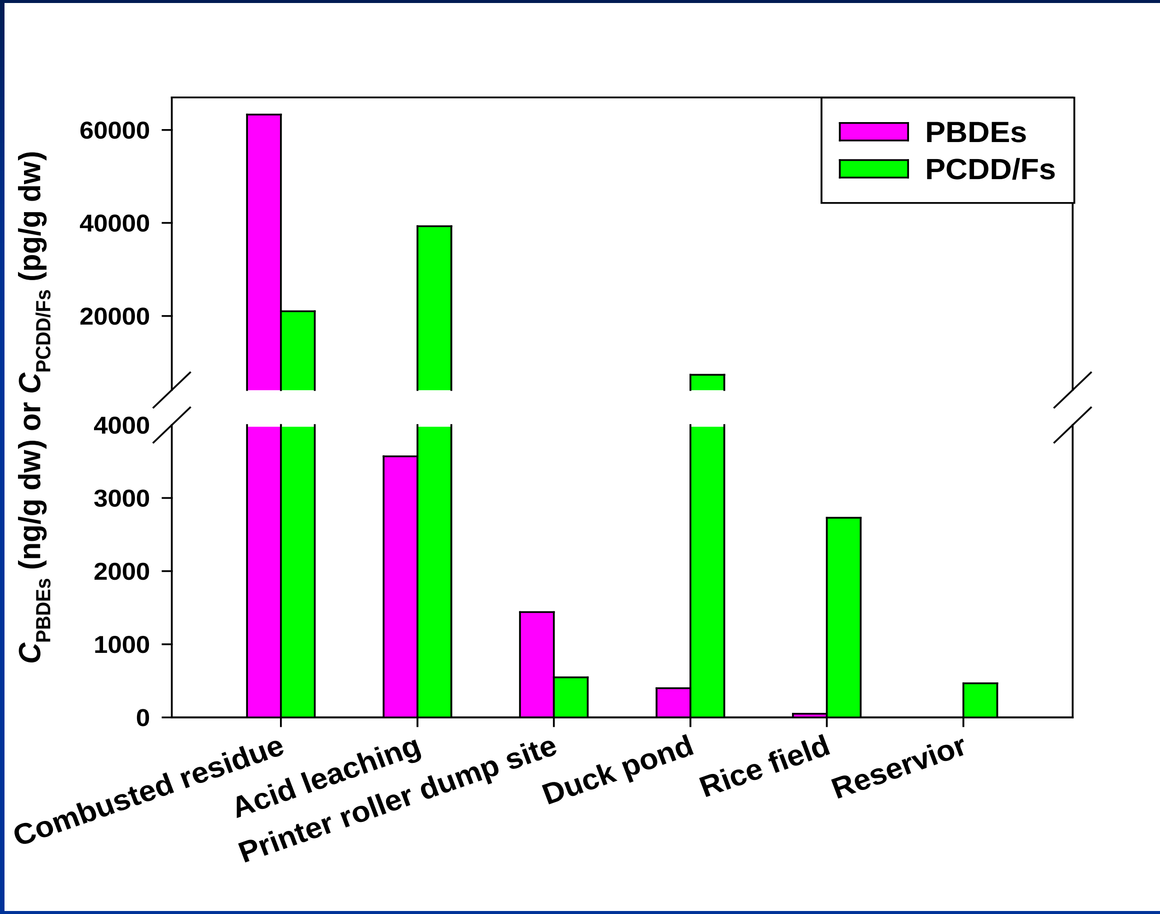
140 times

70 times

So far, the highest values documented worldwide.

Ambient air in e-waste dismantling areas has been severely contaminated by POPs.

Contaminants in soil



Crude e-waste recycling procedures are the main cause to release POPs (e.g. PBDEs, PCDD/Fs) to the environment (Guiyu, South China).

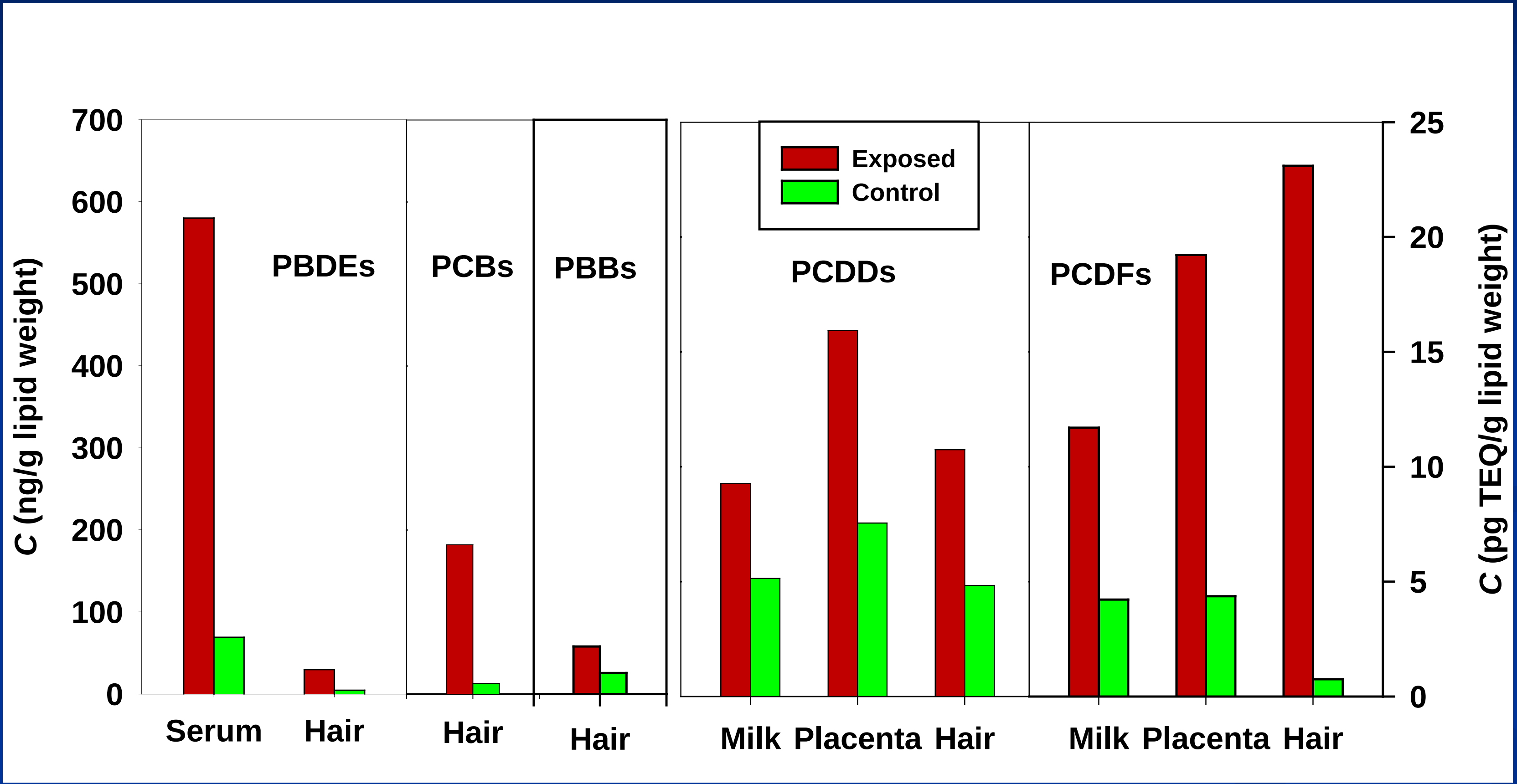
Leung et al. *ES&T*, 2007

Contaminants in biota

Site	Organism	PBDEs	PCBs	Reference
Longtang, Qingyuan	Fowl	1.5-7897 [a]		Luo et al. 2009a
Longtang, Qingyuan	Duck	1.9-134[a]		Luo et al. 2009a
Longtang, Qingyuan	Wild aquatic species	52.7-1702[b]	20.2-25958[b]	Wu et al. 2008
Control	Wild aquatic species	13.0-20.5[b]	75.4-82.8[b]	Wu et al. 2008
Longtang, Qingyuan	Birds	37-2200 [a]	960-1400000 [a]	Luo et al. 2009b

[a] ng/g lipid weight; [b] ng/g wet weight

Contaminants in human tissue



E-waste workers had higher risks on exposing to e-waste-derived contaminants than other people groups

TEQ-toxic equivalency

Zhao et al.2008; Bi et al. 2007; Yuan et al. 2008; Wen et al. 2008; Chan et al. 2007

Severe contamination observed in the sites where informal e-waste recycling was practiced.

But…

How about the surrounding areas?

Objectives

Evaluate the short-range transport (SRT) potential of contaminants from an e-waste recycling site to the surrounding regions in South China by analyzing contaminants residues in surface soil.

- Compare the SRT potential of PBDEs, PCBs and heavy metals released from e-waste recycling site.
- Assess the risks of those contaminants might pose on the surrounding areas.

Target e-waste recycling site

Longtang, Qingyuan, located about 50 km north of Guangzhou (the capital of Guangdong Province)

Sampling sites

Center:

Ding'an Village in Longtang (LT0), 30 years
>1300 workshops

Four directions: LY, LB, LZ, and LC

Six circles with radii of 2.5, 5, 10, 20, 30, and 40 km

Sample preparation

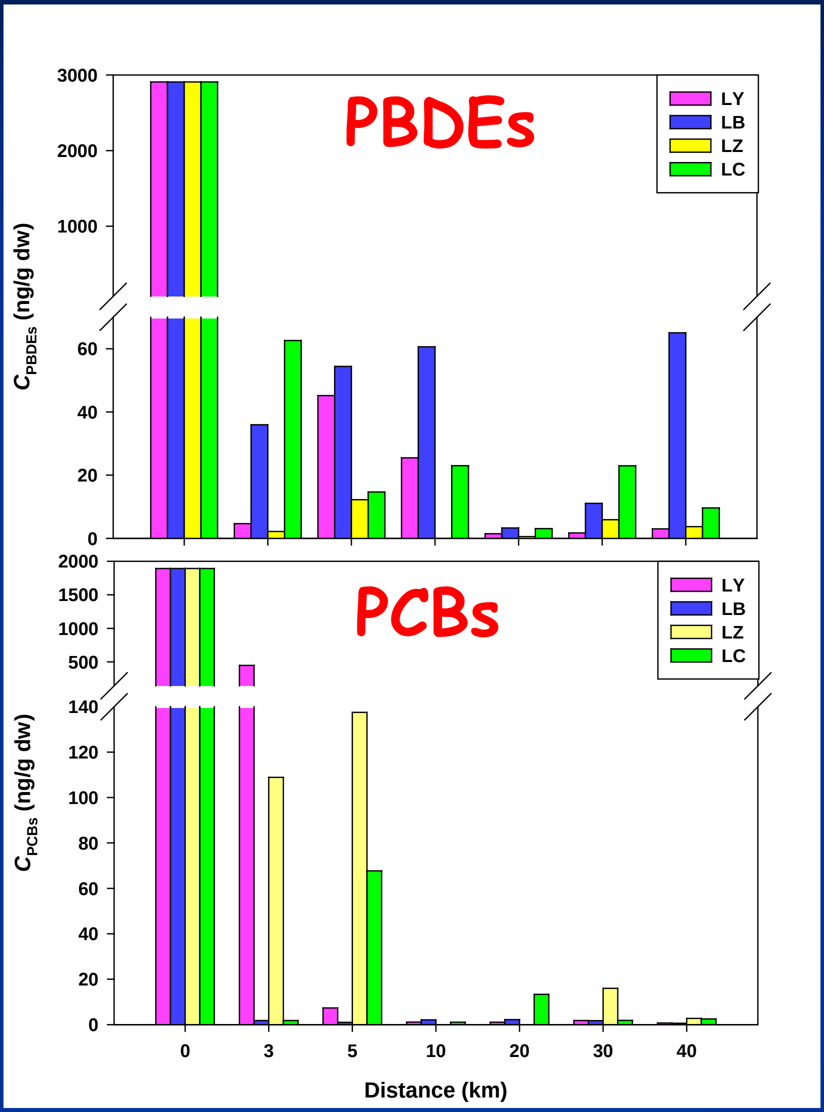
Air dried soil → UAME → Silica gel-alumina column → GC/MS → 27 PBDEs, 27 PCBs

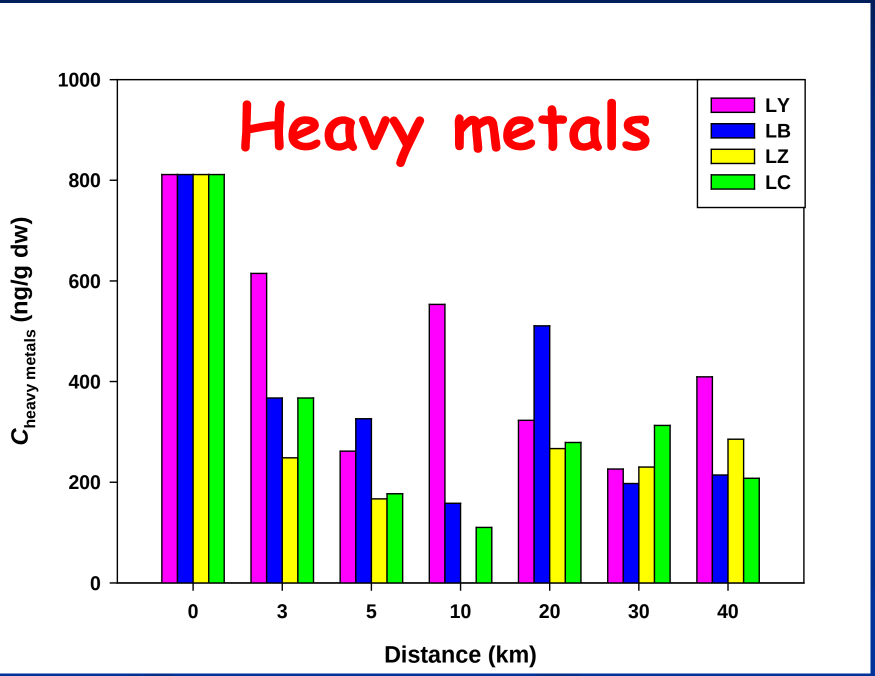
Air dried soil → Microwave digestion → ICP/MS → 12 heavy metals: Ag, As, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Se, Zn

UAME-ultrasound-assisted microwave extraction

Li et al. *Talanta*, 2010

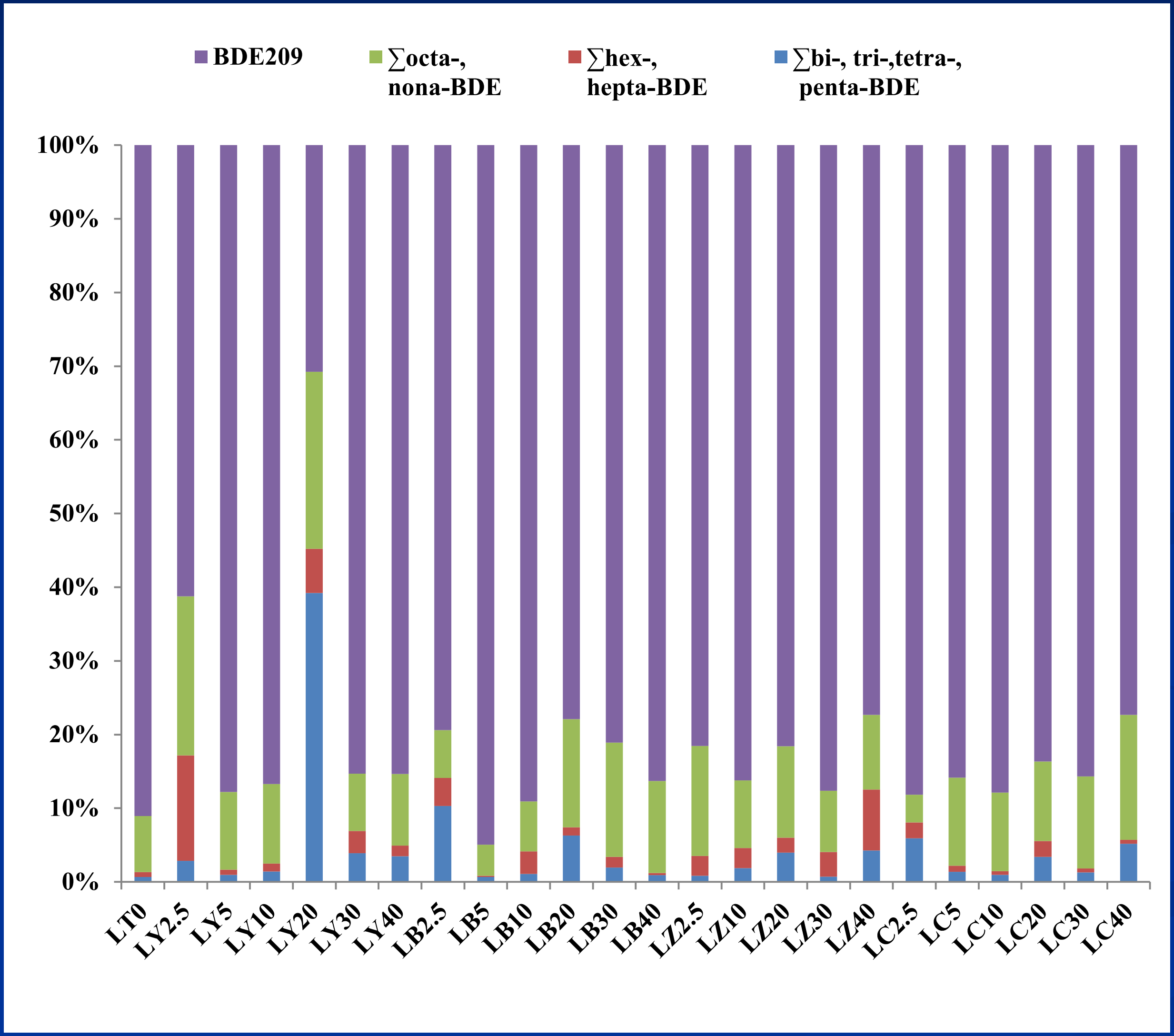
Contaminants in soil





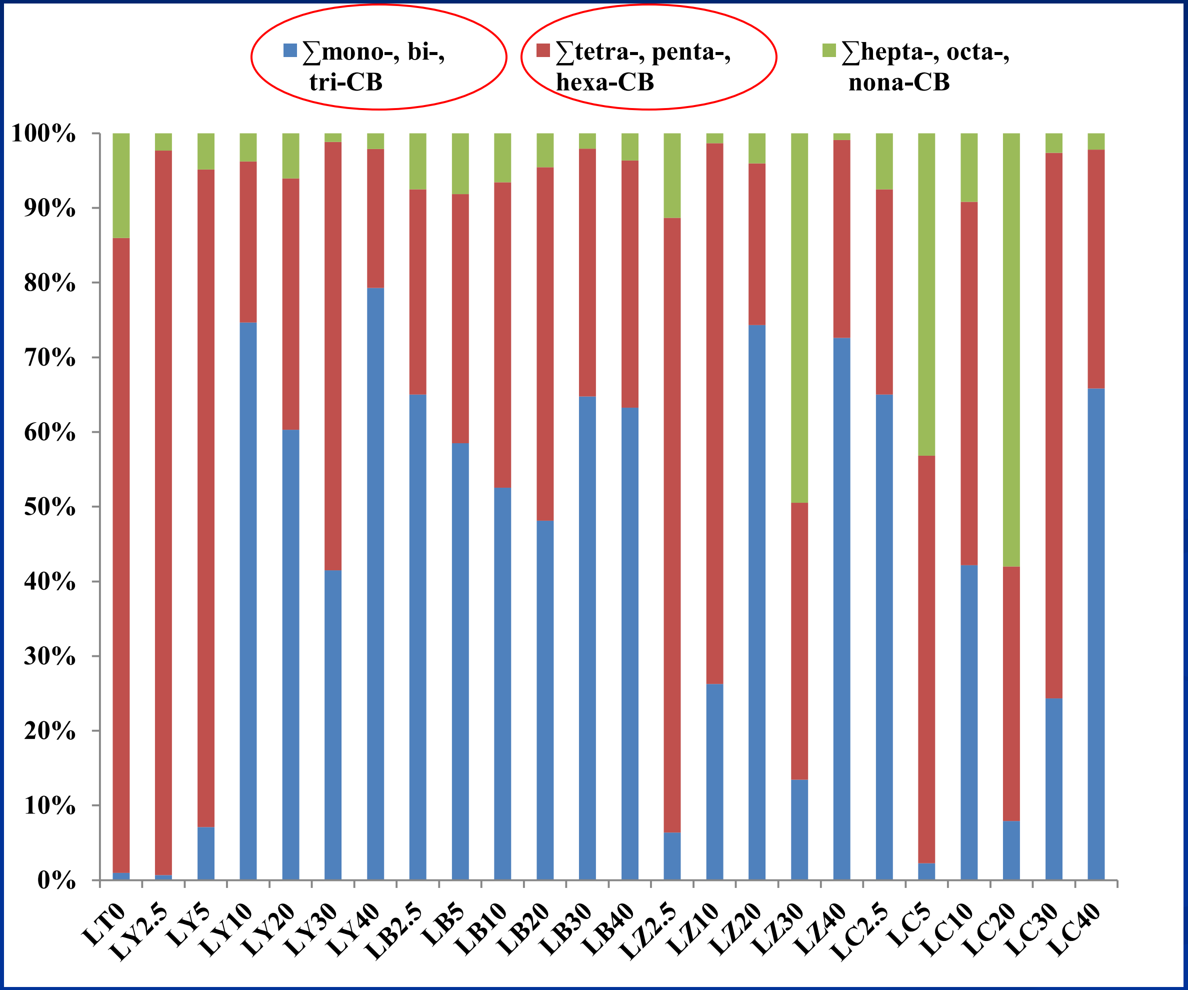
The highest concentrations of sum PBDEs, PCBs, and heavy metals in soil were all found in Dingan Village (LT0)

PBDEs composition



- BDE-209 accounted for 83% of all PBDEs in use.
- In the soil samples, BDE-209 contributed 61–95% of all PBDEs, except of LY20 (31%)

PCBs composition



- The commonly used CB52, CB101, CB118, CB153 accounted for a large portion of total PCBs
- Small quantity of usage of less-chlorine-substituted PCBs
- But, relative high transport potential

Transport potential

Transportability: chemical volatility, atmospheric or biota degradation, terrain, wind direction, and other weather conditions

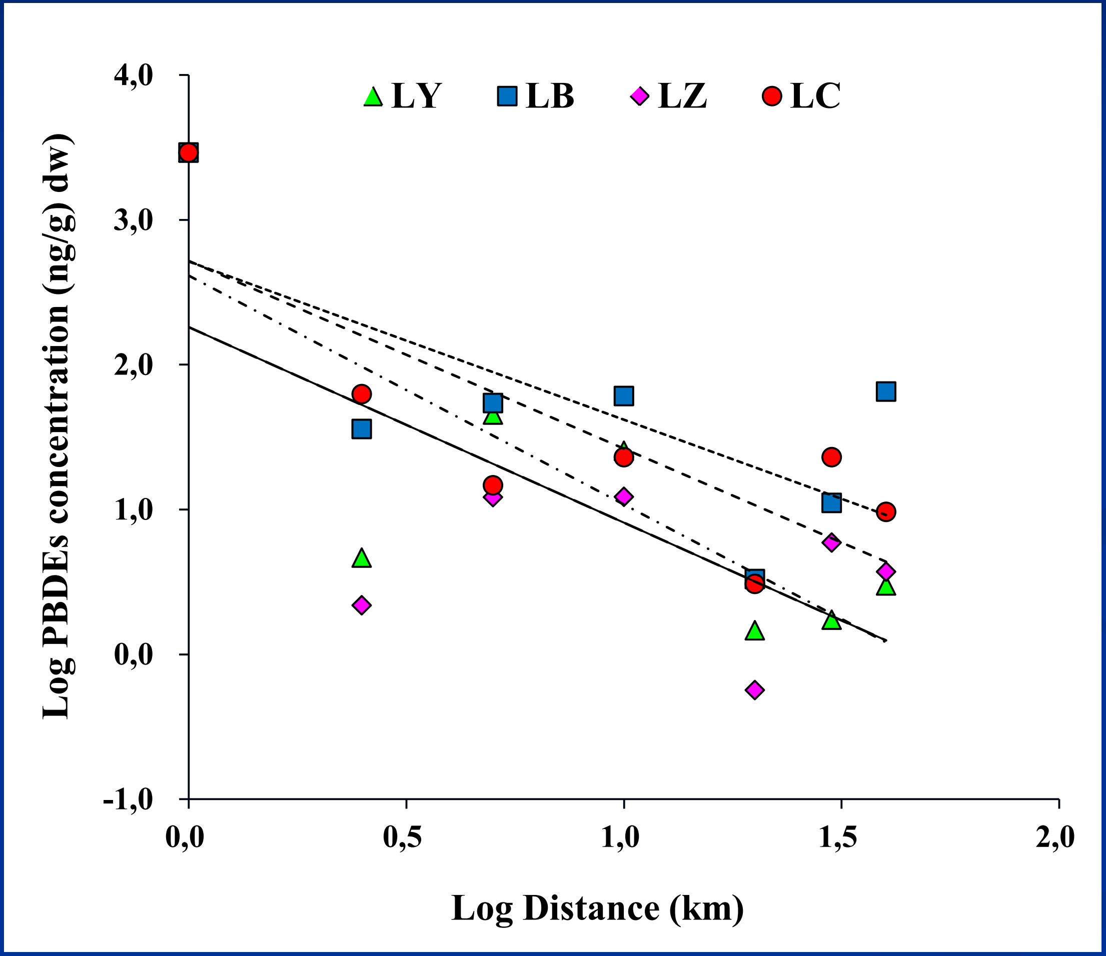
- Short range transport (SRT): environmental factors, e.g. terrain
- Long range transport (LRT): chemical characteristics, e.g. volatility and degradation potential

Transport potential (metals)

Heavy metal residues in soil:

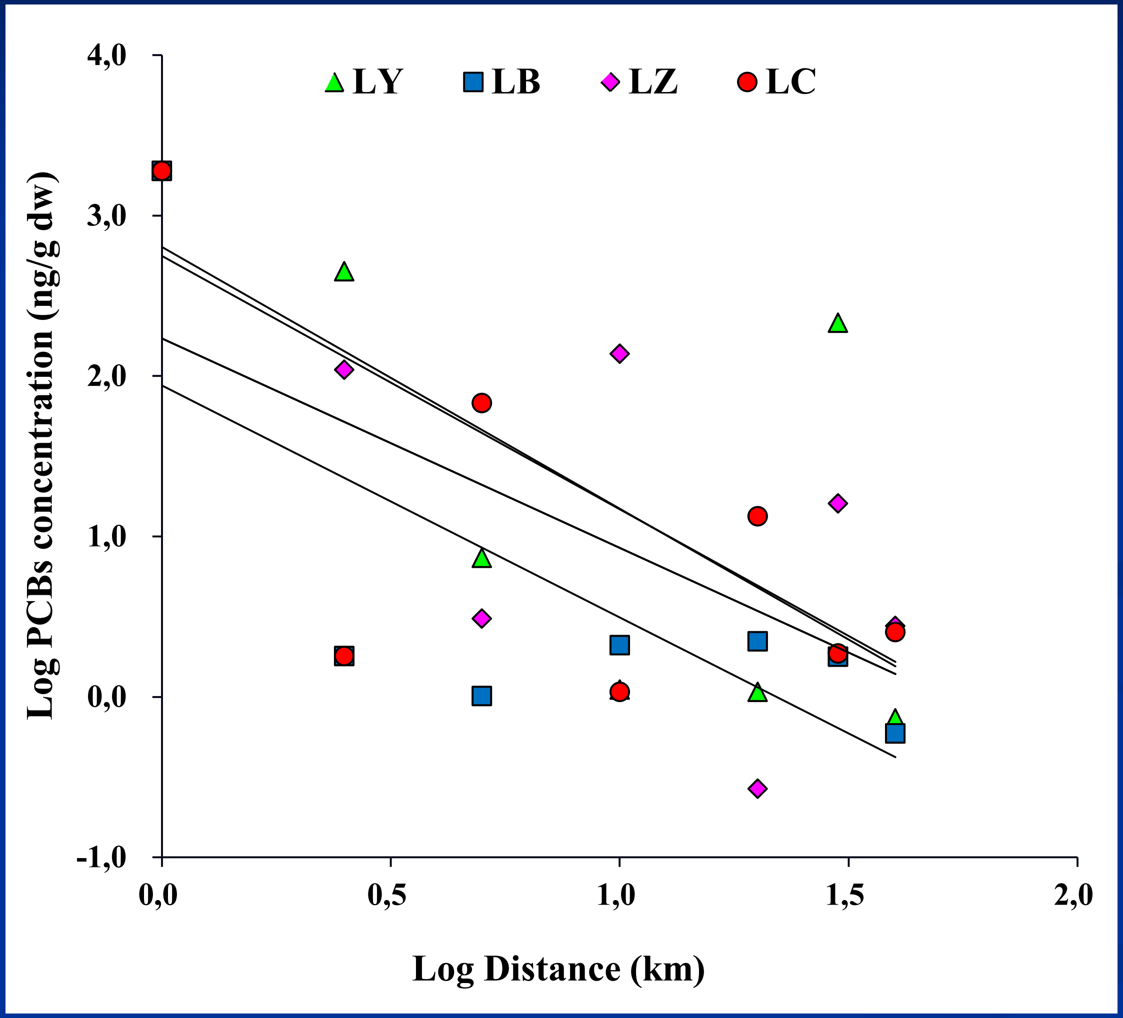
- No distinct trend
- Low vapor pressures
- Stay in the original place rather than transport to the surrounding areas

Transport potential (PBDEs)



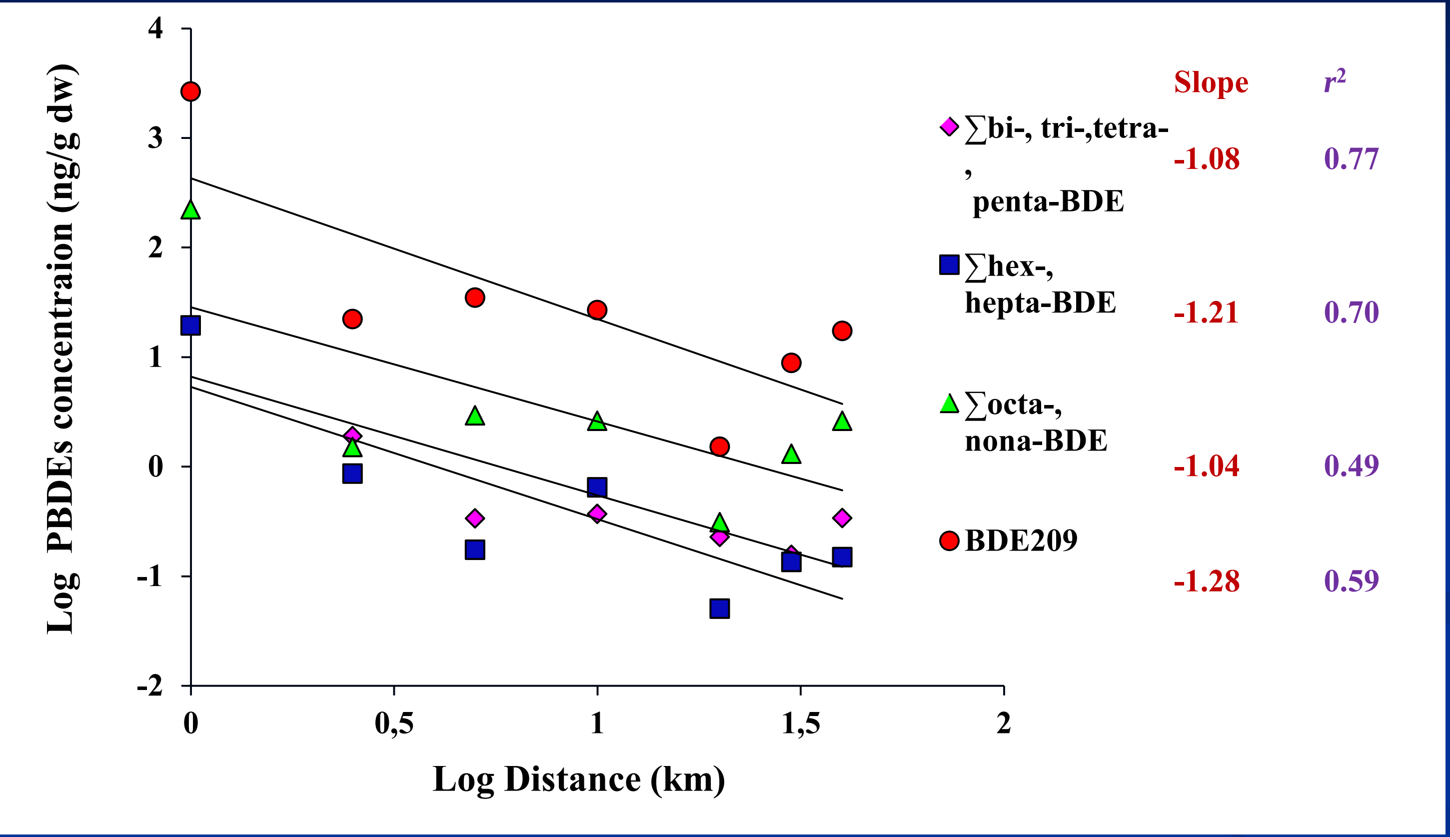
- PBDE residues in soil decreased with increasing distance
- Slopes of the regression lines: -1.09 to -1.58; r^2: 0.46-0.65
- No significant differences in transport among the four directions

Transport potential (PCBs)



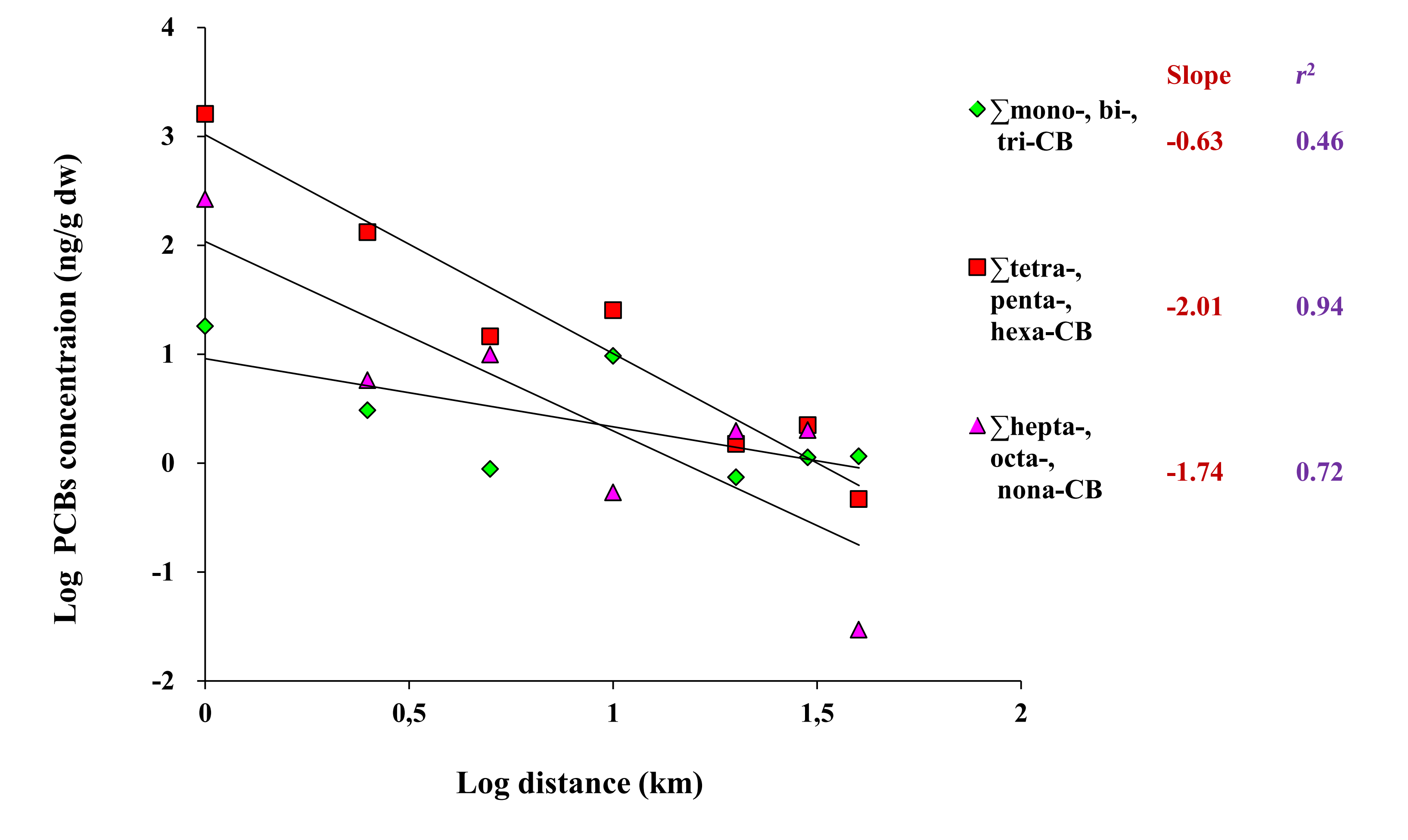
- PCB residues in soil decreased with increasing distance
- Slopes of the regression lines: -1.31 to -2.12; r^2: 0.43-0.85
- No significant differences in transport among the four directions
- The SRT potential of PBDEs and PCBs showed no difference

Difference among homologue groups (PBDEs)



- No significant difference for the highly and less brominated PBDEs
- Levels of BDE-209 decreased quicker than less brominated PBDEs
- The percentage of BDE-209 in total PBDEs slightly decreased
- BDE-209 had less transport ability than other PBDEs

Difference among homologue groups (PCBs)

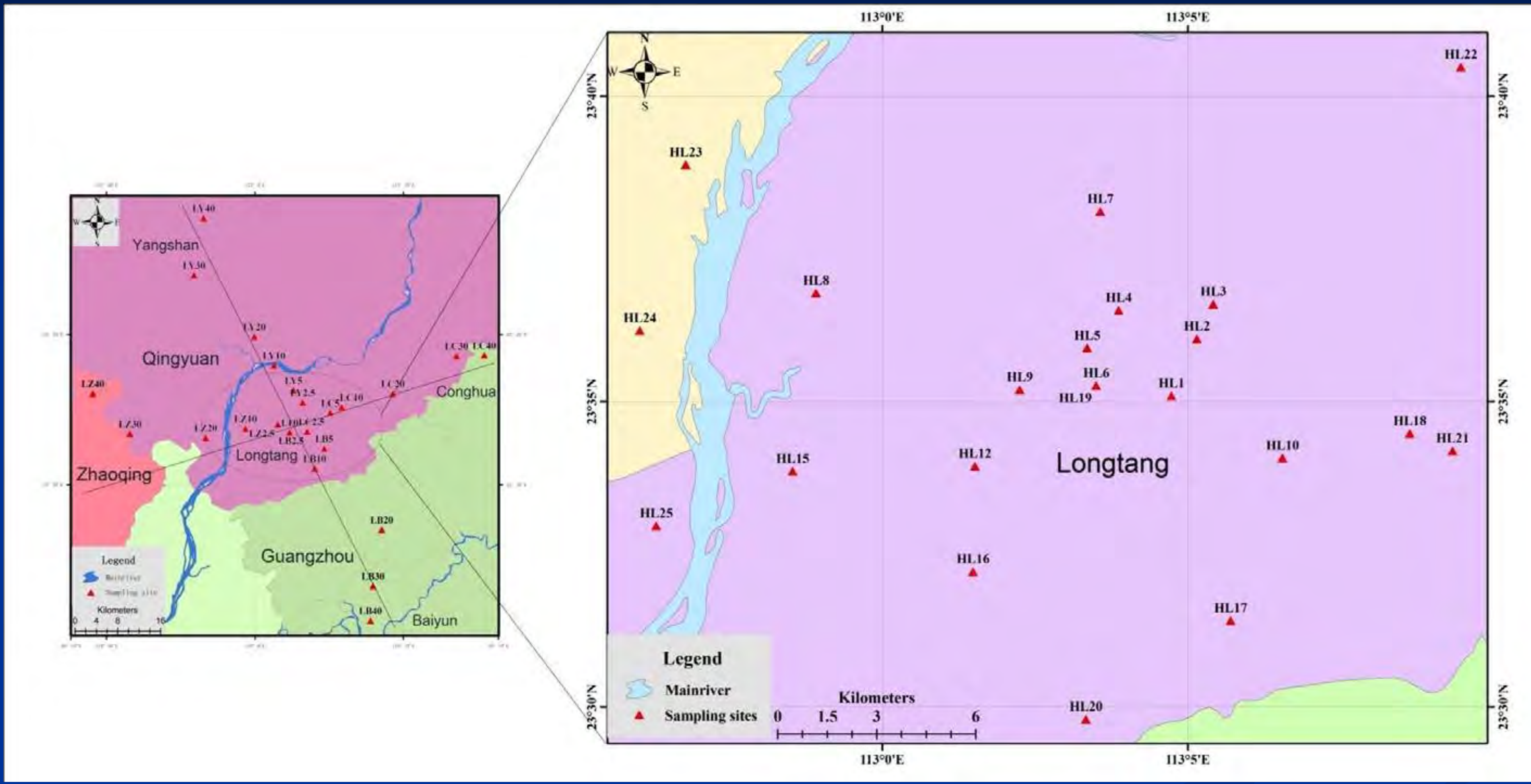


- No significant difference for the highly and less chlorinated PCBs
- ΣMono-, bi-, tri-CB had relatively higher transport potential

Summary

- High concentrations of PBDEs, PCBs, and heavy metals in soils in an e-waste site in Longtang, Qingyuan
- E-waste recycling activities had caused severe local contamination
- Heavy metals seemed to stay in the local due to their low vapor pressures
- PBDEs and PCBs had ability to transport from the pollution source to the surrounding areas
- BDE-209 showed slightly less transport potential than other PBDEs or PCBs

More assessment



Additional 21 soil samples were collected within an 8 km-radius circle of Ding'an Village to assess the risks of the e-waste recycling processes

Mass inventory

- Mass inventories (I) of the contaminants were calculated:

$$I = \sum kCAd\rho$$

- The calculated mass inventory of BDE-209, sum PBDEs, sum PCBs and sum heavy metals were 0.92, 0.134, 0.860 and 1434 tons, respectively
- The mass inventories of Cd, Cu, and Pb were estimated as 4.68, 757, and 673 tons
- The e-waste dismantling activities caused severe contamination to the local environment

Conclusions

- The primitive and unprotected e-waste dismantling and recycling procedures had made Longtang a pollution source of different kinds of contaminants, and might pose severe treat to the surrounding areas due to the SRT potential of POPs

Future work

- Better understand the transportability of POPs in short- and long-range scales

- Assess the risks on biota and human health caused by the transport of contaminants from e-waste recycling site (pollution source)

Acknowledgements

- Zaicheng He, Wenfen Zhang for map preparation and soil sampling
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Can be the polybrominated compounds a hazard for the pregnant women in an environment of electronic compounds exposure?

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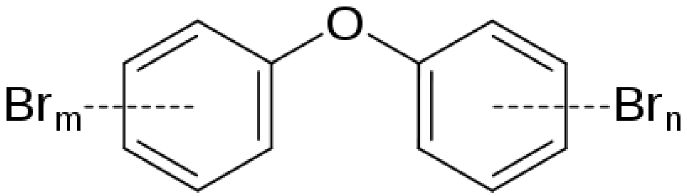
Introduction

- Polybrominated diphenyl ethers. Family 209 congeners.



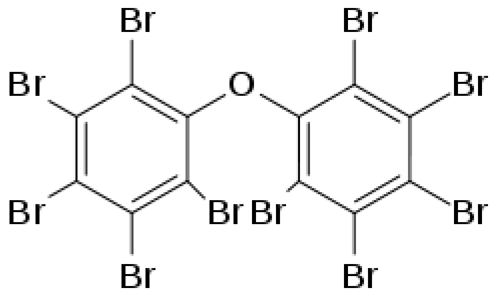
- Use as a flame retardant in electronics, plastics, textile and furnish.

- Bioaccumulative, persistent & toxic.

- Endocrine-disrupting activity.

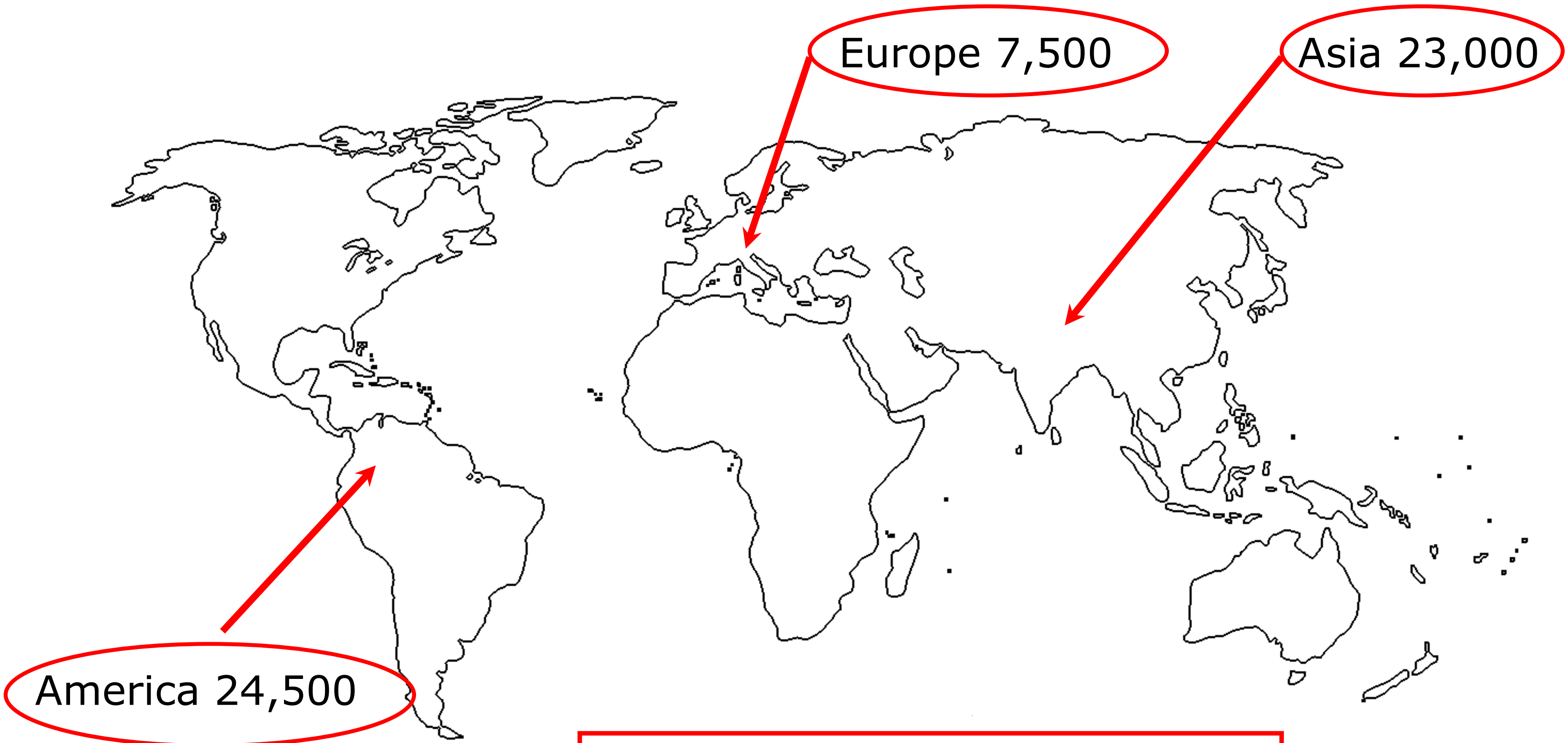
PBDE-209

- Decabromodiphenil ether (PBDE-209)



- PBDE-209 can cause neurobehavioral deficits and can cause cancer in animals
- Stockholm approved the elimination of PBDE-209
- Now, is still produced mainly in undeveloped countries

Annual consumption of PBDE-209 in 2001



World production 56,100 tones

Alternative to testing methods

- Testing methods

- In Silico

- **In vitro**

- European regulations foresee the use of methods alternative to animal tests

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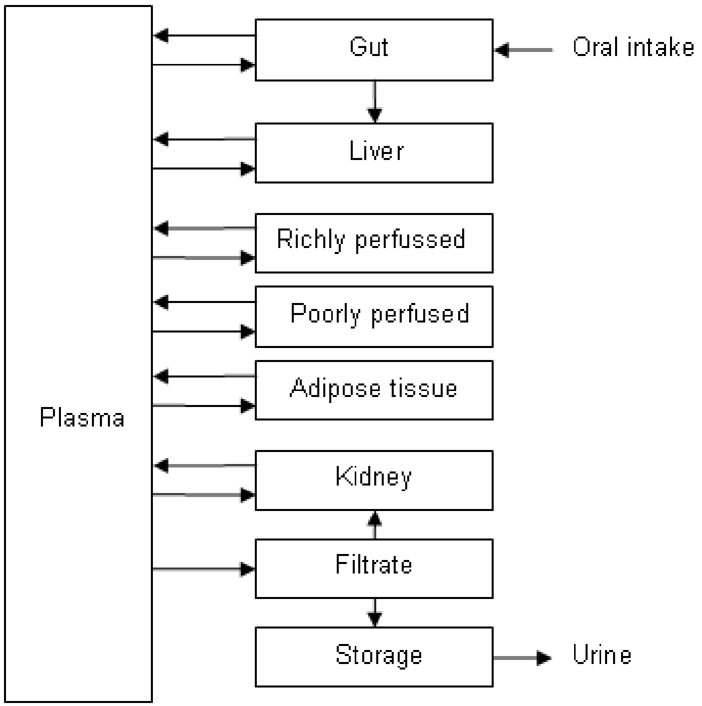
PBPK models as alternative testing methods

- Physiologically based on pharmacokinetic models (PBPK)
- Mathematical representations of animals or human body, where the organs are considered as compartments.
- Use in health risk assessment & drug development

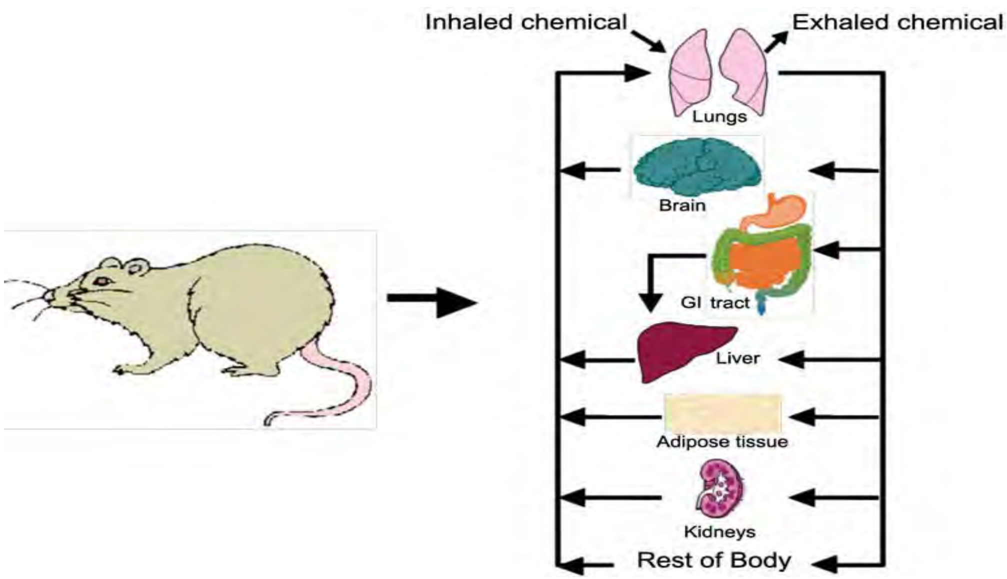


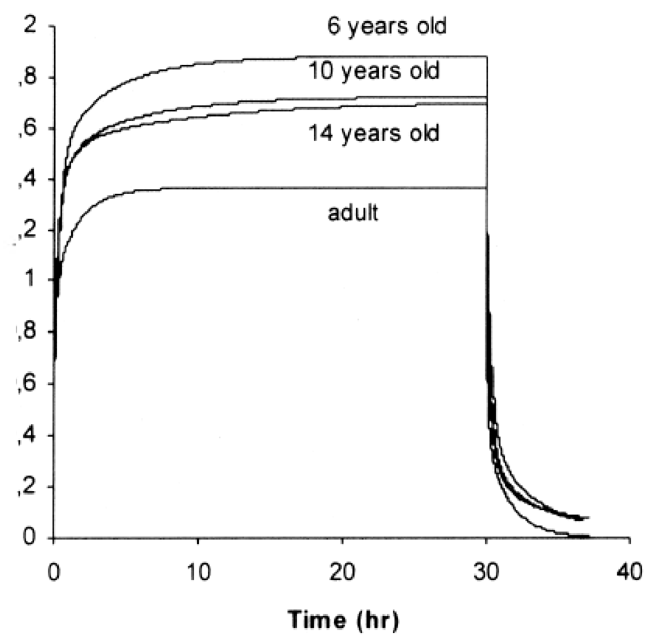
Objectives

- Elaborate a PBPK model for PBDE-209
- Evaluate the accumulation in human breask milk for women in Guiyu (China)

Model elaboration

- Tissue and blood flow variability along the time in acute exposure





- Emond C,et al. 2010. Toxicology and Applied Pharmacology 242:290-298.
- Price K et al. 2003. J Toxicol Environ Health A 66:417–433.

PBPK parameters

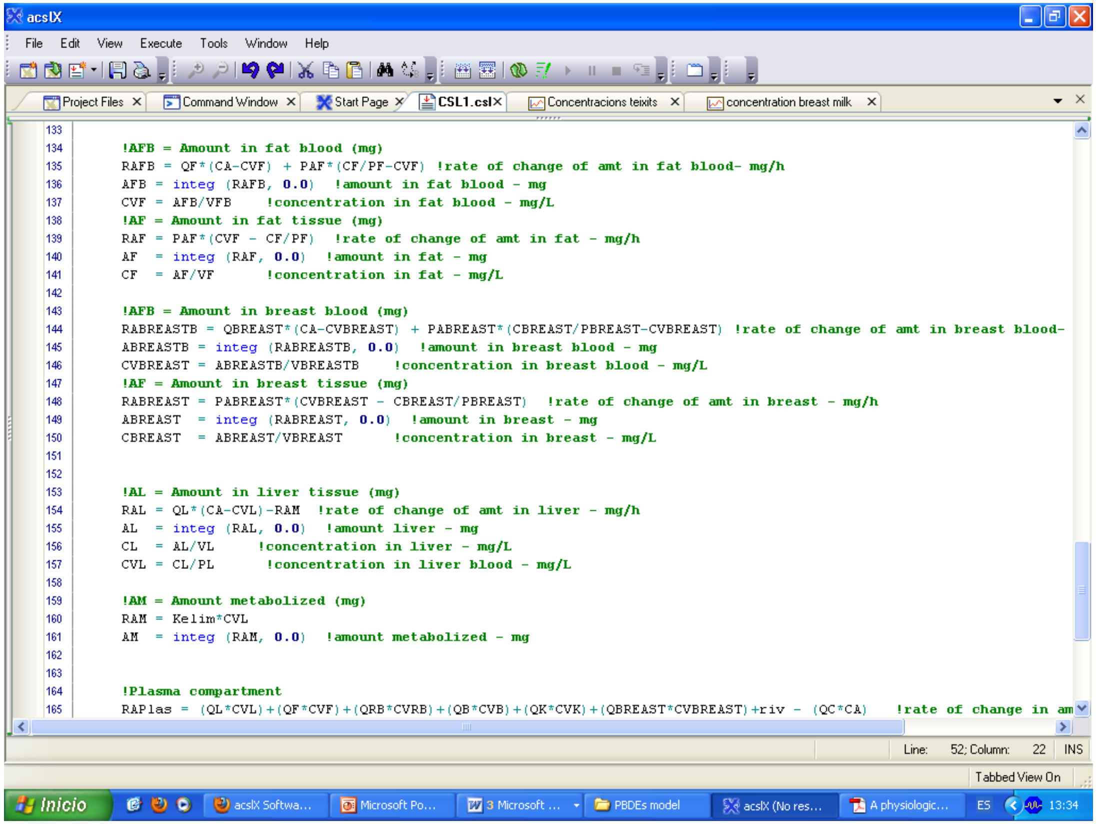
- PBPK parameters extracted from literature.
- Equations:

$$\frac{dC}{dt} = \frac{F}{V} \times \left(Cvenous - \frac{C}{P} \right)$$

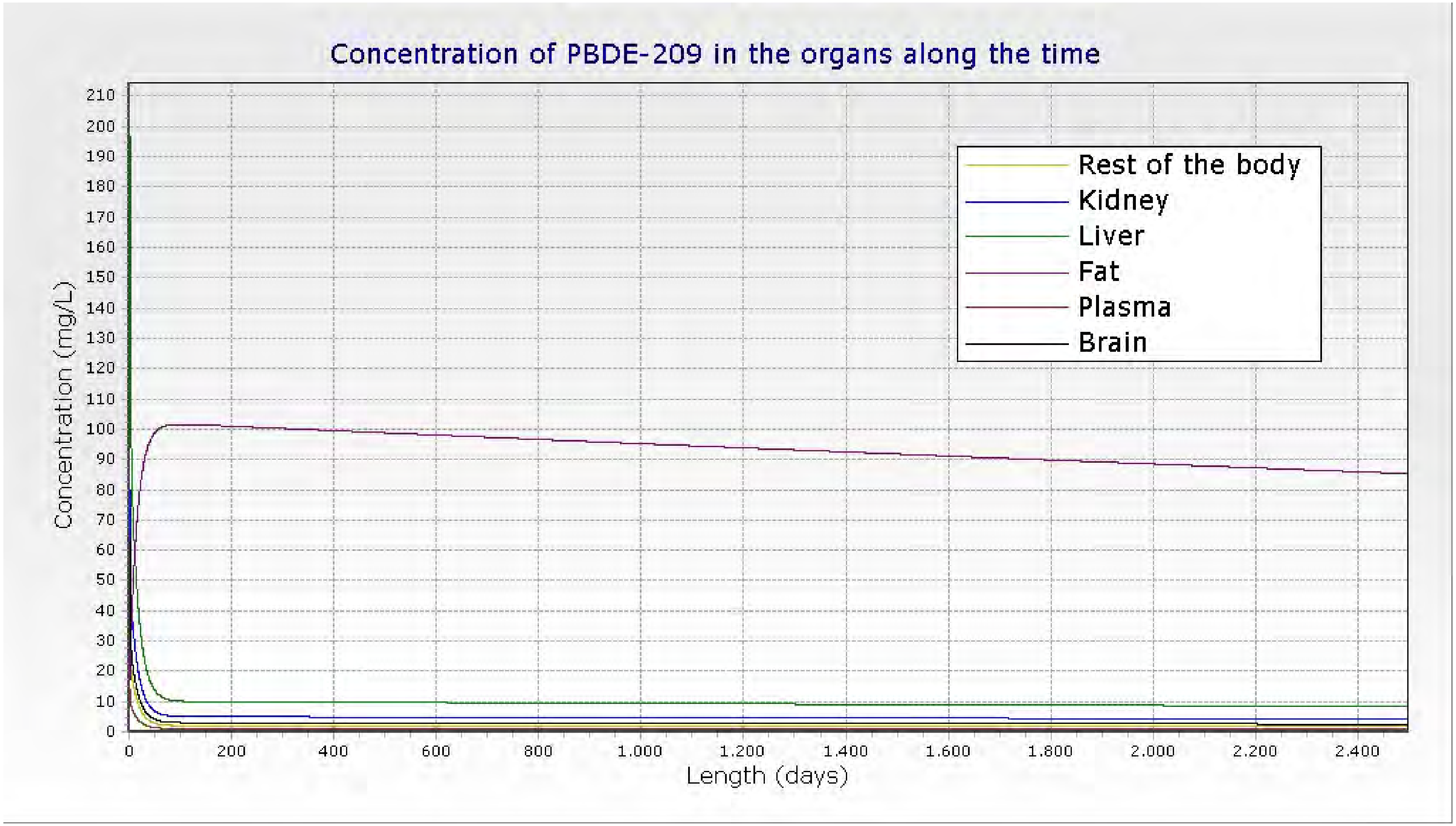
- F: Flow enter in the organ mL/h
- V: Organ volume mL
- C venous: concentration enter in the compartment mg/mL
- C: concentration inside the compartment mg/mL
- Partition coefficient: ratio to the tissue concentration to the arterial concentration in equilibrium

PBPK AcslX programming

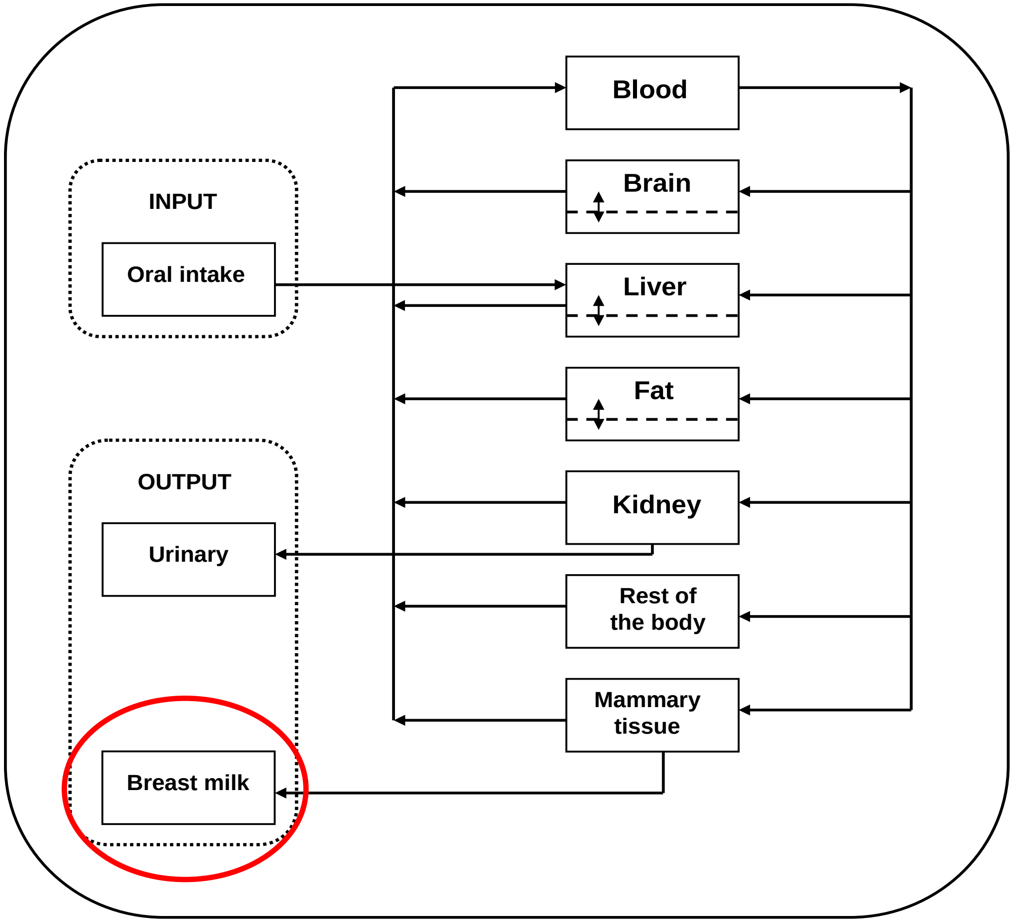
- Use of AcslX software for modeling and simulation of dynamic systems and processes



PBDE-209 concentrations



PBPK application for breast feeding



- PBPK model for PBDE-209
- Chronic exposure model
- Metabolism in liver compartment
- Well mixed compartments

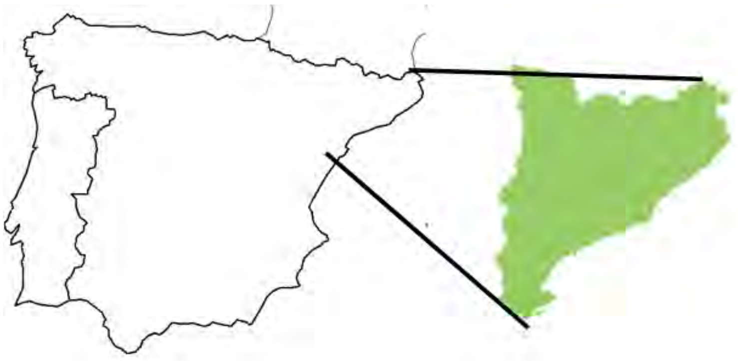
Model validation

- Model validated using human data of the population of the area of Catalonia (NE Spain)

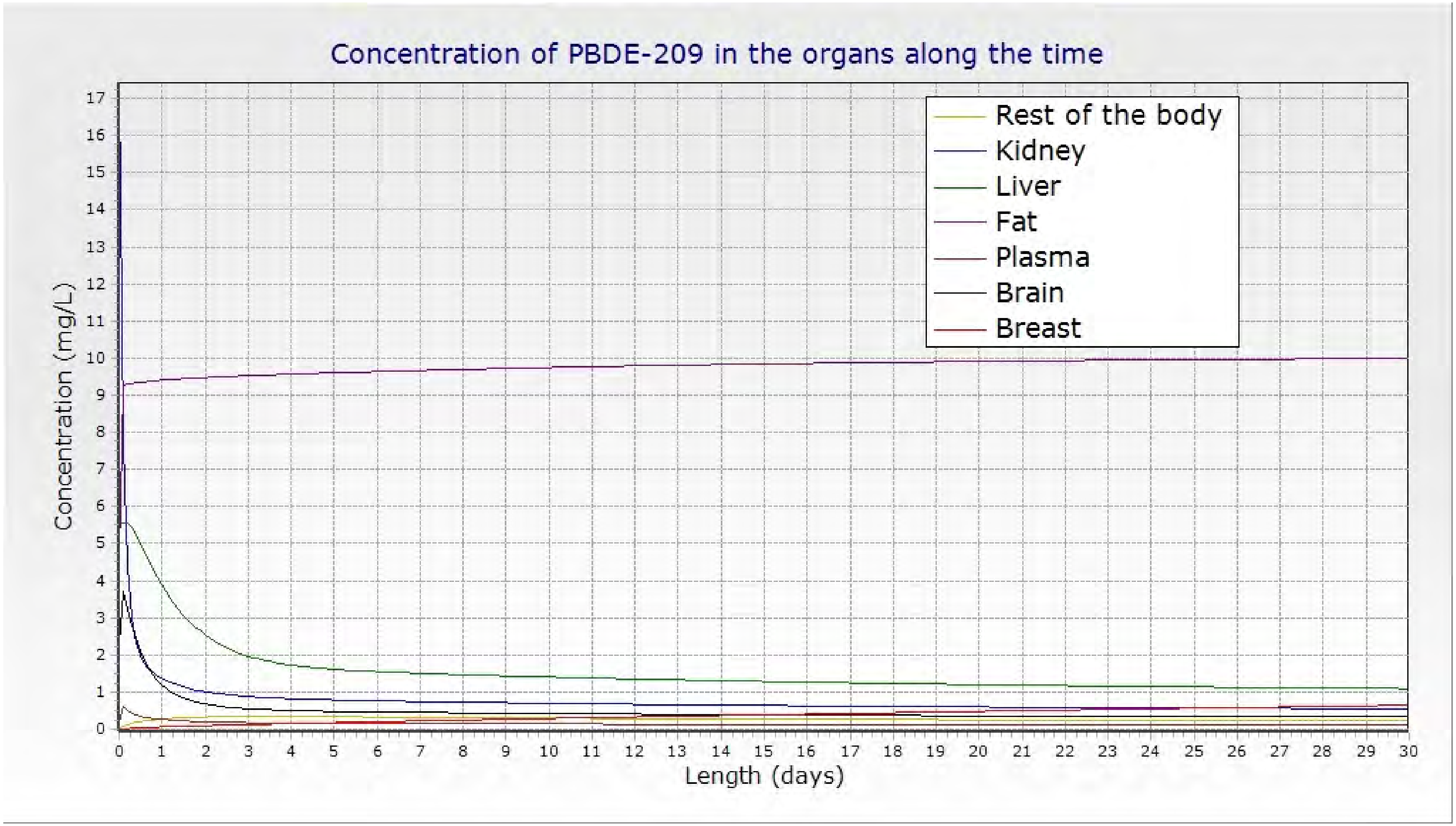
- Intake PBDE =1.1 ng/KgBW/day

- Breast milk

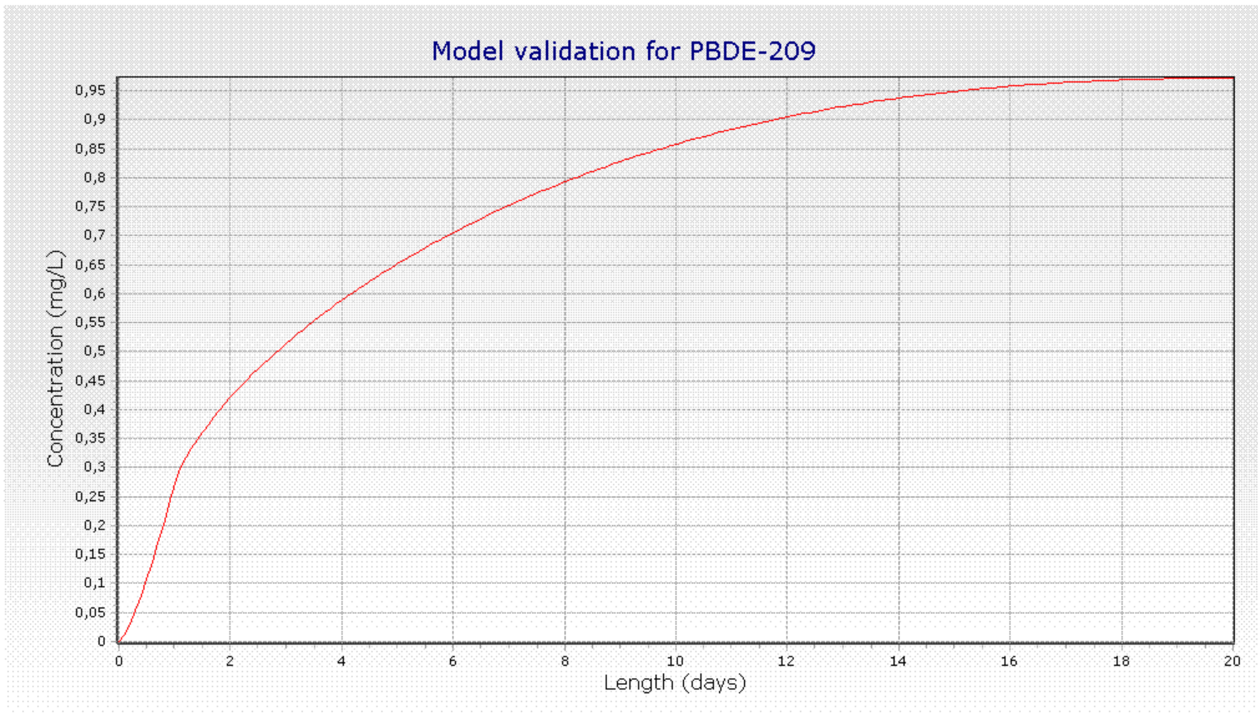
  Mean concentration=2.5ng/g fat
  Min conc.= 0.57
  Max conc.=5.9
  SD=1.6



Acumulation in breast milk (Tarragona case study)



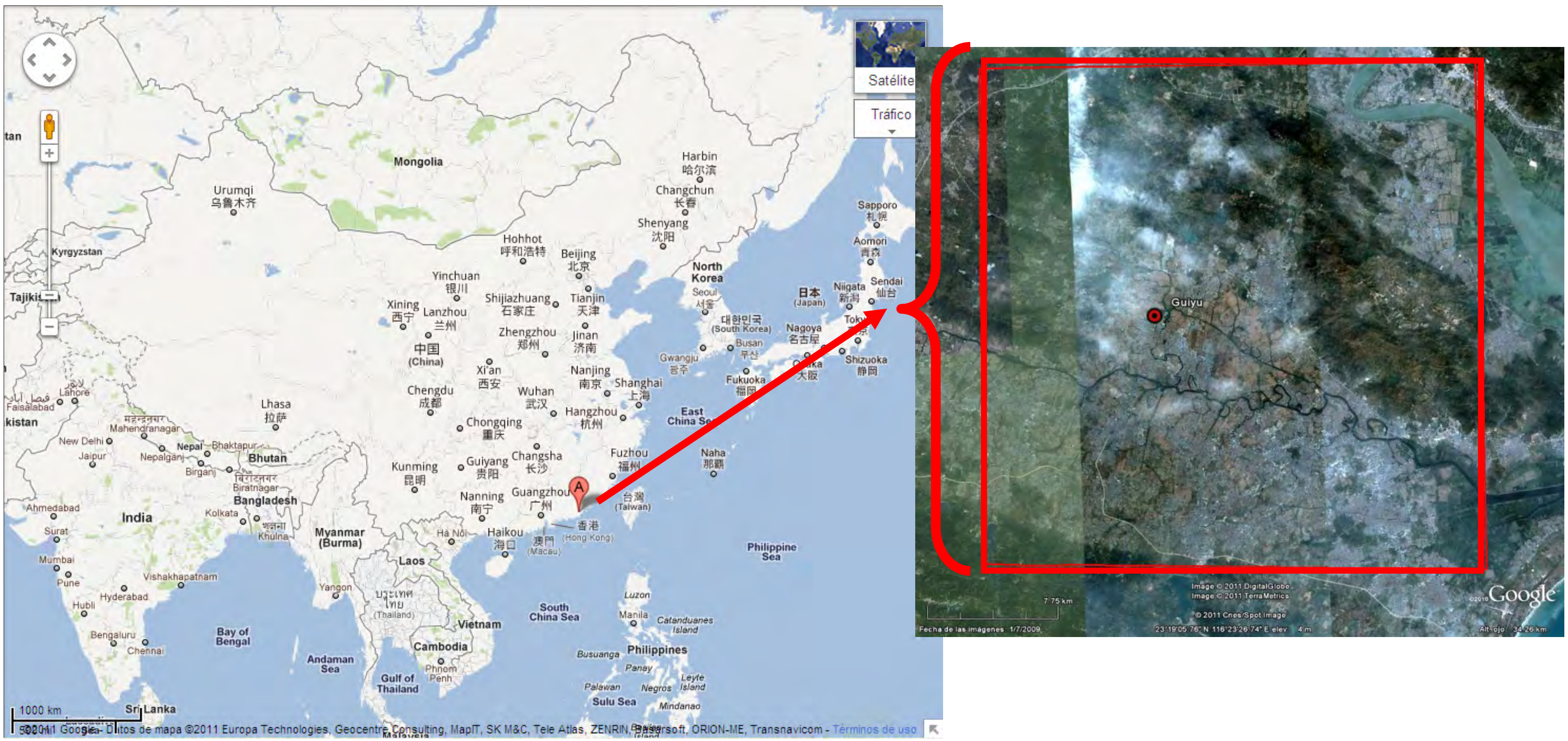
Model validation



- Max conc.=1.058ng/g fat in breast milk
- Well approximate results

Area under study

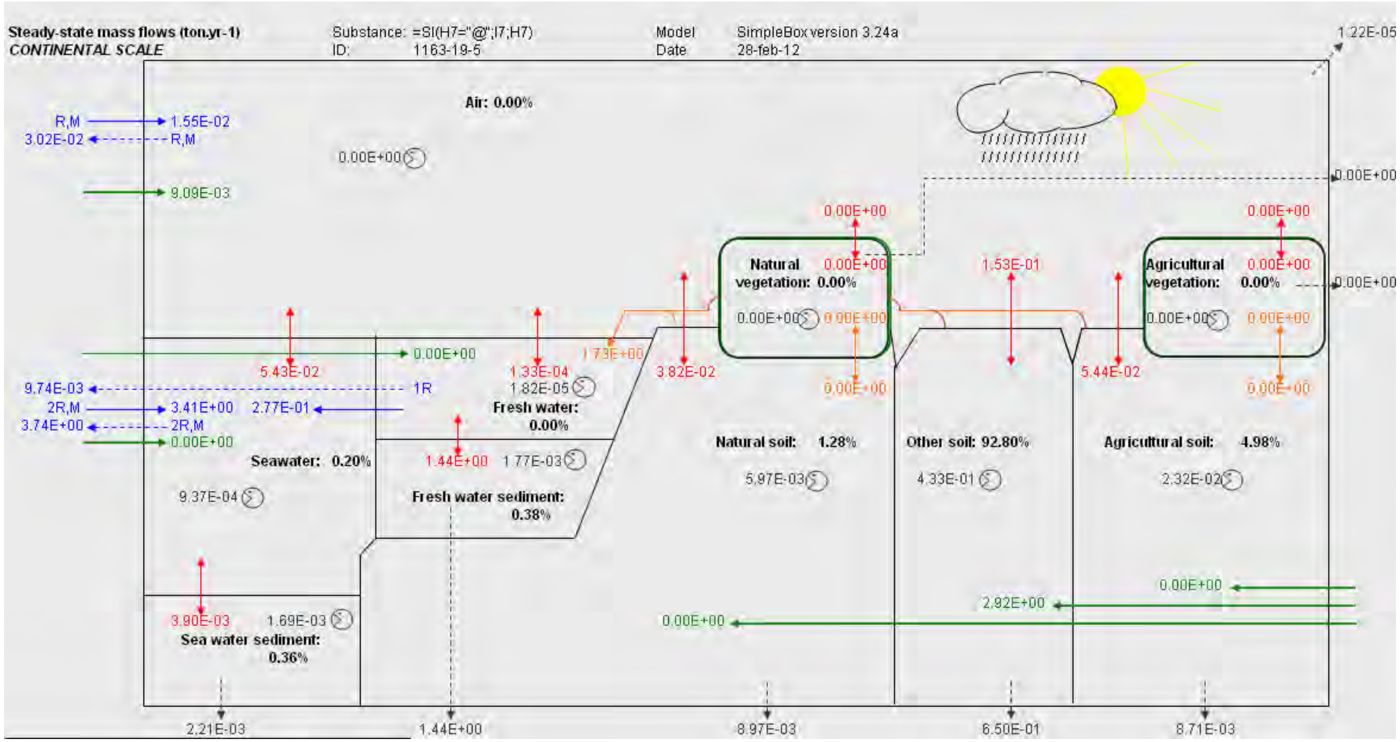
- Guiyu (China)



E-waste recycling in Guiyu

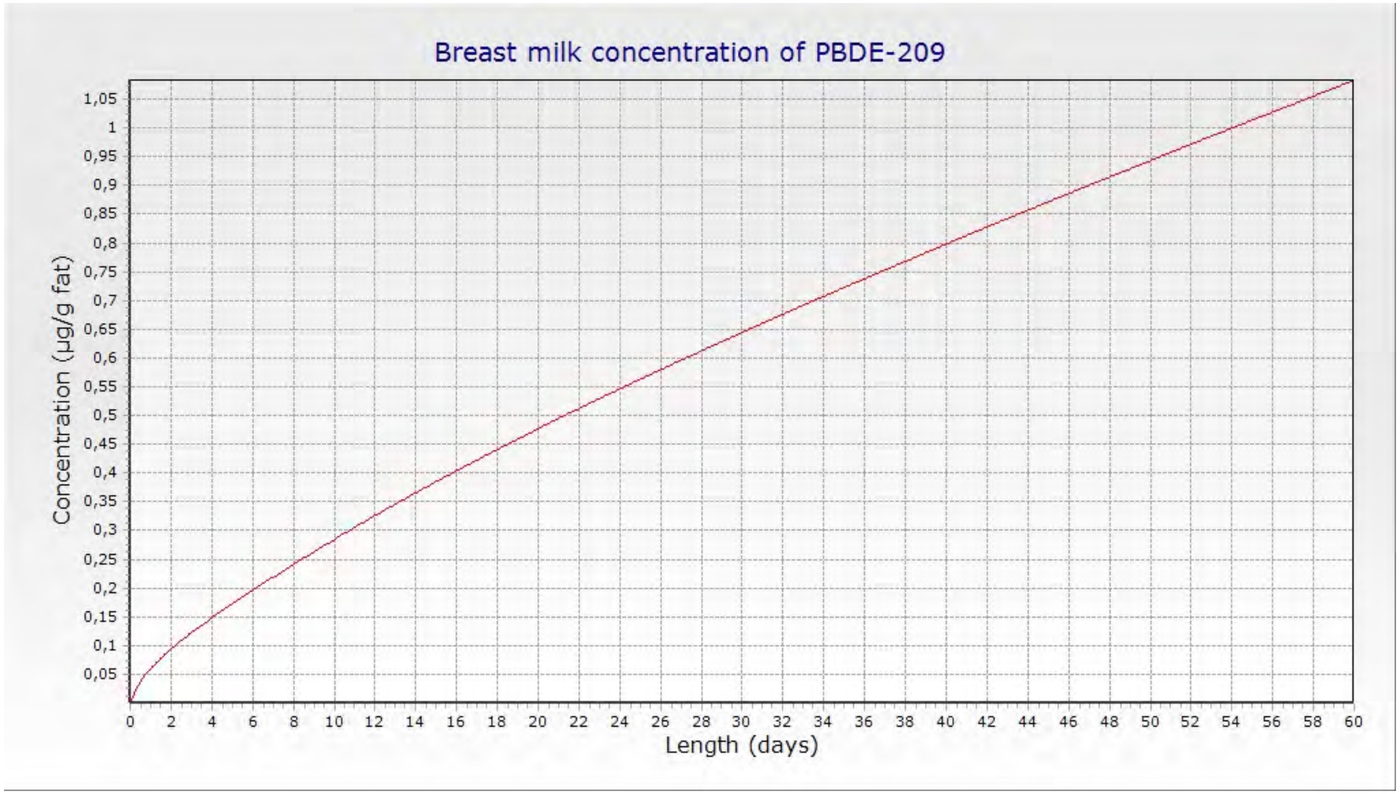
- 60,000 e-workers in Guiyu on 2005
- Higher PBDE exposure comparing with European areas
- Risk for the population under study

Dietary intake from EUSES



- Oral intake (food & water) of 24mg/Kg BW/day
- Inhalation intake of $3.4 * 10^{-9}$mg/Kg BW/day
- Rf Dosis = 0.007 mg/Kg BW/day

Results of breast milk in chronic exposure



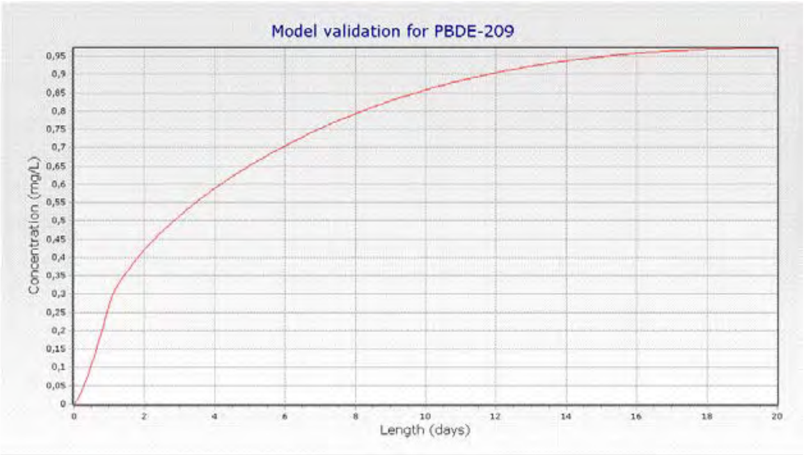
- Maxim concentration of 1,008ng/g fat after 60 days of exposure.

PBDE tissue concentration

	Before pregnance (30 years)	1 month after pregnance	3 months after pregnance
Blood	33.21	0.11	0.10
Brain	79.63	0.33	0.29
Liver	209.79	1.09	0.98
Fat	101.59	9.99	10.01
Kidney	159.94	0.54	0.49
Rest of the body	20.53	0.22	0.20
Breast		0.64	1.48

Units: Breast μg/g, the rest of the tissues mg/L

Breast milk comparative



- Tarragona
  Time to reach maxim concentration of 20 days

- Guiyu
  Time to reach maxim concentration of 5 years

- Difference due to the high intake of the Guiyu area.

Conclusions

- Strong accumulation in breast milk
- High risk for breast feeding children
- Poor metabolism and urinary elimination
- PBPK can be used as an alternative no testing method for risk evaluation after chronic exposure

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Thank you for your attention!

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Human and Environmental impact producted by the E-waste releases at Guiyu Region (China)

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Summary

- Objectives
- Introduction
- Application of the selected models
- Results
- Conclusions

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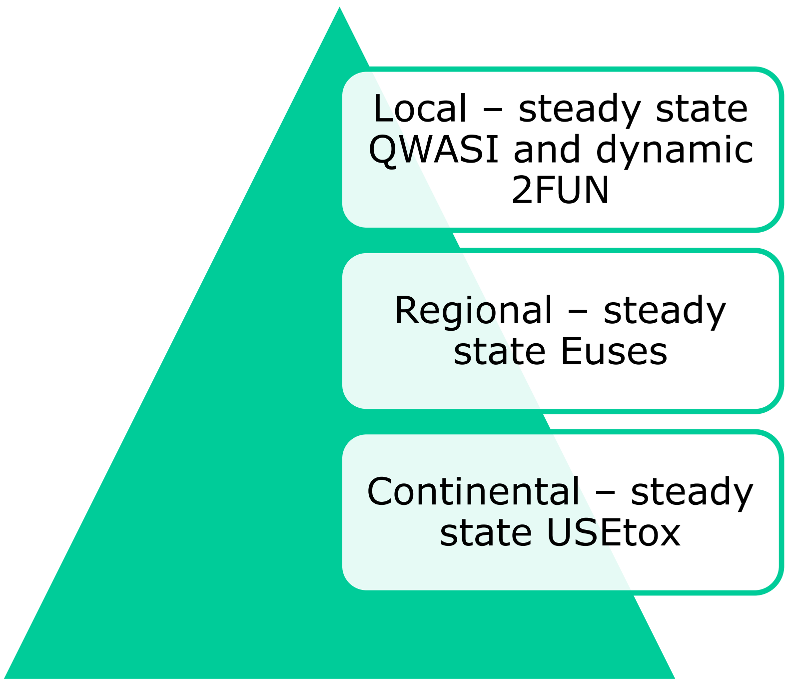
Objectives

- **To evaluate the distribution of two electronic device additives, lead (Pb) and decabrominated diphenyl ether (DeBDE), into the different environmental compartments during the e-waste recycling and their potential impact on the environment and workers'/habitants' (adults and children) health.**



- Uncertainty treatment with the selected models
- Assessment of the strengths and weaknesses of the models

Introduction - what is e-waste?

❖End-of-life electronic products (computers, printers, photocopy machines, TVs, mobile phones, etc.)

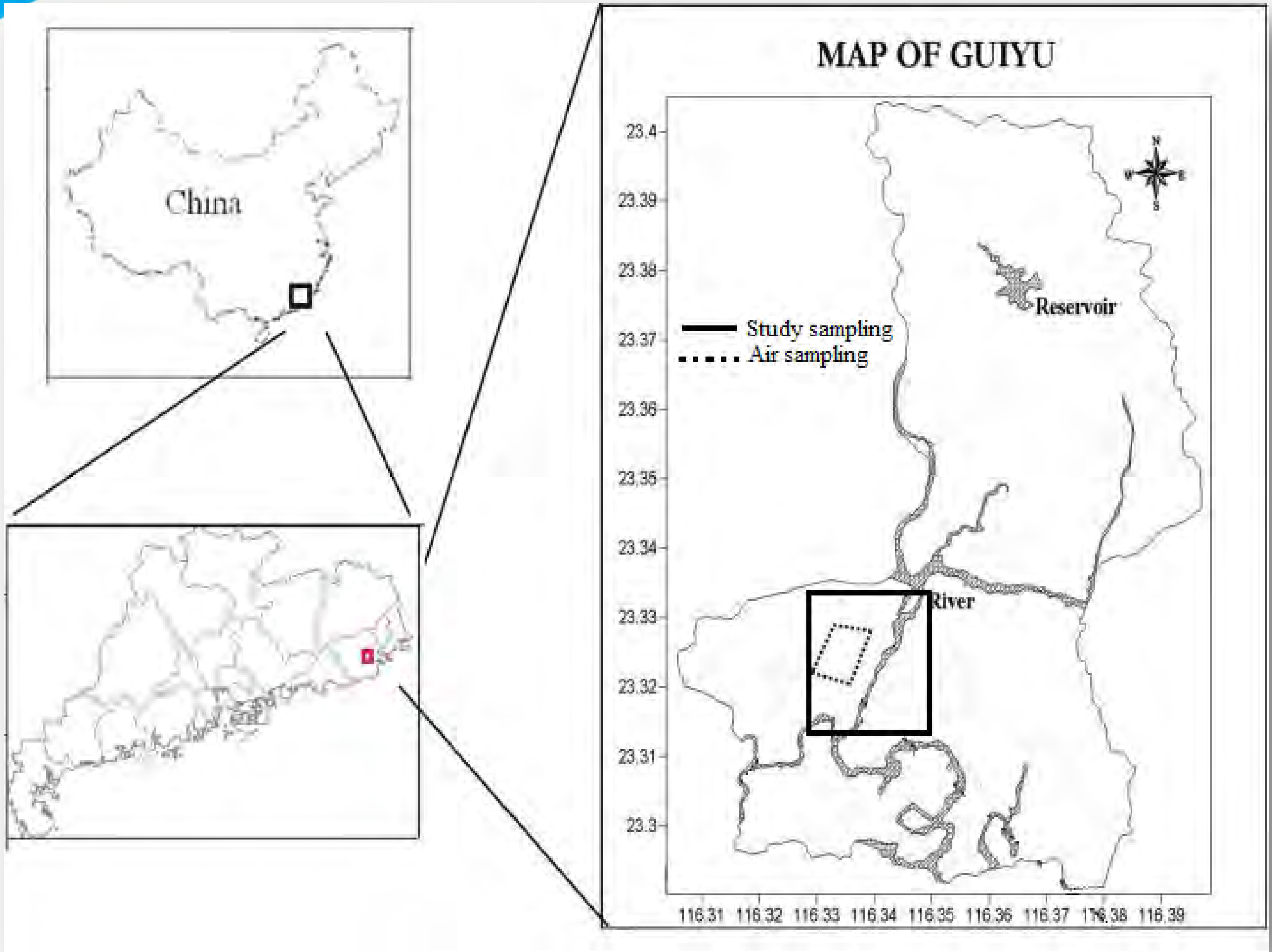
❖ Global e-waste production 20-25 million tones per year[1]

- Europe, the U.S. and Australasia are the biggest producers of e-waste
- 2005 EC estimates 8.8 million tones of e-waste in Europe

❖80% of all e-waste are exported to Asia

[1]Robinson, B. H. (2009). "E-waste: An assessment of global production and environmental impacts." Science of The Total Environment 408(2): 183-191.

Introduction – Selection of the study area



Map of Guiyu Town. The rectangles show the sampling area when the literature concentration values for Pb (air and water) are considered for the study

Introduction – Selection of the study area

- The town of Guiyu is the largest e-waste site on the world and among the most polluted spots.
- Since 1995, e-waste from U.S, Europe and elsewhere have been continuously transported to Guiyu and "recycled" by villagers
- "Recycling" operations
  - Separation, processing and recycling of plastics
  - Manual separation of products
  - Removal and collection of solder using heating
  - Acidic extraction of metals from complex mixtures
  - Burning of wastes to remove combustible plastics and isolate metals
  - Glass recovery from cathode ray tubes (CRTs)
- Works undertaken by men, women, and even children with little or no protection to health

Introduction – Selection of the study area

Typical E-scrapping dismantling operation.

Typical acid extraction

Open landfills in Guiyu area

©2001 Basel Action Network (BAN)

Introduction- Modelled substances

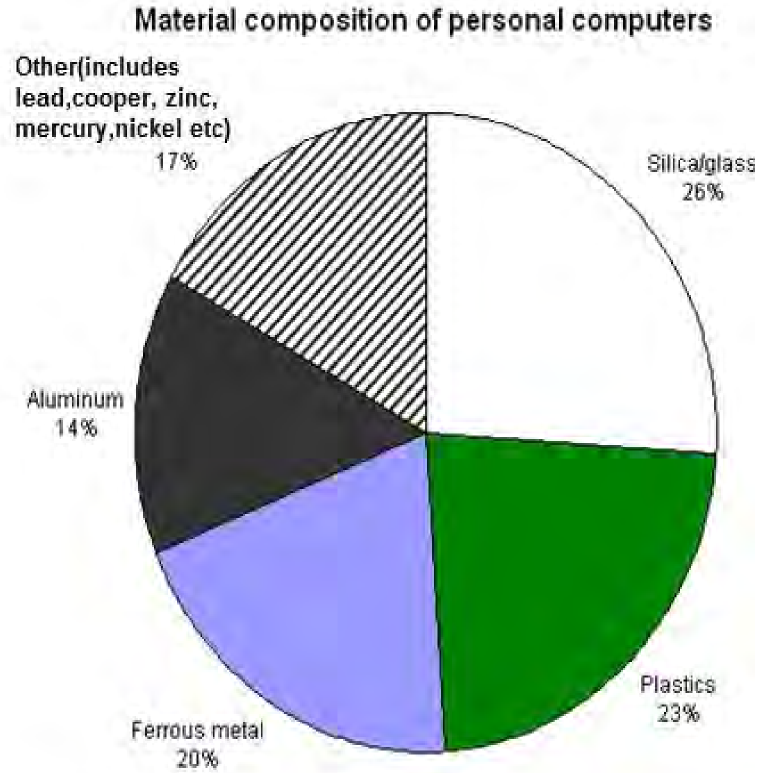
➢ Considered substances – Pb and DeBDE

➢More than 6% of a computer is Pb; just 5% of total Pb is recycled

➢ Pb – can cause permanent damage to the brain and nervous system, causing retardation and behavioral changes - infants and young children

➢DeBDE – can be found in printed circuit boards, in components such as connectors, in plastic covers and in cables

➢DeBDE - likely to be carcinogen, endocrine disrupter and/or neurodevelopment toxicant



Source: Environment Canada.

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Models Application

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USEtox TM

- Scale – Continental (China)
- Background
  - Landscape data. Parameters for China (e.g. Population, fresh water fraction, natural soil, etc.)
  - Substance data. Information for Pb and PBDE, both imported from RISKCYCLE database
- Inputs:
  - Pb: emission to water (2.437 t/yr), soil (28.64 t/yr) and air (0.179 t/yr) from SFA (with focus on China)
  - DeBDE: emission to water ($9.38 \cdot 10^{-2}$ t/yr), soil (0.736 t/yr) and air ($2.72 \cdot 10^{-2}$ t/yr) from SFA for China

USEtox TM

- Outputs
  - Concentrations in the environmental compartments - calculated considering processes such as advection, transportation, degradation, etc. among the different scales implemented by USEtox^{TM}.
  - Human intake fractions of Pb and DeBDE ($kg_{intake} \bullet kg_{emitted}^{-1}$) for different exposure pathways

EUSES Model

- Scale – Regional for Guiyu region (10^3 km^2)
- Background
  - Landscape data. Parameters for Guiyu region (e.g. Population, fresh water fraction, natural soil, etc.)
  - Substance data. Information for DeBDE imported from RISKCYCLE database
- Inputs:
  - DeBDE: emission to water (range from $5.6 \cdot 10^{-3}$ to $5.6 \cdot 10^{-2}$ t/yr), soil ($2.4 \cdot 10^{-1} \pm 5.7 \cdot 10^{-2}$ t/yr) and air ($8.7 \cdot 10^{-3} \pm 1.7 \cdot 10^{-3}$ t/yr) from SFA in Guiyu region.

EUSES Model

- Outputs
  - Concentrations in the environmental compartments (water, soil, sediment and air) using the multi-media fate model SimpleBox 3.0. present in EUSES.
  - Human intake doses for different exposure pathways in Guiyu region.
  - Risk characterization - human health and environment are assessed, exposure levels are compared to suitable no-effect levels.

Qwasi Model

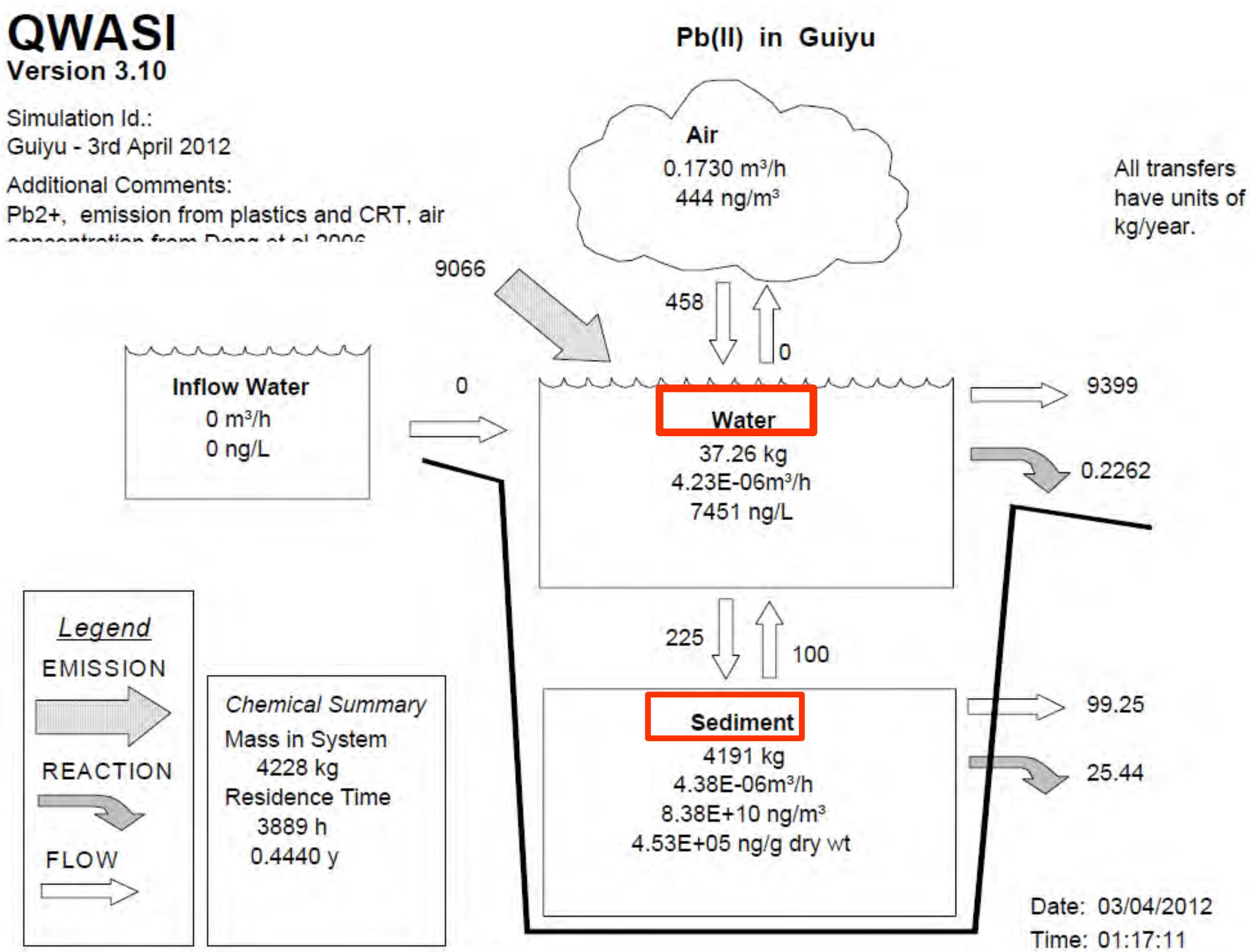
- Scale - local
- Background – defined landscape regarding length and depth of river, depth of sediment layer
- Inputs:

✓ Pb emission to water from SFA (leachate: about 9020 kg/yr), scenarios for different atmospheric concentrations and rain rates

✓ DeBDE: scenarios for different emissions to water (leachate from disposal sites: 0 – 30 kg/yr)

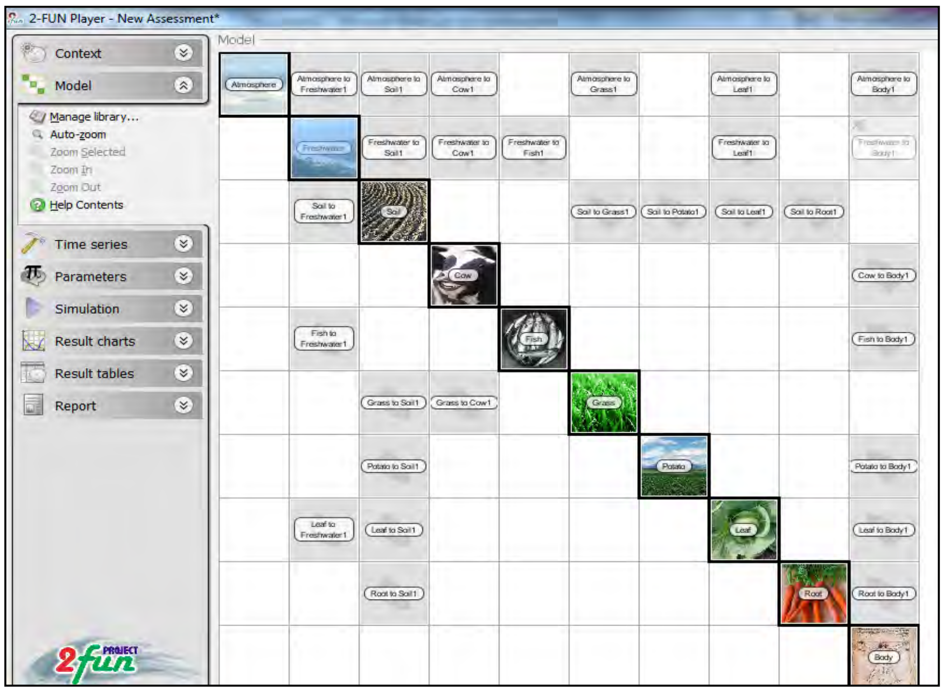
Qwasi Model

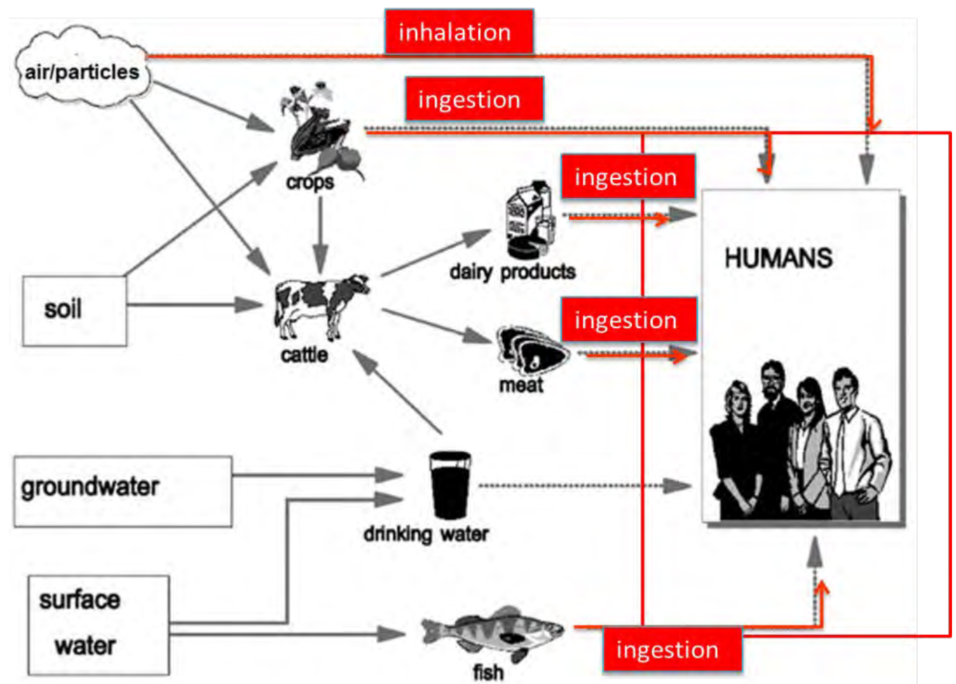
- **Outputs**



2 FUN Tool

- Scale -local
- Background- scenario development and pathways definition

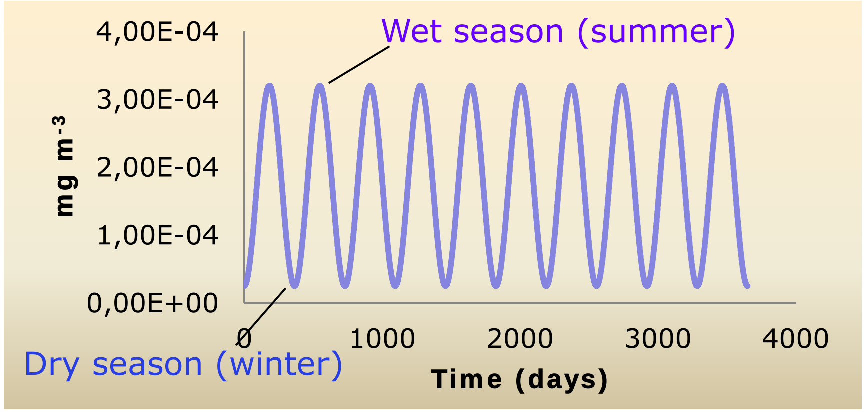




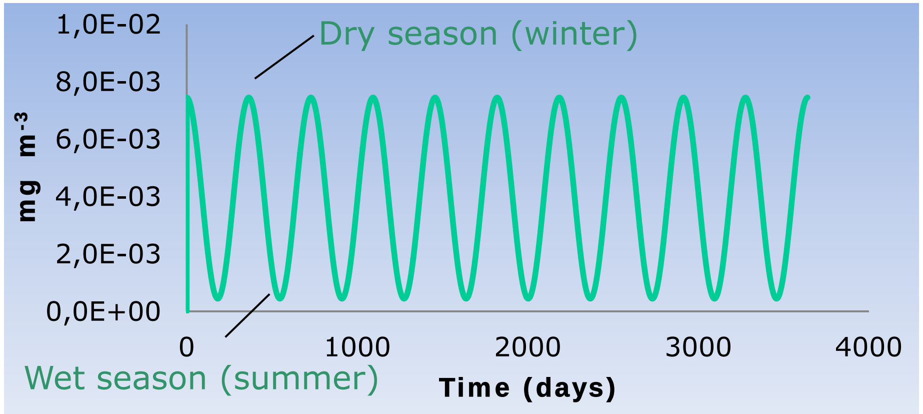
2 FUN Tool

- **Inputs**

Pb concentration in the river water



Pb concentration in the air flow (on TSP)



❖Monthly precipitation average

❖Monthly wind speed average

❖Monthly soil temperature - created based on air temperature

❖Global solar radiation

❖Total suspended particles in atmosphere

❖River geometry, river water flow rate

❖Daily fish, vegetables (root, leaf, potato), milk and beef ingestion rats by humans

- **Outputs**

Pb concentration in arterial blood (μg dL^{-1})

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Pb Properties in 2 FUN Tool, for probabilistic estimations

Property	PDF* / calculation
Partition Coefficient at the sediment pore water interface; $k_{d\text{-}sed}$ (m^3/g)	LN2(-3.2,4.4)
Partition coefficient at the water – SPM interface; $k_{d\text{-}SPM}$ (m^3/g)	LN2(-0.69,0.92)
Bioconcentration Factor; BCF (m3/g fw)	Log(BCF)=f(log(C_dis_water))
1st regression coefficient of the relationship Log(BCF)=f(log(C_dis_water)); α_{fish_metal} ($\log(m^3/g)$)	norm(5.2,0.38)
2nd regression coefficient of the relationship Log(BCF)=f(log(C_dis_water)); β_{fish_metal}	norm(-0.85,0.073)

*Probabilistic density function

RISKCYCLE

SEVENTH FRAMEWORK PROGRAMME

Results - Continental

USEtox model results

- Pb concentrations and intake doses obtained with USEtox have resulted to be much lower than the limit values found in literature
  (Air, $8{,}47\cdot10^{-11} < 5\cdot10^{-2}$ µg·dm^{-3}; Water, $9{,}24\cdot10^{-4} < 50$ µg·dm^{-3}; TDI $2.99\cdot10^{-3} < 25$ µg/(kg bw·d)$^{-1}$).

- DeBDE concentrations and intake doses obtained with USEtox have been lower than the limit values found in literature
  (Air, $1{,}29\cdot10^{-11} < 1.24\cdot10^{-8} – 9.89\cdot10^{-11}$ µg·dm^{-3}; Water, $2{,}20\cdot10^{-5} < 6.52\cdot10^{-5} – 3.35\cdot10^{-7}$ µg·dm^{-3}; TDI $1{,}41\cdot10^{-6} < 0{,}1$ µg/(kg bw·d^{-1});

The situation for the Chinese country with regard to the hazards caused by the e- waste additives Pb and DeBDE is NOT risky

Results - Regional

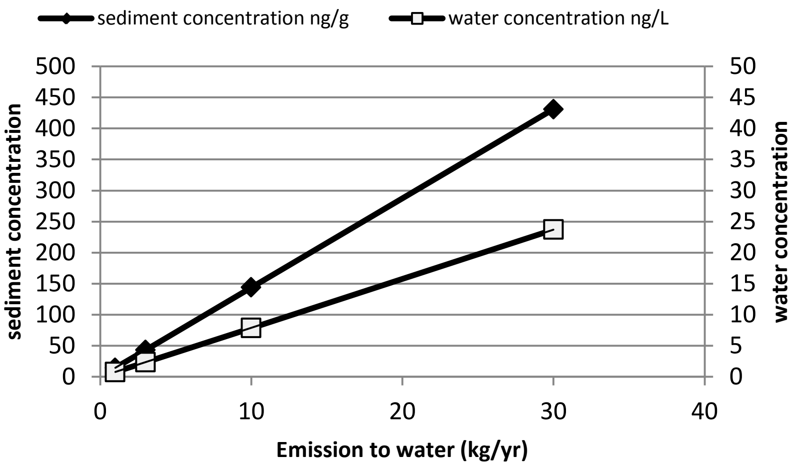
EUSES model results

- DeBDE concentrations obtained with Euses have resulted to be in agreement with the values found in literature (Air, $1.4 \cdot 10^{-8} \pm 2.8 \cdot 10^{-9} \cong 9,89 \cdot 10^{-8} mg \cdot m^{-3}$; Soil, $1.3 \cdot 10^{1} \pm 3.4 \cong 2.78 \pm 1.17$ $mg \cdot kg^{-1}$; Sediment , $7.6 \cdot 10^{-3} \pm 1.8 \cdot 10^{-3} \cong 3.0 \cdot 10^{-2} \pm 2.0 \cdot 10^{-2}$ $mg \cdot kg^{-1}$).
- Regional TDI of DeBDE for human beings - 29.7 $mg \cdot /(kg\ bw \cdot d)^{-1}$ (7.8 to 72.5 $mg \cdot (kg\ bw \cdot d^{-1})$) **>** $7.0E^{-03}$ $mg \cdot (kg\ bw \cdot d)^{-1}$ (EPA daily oral reference).
- Main regional pathway of exposure (99.9%) - daily intake of root crop.
- Carcinogenic risk - 8.9 cancer cases in 1000 inhabitants; much higher than acceptable value.
- Regarding environmental risk, there is a high risk situation for soil ecosystem and especially in the case of worm-eating predators (120).

Results - Local

Qwasi model results

Atmospheric input is not important for DeBDE but very important for Pb as pathway to water and sediment

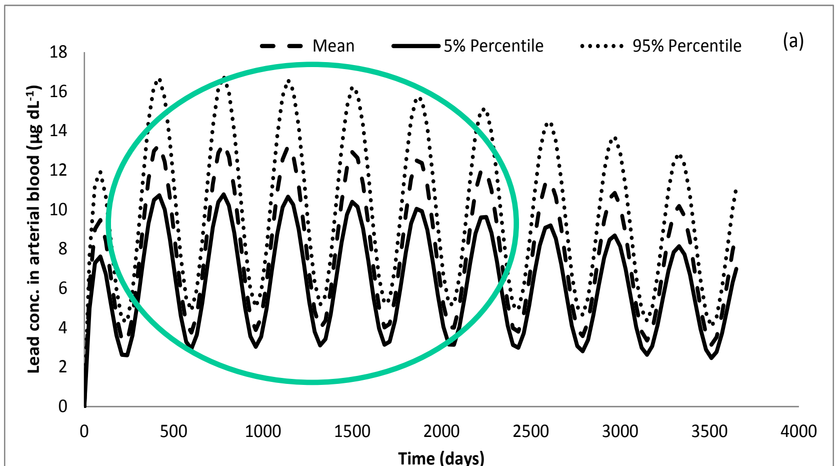


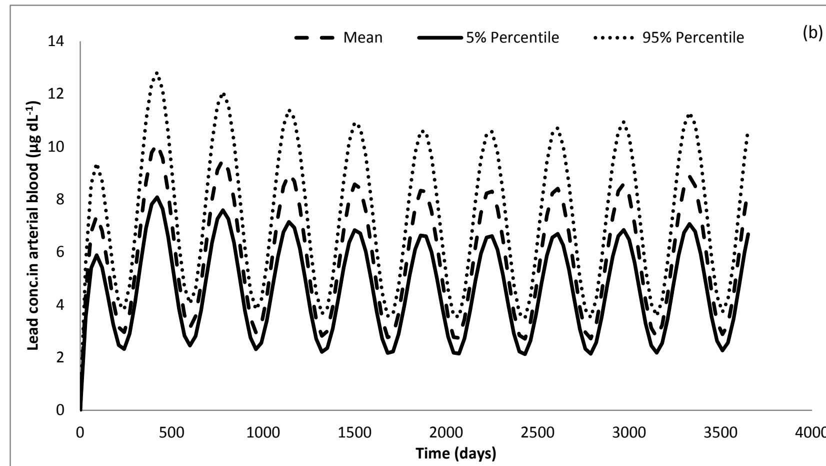
Pb WATER concentration (mg*L^{-1})				
		Rain rate in m*y^{-1}		
		Low 0.021	Average 2.2	High 4.38
Concentration in Air	Low (0.44*10^{-3}mg*m^{-3})	7*10^{-3}	2.5*10^{-2}	4.4*10^{-2}
	High (7.45*10^{-3}mg*m^{-3})	9*10^{-3}	3.2*10^{-1}	6.3*10^{-1}
Pb SEDIMENT concentration (mg*kg^{-1})				
		Rain rate in m*y^{-1}		
		Low 0.021	Average 2.2	High 4.38
Concentration in Air	Low (0.44*10^{-3}mg*m^{-3})	0.4*10^{-3}	1.6*10^{-3}	2.7*10^{-3}
	High (7.45*10^{-3}mg*m^{-3})	0.5*10^{-3}	1.9*10^{-2}	3.8*10^{-2}

Results - Local

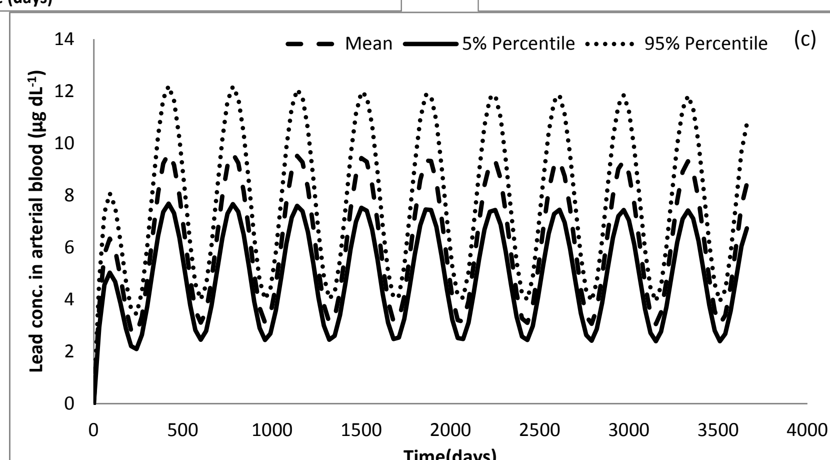
2FUN TOOL results

Lead concentrations in arterial blood (μg dL^{-1}) over 10 years simulation; (a) initial age 2 years, (b) initial age 10 years, (c) initial age 20 years



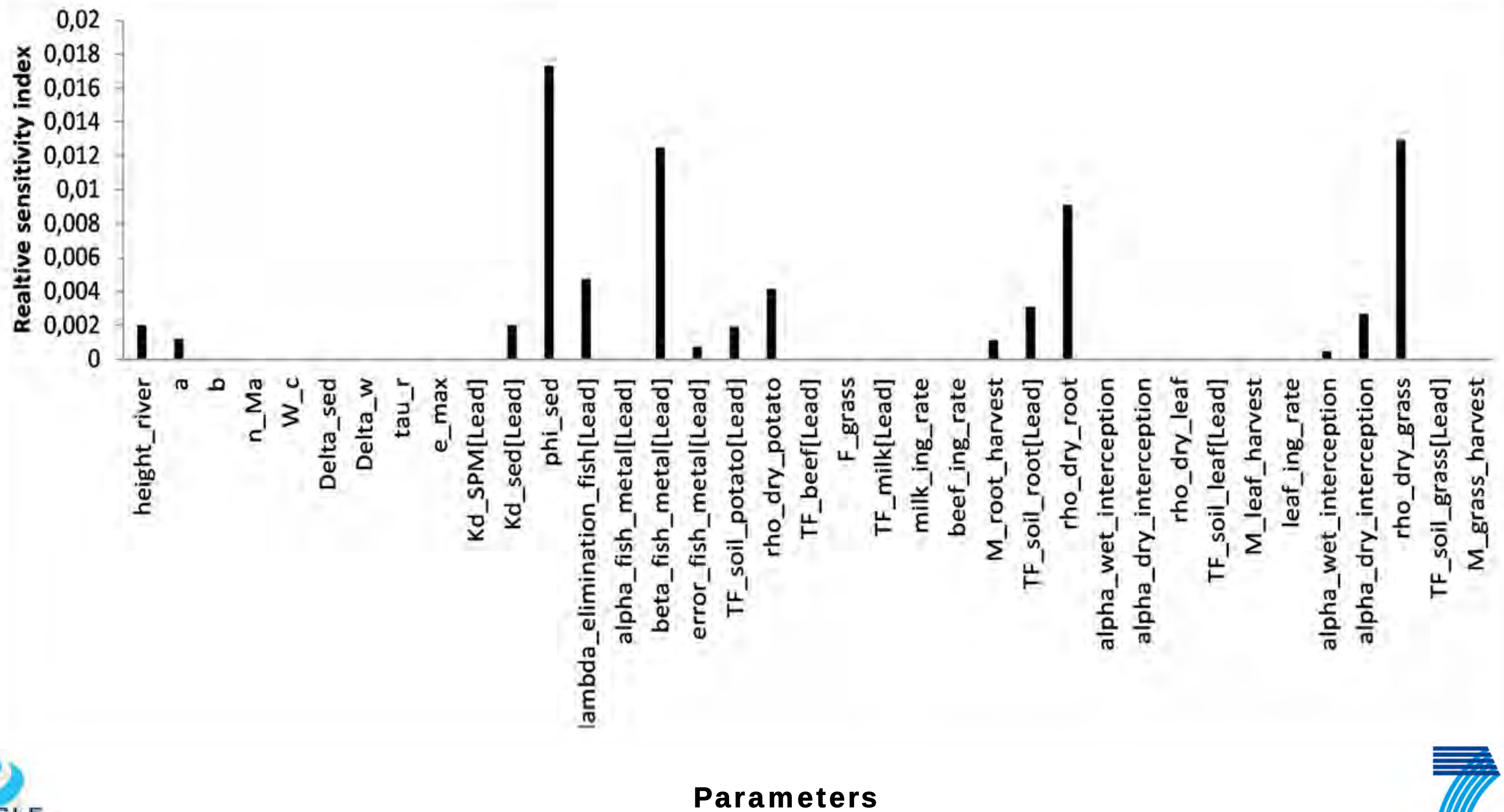


70,8% of 165 children in Guiyu have value of BLL >10 μg/dL

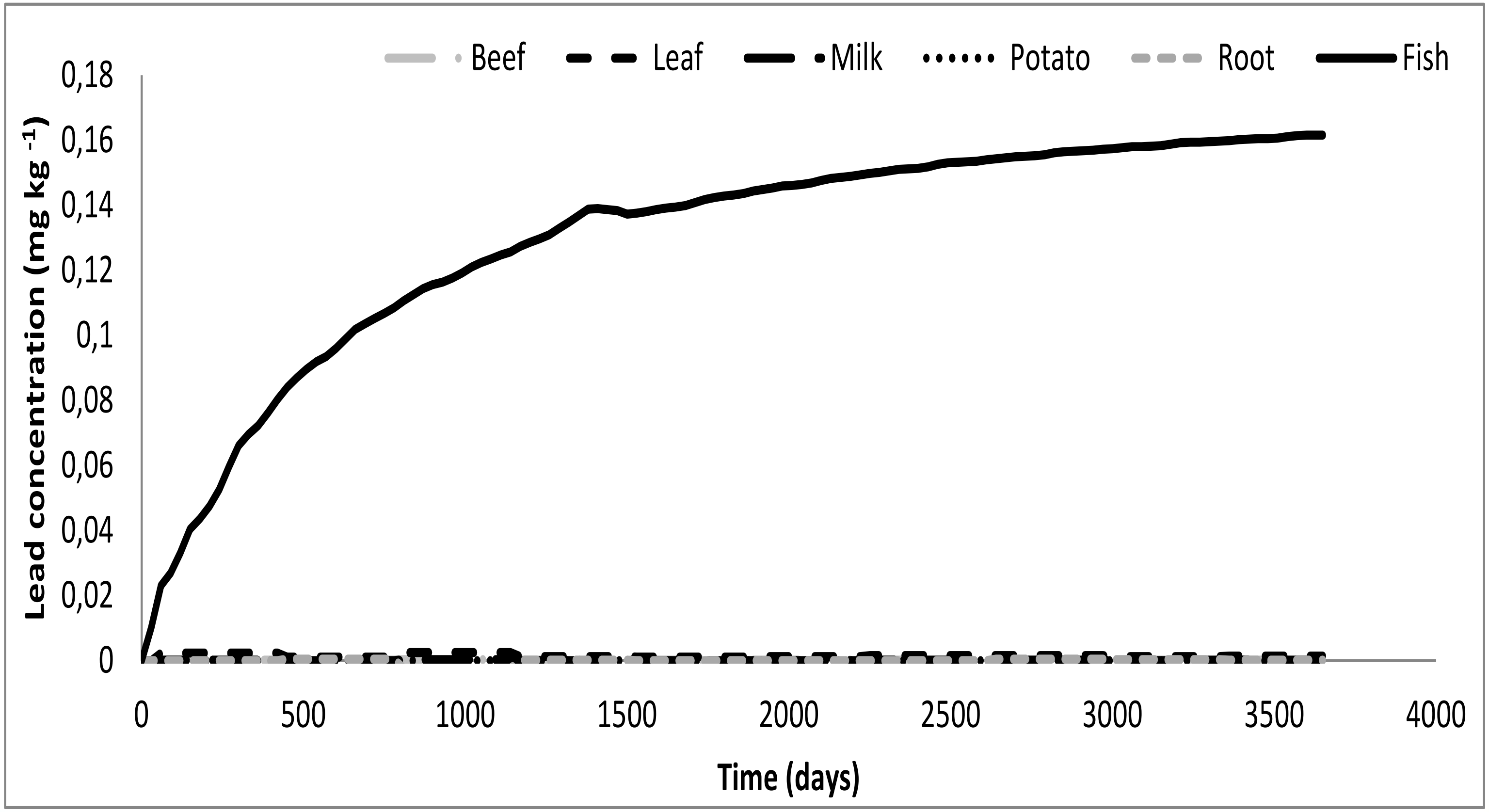


10 μg/dL- limit of concern by CDC

Global sensitivity analysis for Pb concentration in arterial blood



Pb concentration in fish, potato, root, leaf , milk and beef (mg kg^{-1})



Conclusions

- ✓ Uncertainty has often been present in this study; this has implied that some assumptions have been taken.
- ✓ The results obtained after the models calculations were quite acceptable; comparing the results of each model with values extracted from literature, the predicted values were at the same order of magnitude as the monitored values.
- ✓ Concerning risk characterization of Pb and DeBDE, a clear increase of the risk for the environment and human health when reducing the scale of the study was observed.
- ✓ USEtox^{TM} obtained low concentrations of Pb and DeBDE when assessing the environmental distribution of additives for the country of China.
- ✓ EUSES obtained a high level of risk for both environmental and human health in Guiyu region.

Conclusions

- ✓ Qwasi; DeBDE-leaching from deposited waste material important route of water and sediment contamination; fraction that is transferred to the atmosphere has a less impact. Pb concentration in the environment is strongly influenced by air concentration and rain rate, in addition to direct emissions.

- ✓ 2 FUN; real health risk for workers/habitants of the Guiyu town due to the released of Pb during e-waste recycling processes. A higher risk was observed for very young children

- ✓ From the combination of all the selected models, a better understanding of the e-waste informal recycling processes has been achieved.

EUROPEAN COMMISSION
Community research

Thank you for your attention!

RISKCYCLE

SEVENTH FRAMEWORK PROGRAMME

Risk assessment of informal E-waste recycling activities

Vera Susanne Rotter
Maarten A. Siebel
Bernd Bilitewski
Alexander Janz

RISKCYCLE

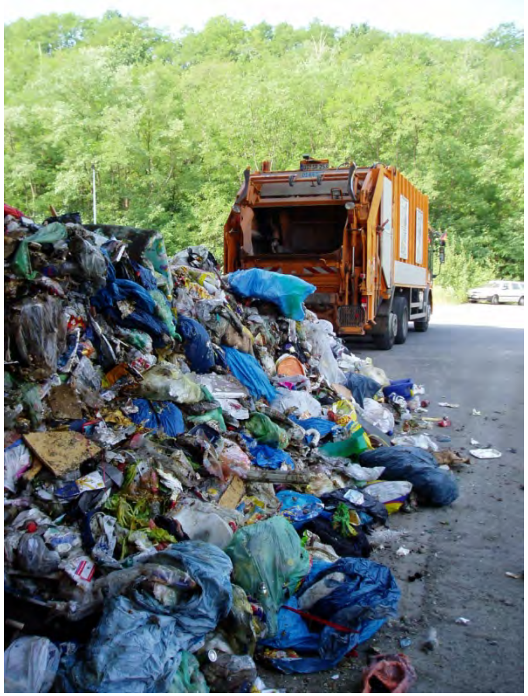
8-9 May 2012
Dresden, Germany

End-of-life management

Overview

- Heavy metal potential in Waste Electric and Electronic Equipment (WEEE)
- Test methods for assessing fate of heavy metals during recycling
- Dissipative distribution of heavy metals during landfilling and open dumping
- Outlook / Discussion:

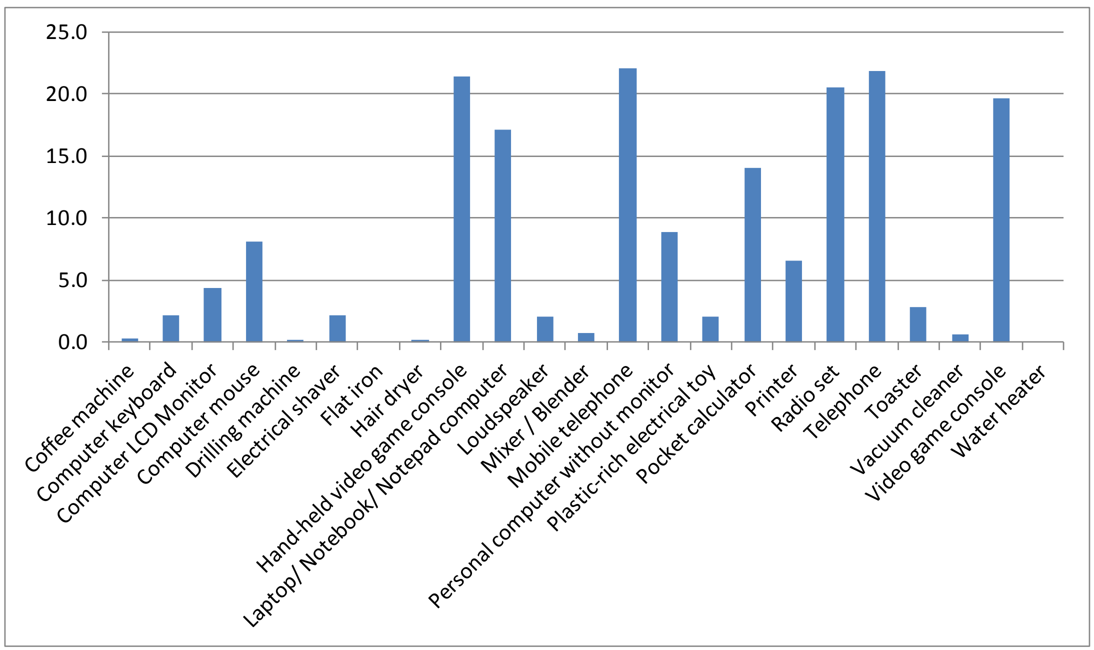
The problem of dissipative distribution of damaging trace metals with WEEE into the environment



Heavy metals in WEEE

- Printed Circuit Boards (PCB) account for 1-25% of WEEE
- contain
  - up to 300 ppm Gold
  - 14% Copper
  - 2% Lead
  - 70 ppm Cadmium

PCB content of WEEE in %



Vera Susanne Rotter

Annex II (abridgment) of Directive 2002/96/EC on waste electrical and electronic equipment (WEEE): Avoidance of env./heath protection

ANNEX II

Selective treatment for materials and components of waste electrical and electronic equipment in accordance with Article 6(1)

1. As a minimum the following substances, preparations and components have to be removed from any separately collected WEEE:

   — polychlorinated biphenyls (PCB) containing capacitors in accordance with Council Directive 96/59/EC of 16 September 1996 on the disposal of polychlorinated biphenyls and polychlorinated terphenyls (PCB/PCT) ([1]),

   — mercury containing components, such as switches or backlighting lamps,

   — batteries,

   — printed circuit boards of mobile phones generally, and of other devices if the surface of the printed circuit board is greater than 10 square centimetres,

   — toner cartridges, liquid and pasty, as well as colour toner,

   — plastic containing brominated flame retardants,

   — asbestos waste and components which contain asbestos,

   — cathode ray tubes,

   — chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluorocarbons (HFC), hydrocarbons (HC),

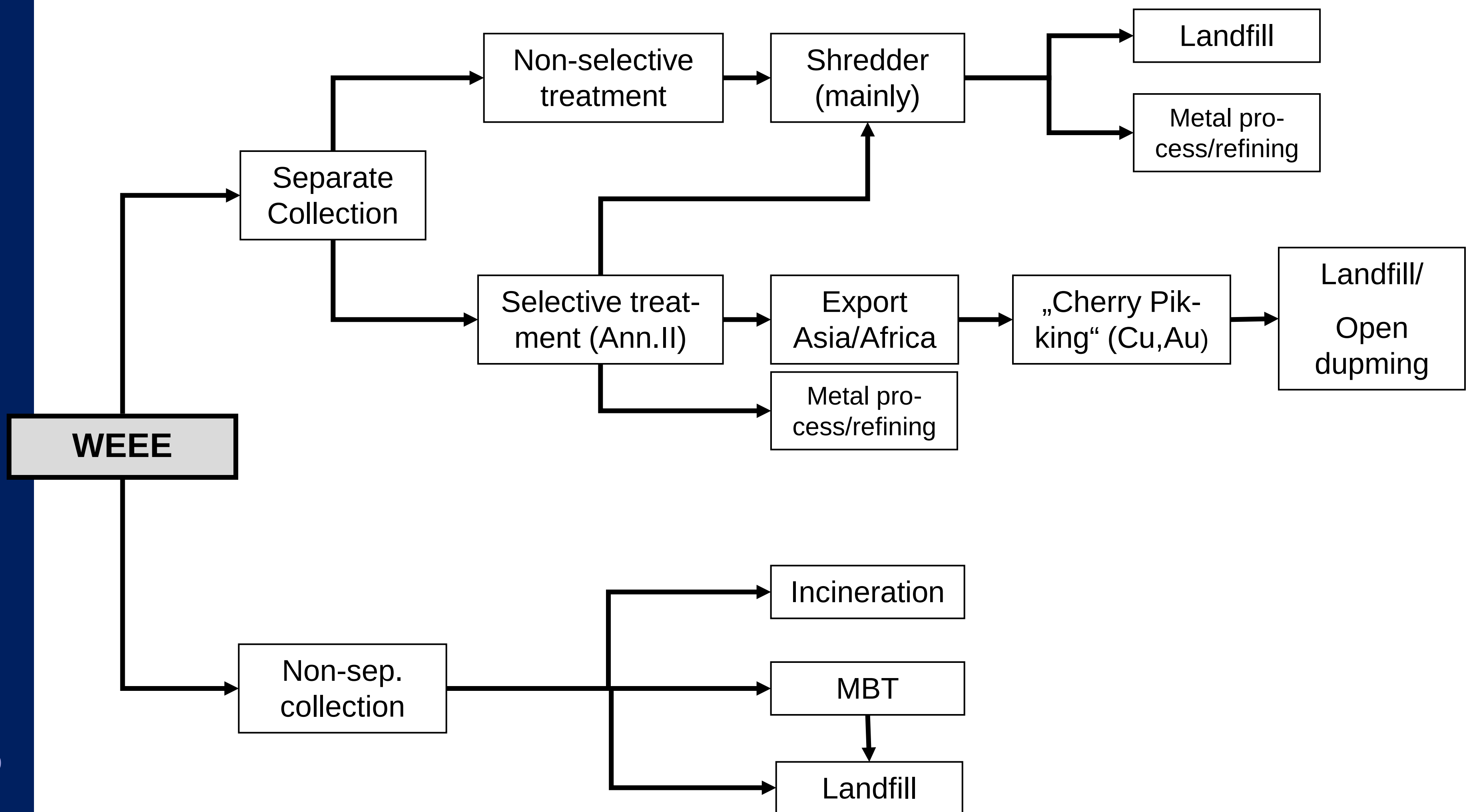
   — gas discharge lamps,

   — liquid crystal displays (together with their casing where appropriate) of a surface greater than 100 square centimetres and all those back-lighted with gas discharge lamps,

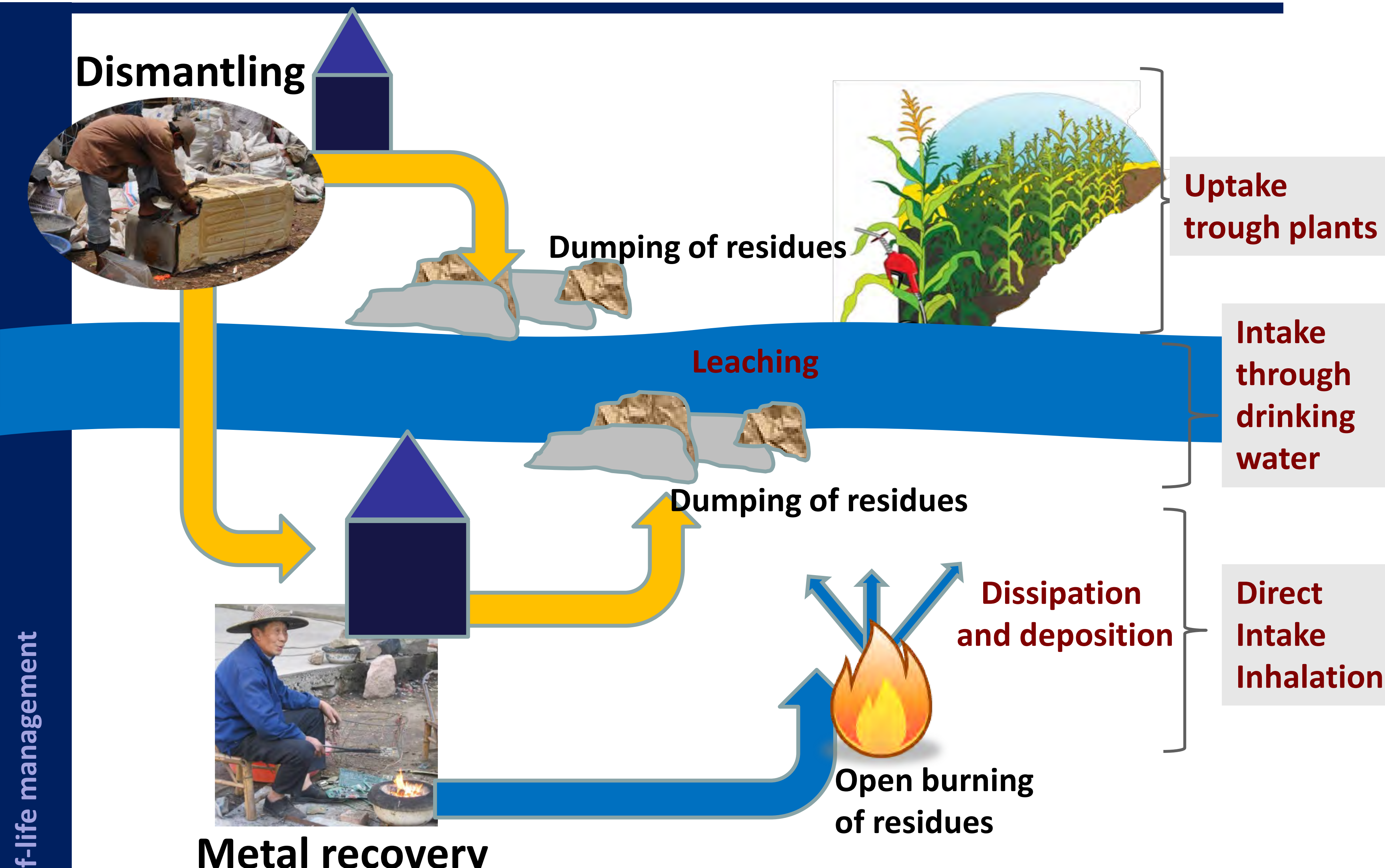
   — external electric cables,

   — components containing refractory ceramic fibres as described in Commission Directive 97/69/EC of 5 December 1997 adapting to technical progress Council Directive 67/548/EEC relating to the classification, packaging and

Recycling and disposal ways of WEEE & PCB (EU)



Pathways of heavy metals related to informal WEEE recycling

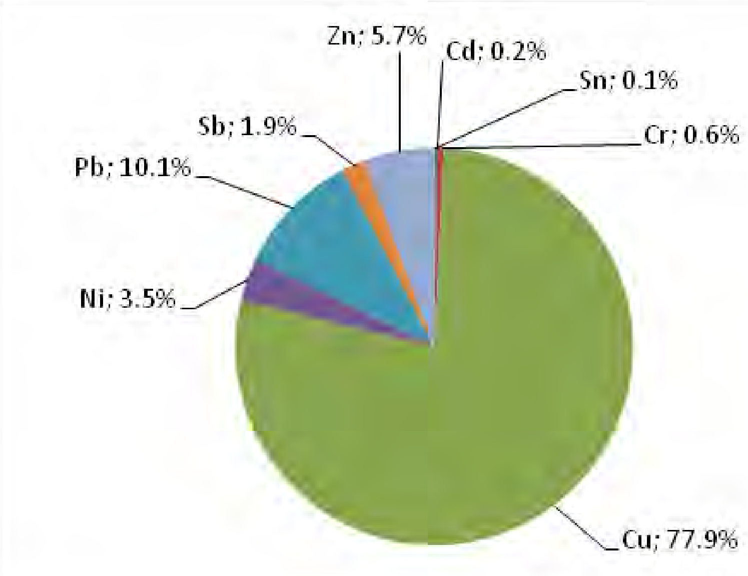


Heavy metals in WEEE

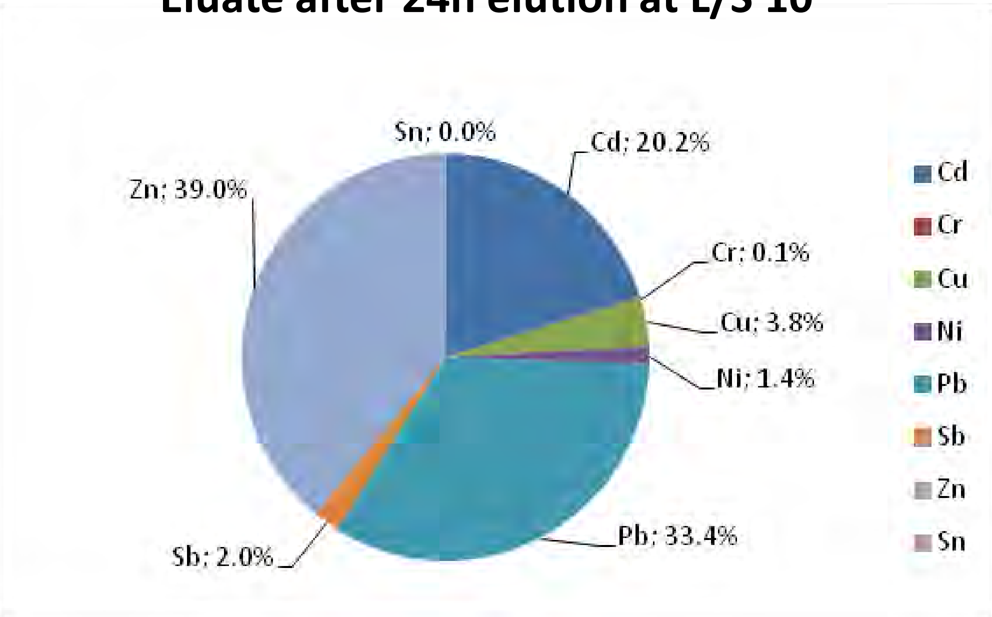
- Printed Circuit boards account for 3-30% of WEEE
- Contain
  - up to 300 ppm Gold
  - 14% Copper
  - 2% Lead
  - 300 ppm Cadmium

Distribution of 8 key metals in printed circuit boards

Total content



Eluate after 24h elution at L/S 10



Test methods for assessing the fate of metals

BATCH LEACHING TESTS

➢ **One stage batch test /** EN 12457-4
Compliance test used inside the EU to assess the suitability of waste for landfilling

Principle:

leachant	De-ionized water
pH	depending on matrix
L/S ratio	10:1, 2:1
Duration	24 h

Test methods for assessing the fate of metals

BATCH LEACHING TESTS

- **Controlled pHTest /** DIN CEN TS 14 429
  Test for basic characterization of waste to obtain information on short-term and long-term and specific characteristics

Principle:

leachant	Deionized water with varying amount of HNO_3 & NaOH depending on buffer
pH	controlled and fixed
L/S ratio	10:1,
Duration	24 h at each pH

- **TCLP** US-EPA SW- 846 , method 1311
  developed by USEPA to simulate the leaching of metals in co-disposal hazardous waste and MSW in a "worst - case scenario"

Principle:

leachant	buffered acetic acid solution
pH	2.88 ± 0.05
L/S ratio	20:1
Duration	20 h

Test methods for assessing the fate of metals

COLUMN TESTS

- **Up-flow percolation Test /**
  EN 14 405/
  Test for basic characterization of waste to describe the L/S dependence of leaching

Principle:

leachant	De-ionized water
pH	depending on matrix
L/S ratio	continuously increased till L/S 1:10
Duration	30 days

Test methods for assessing the fate of metals

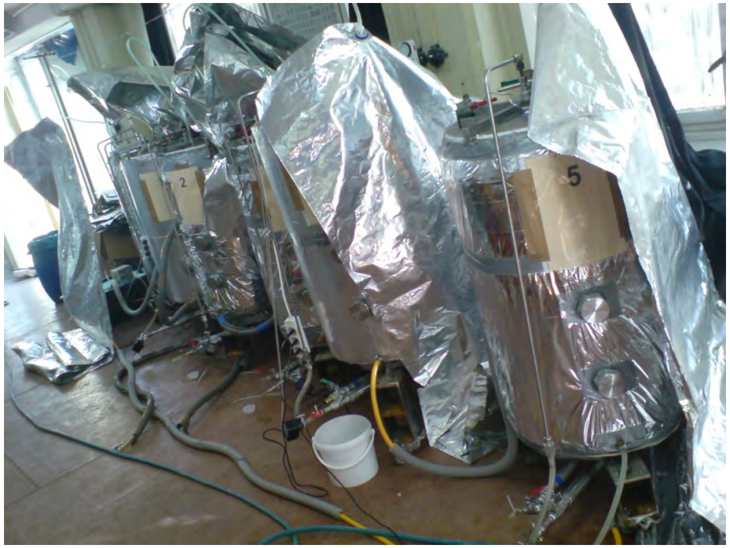
LYSIMETER TESTS

➢ **Lab-scale Lysimeter**

Test for simulating long-term leaching behavior in anaerobic landfills

Principle:

leachant	De-ionized water, circulating leachate
pH	depending on matrix
L/S ratio	continuously increased
Duration	150 days



Test methods for assessing the fate of metals

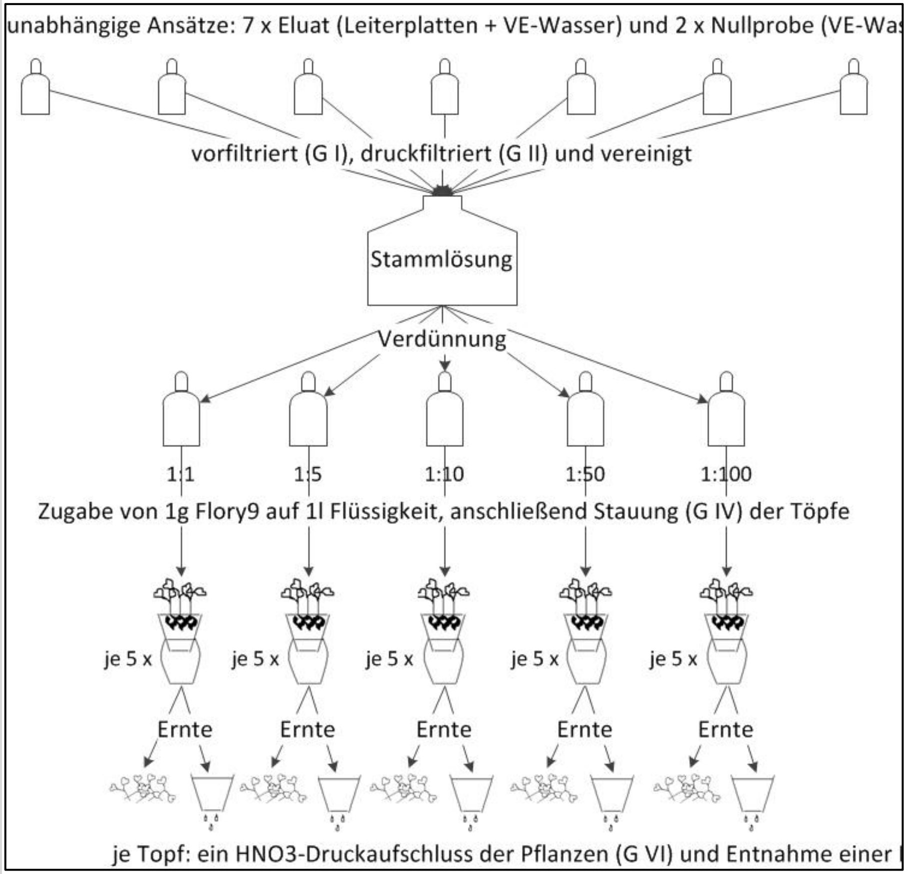
UPTAKE TESTS

➢ **Plant uptake test**

Irrigation of plants with leachate from PCB on a silica soil

Principle:

leachant	from batch leaching test with DI water,
plant	radis
test scheme	variation of dilution
	full analysis of root, leaves and soil
Duration	30 days



Assumptions on dissipative distribution of heavy metals under landfill conditions

- **Anaerobic Phase**
  - Heavy metals mobilized from WEEE (low pH), but remain in landfill body
  - sorption at humic substances
  - sorption at P&C
  - precipitation as sulfides

→ Dissipative distribution in landfill body

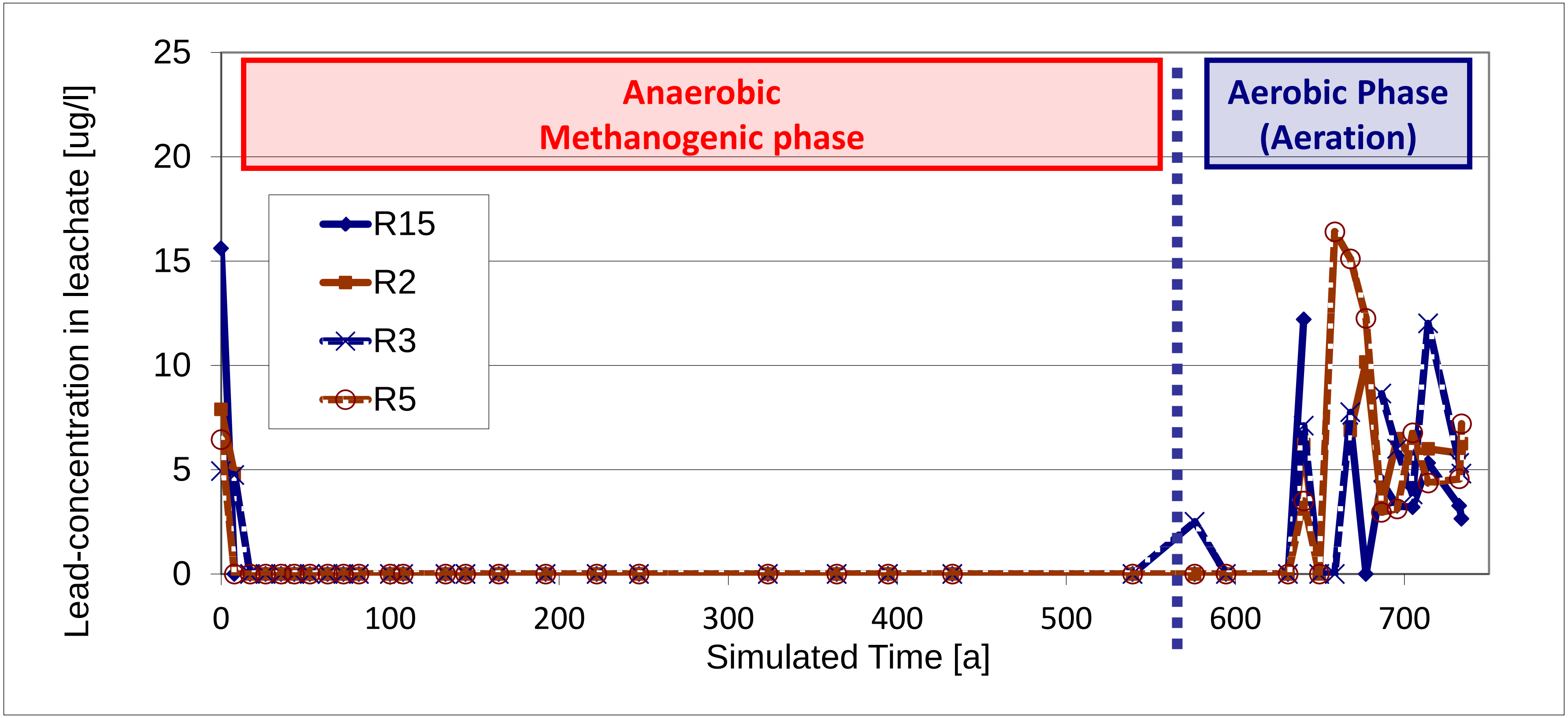
Aerobic phase

In aerobic phase, heavy metals get mobilized into the leachate water

- oxidation of humic substances
- oxidation of P&C
- oxidation of sulfides

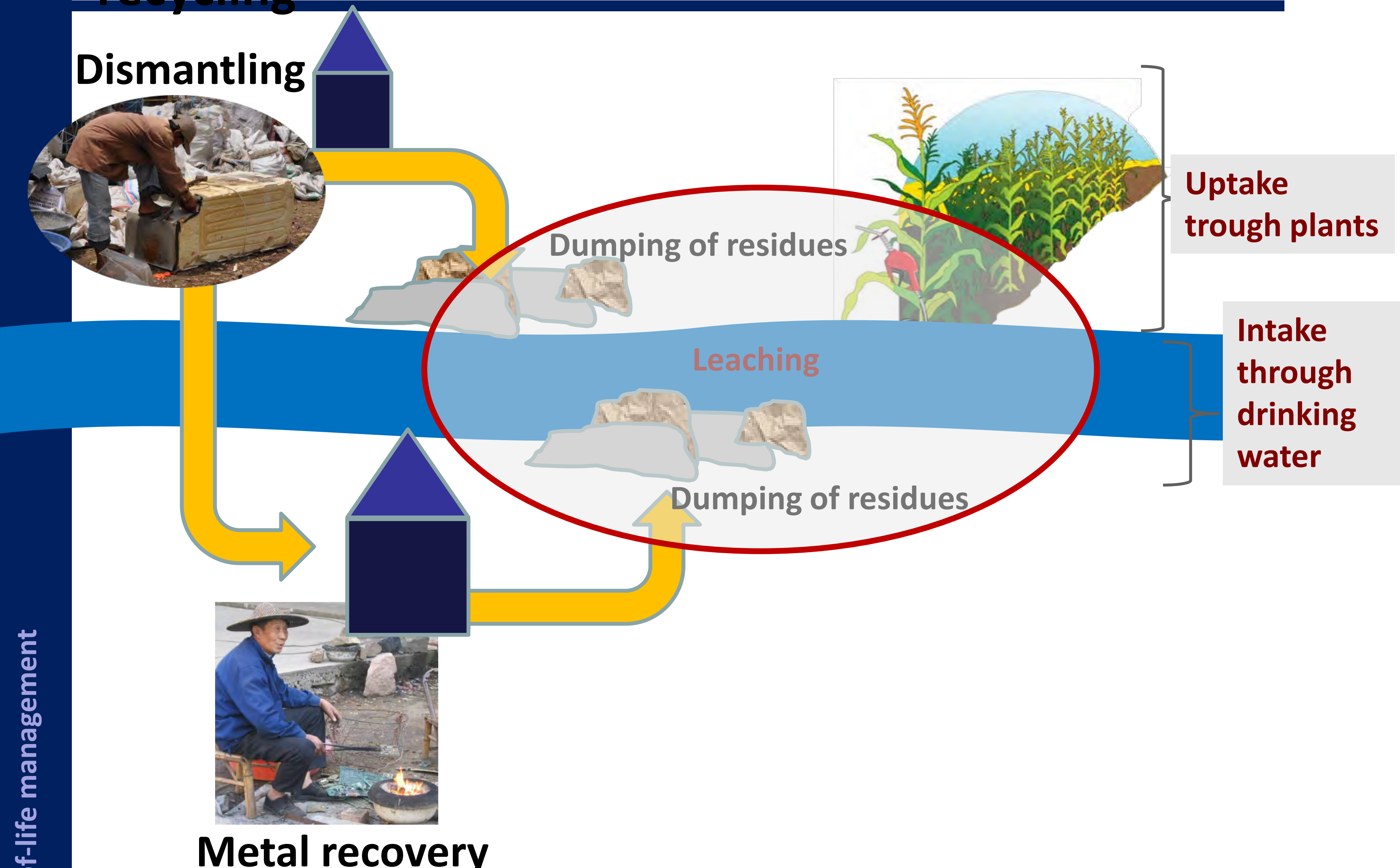
→ Dissipative distribution into environment

Heavy metal release from WEEE under landfill-conditions: Landfill-Simulation-Tests (Example: Lead)

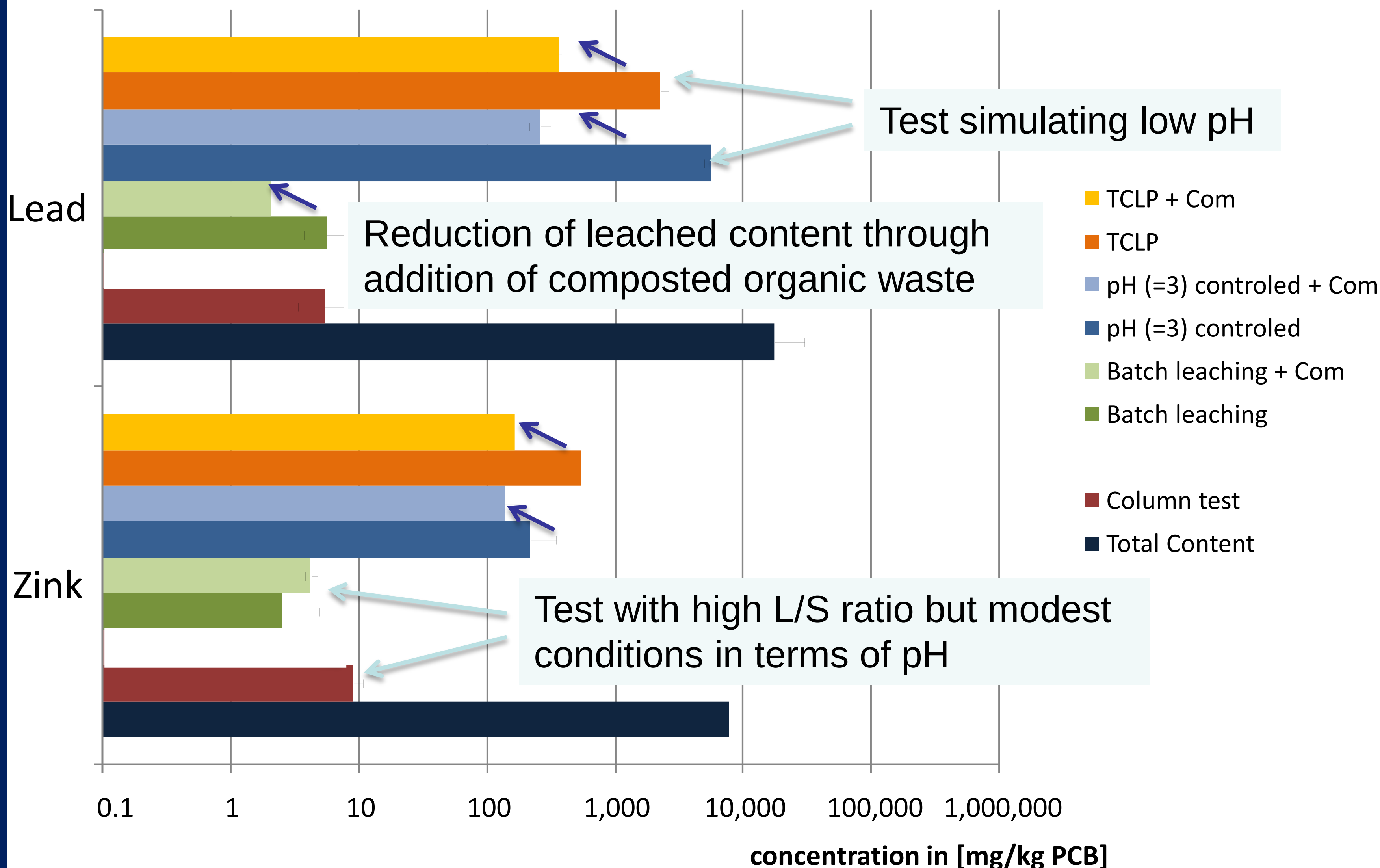


- Anaerobic atmosphere: >90% Zn/Ni/ Cr, >>99% Pb/Cd remain in landfill body
- Down-concentration in PCB, Up-concetration in P&C
- Aerobic atmosphere: increasing heavy metal concentration

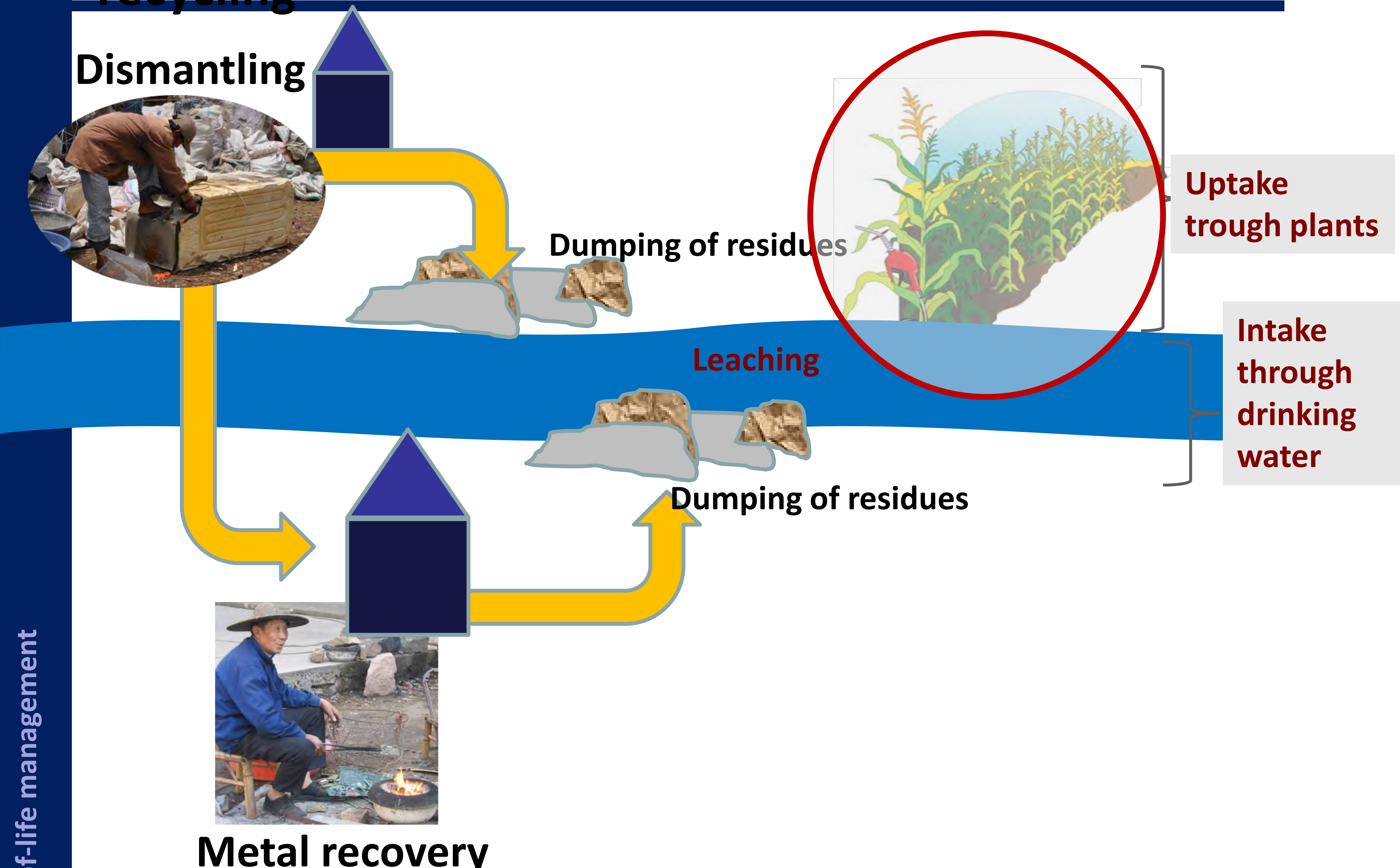
Pathways of heavy metals related informal WEEE recycling



Leaching test to determine metal leaching under worse case conditions

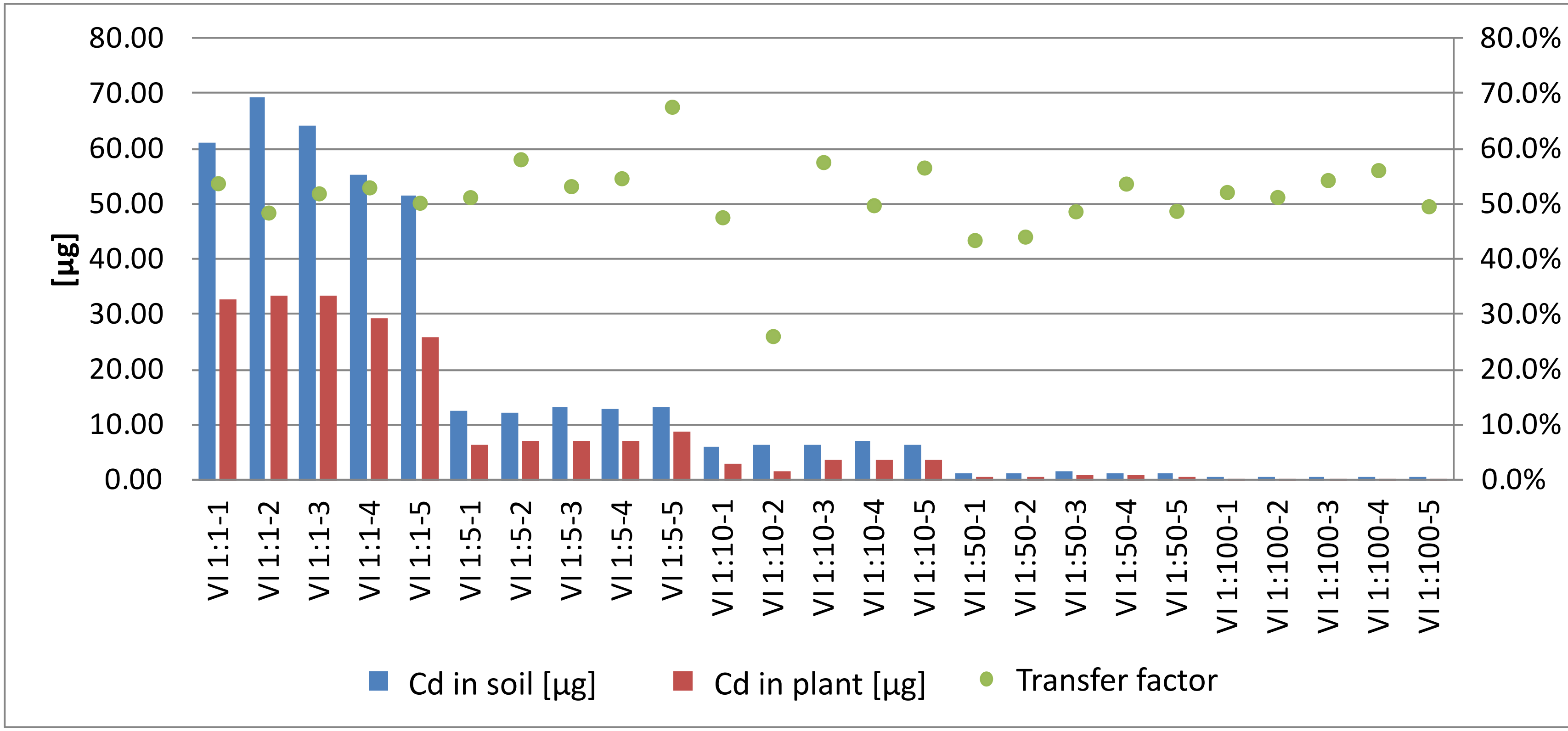


Pathways of heavy metals related informal WEEE recycling



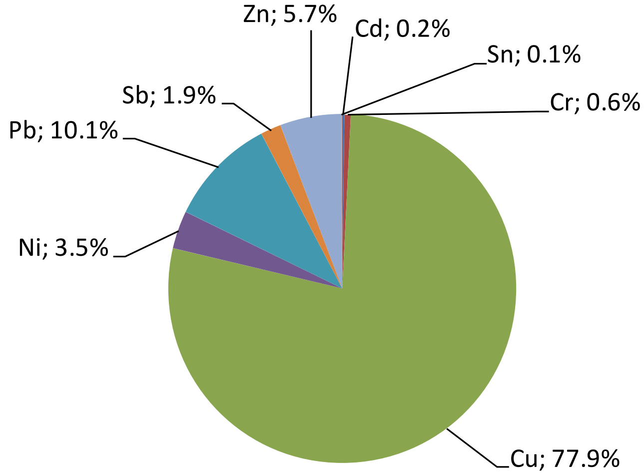
Uptake of heavy metals from WEEE leachates

Cadmium transfer to plants

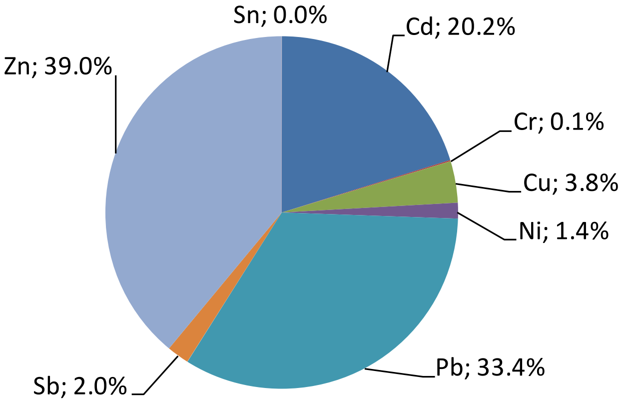


Metal distribution

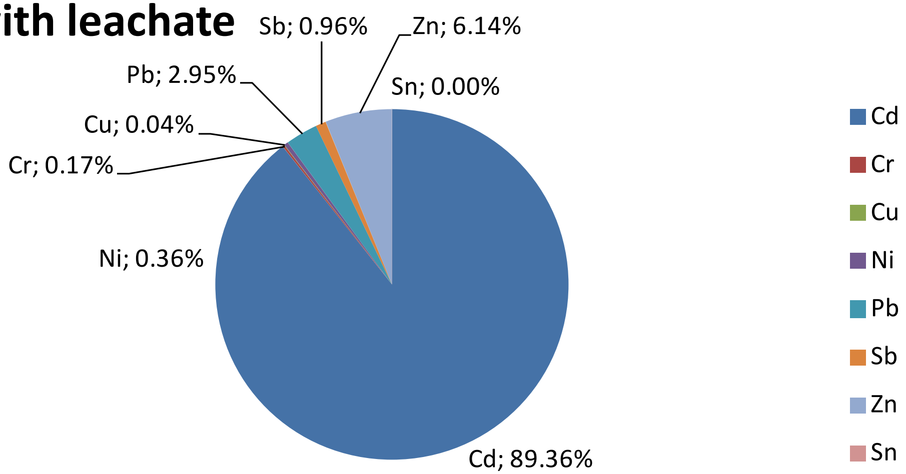
Total content



Eluate after 24h elution at L/S 10



Plant irrigated with leachate



Conclusions

1. Conditions of disposal and dumping von recycling residues vary and are difficult to predict
2. Conditions of disposal influence decisively the fate and impact of metals
3. The applicability of standardized test methods to assess informal recycling scheme could not be proven
4. Easy assessment tools are required to make the right decisions for the design of recycling processes
5. Resource-efficiency considers both, recovery of non-renewable materials and protection of natural resources

Conclusions at the EU level

- **Annex II follows a pollution control paradigm and does not bridge the conflict of dissipation and control of hazardous and valuable substance up to 100%**
- **As practiced, Annex II does not prevent negative impacts through direct disposal of WEEE components**

What could be solutions to avoid dissipative distribution of hazardous / scarce substances?

- ➢ **Wider restriction of the use hazardous substances (Product-Design)**
- ➢ **Improvement of collection of appliances with high concentration of valuable / damaging metals (e. g. refund- or leasing systems)**
- ➢ **Equipment type specific guidelines regarding the treatment (e. g. mobile phones) on BAT-level**
- ➢ **Avoidance of illegal WEEE-exports**

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