Human Exposure Modelling

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Quantitative Sustainability Assessment
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using also material from T.E.McKone & M.Margni

Overview

- What is exposure?
- Exposure concepts and definitions
- Quantifying direct and indirect exposure to contaminants
  - Quantifying exposure: Exposure factors XP, the concentration-to-intake relationship
  - Combining fate and exposure: Intake fraction iF, the emission-to-intake relationship
- The USEtox exposure model

What is exposure?

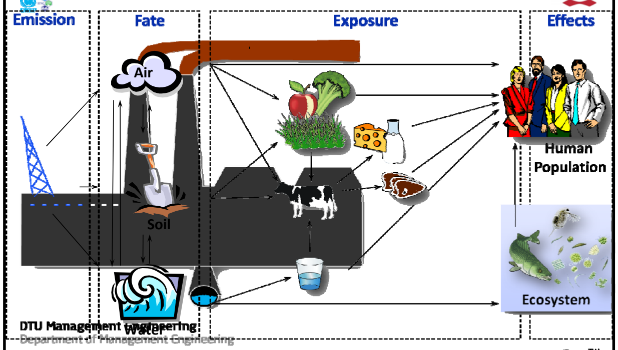
EXPOSURE

"Contact between an **agent** (air, water, food, soil etc. containing a potentially harmful substance) and a **target** (human individual or population). Contact takes place at an **exposure surface** (mouth, skin, eyes) over an **exposure period** at an **exposure frequency**".

EXPOSURE ASSESSMENT

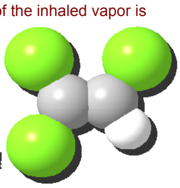
The process of *estimating* or *measuring* the ***magnitude***, ***frequency*** and ***duration*** of exposure to an agent, along with the ***number and characteristics of the population exposed***. Ideally, it describes the sources, pathways, routes, and the uncertainties in the assessment.

Complete source-to-toxic-impact cause-effect chain



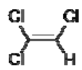
Example Chemical TCE

- Trichloroethylene (TCE) is a chlorinated hydrocarbon solvent, which is still in widespread use as a metal degreaser, and solvent
- Several million kg used world wide
- Ranked as one of the most hazardous compounds (worst 10%) to ecosystems and human health (SCORECARD)
- TCE is absorbed well by the lungs--30 to 50 percent of the inhaled vapor is absorbed into the bloodstream
- Skin contact is also a fairly efficient route of exposure
- TCE is metabolized more than most of the other chlorinated solvents--up to 90% of an inhaled dose is metabolized to reactive intermediates



Estimating Exposure

- Concentration:
  - You spend **8 hours/day** in a **factory** with a TCE concentration of **1 mg/m³**
  - You spend **16 hours/day** in an **environment** with a TCE concentration of **0.1 mg/m³**
- What is your daily exposure to TCE?

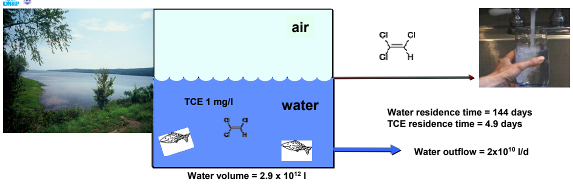


TCE intake

If your average daily breathing rate is 0.8 m³/h:

- What is your daily intake [mg/day]?
- What is your daily dose [mg/kg*day]?
- Do you have confidence in these estimates?

Estimating Exposure



Consider a lake that contains 1 mg/l of TCE and provides 2 l/d of drinking water to a population of 1 million people whose average weight is 70 kg:

- What is the TCE intake per person (mg/d)?
- What is the TCE dose per person (intake per unit body weight) (mg/kg*d)?
- What fraction of the lake's daily flow is being consumed by this population each day?

Multi-media

- Sources are multimedia: the same pollutant can be released to multiple media--air, water, soil, food, …
- Pollutants are multimedia (cross-media): they partition among multiple media--air, water, soil, …
- Exposures are multimedia: a receptor can have contact with multiple exposure media--air, water, food, soil, …

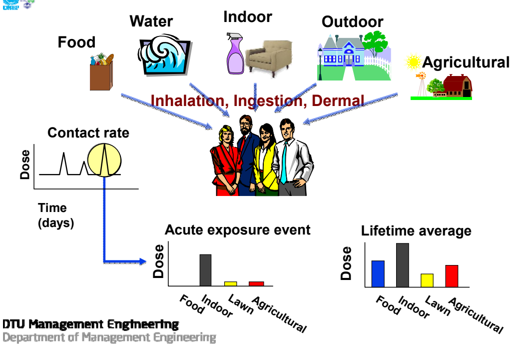
Multi-pathway

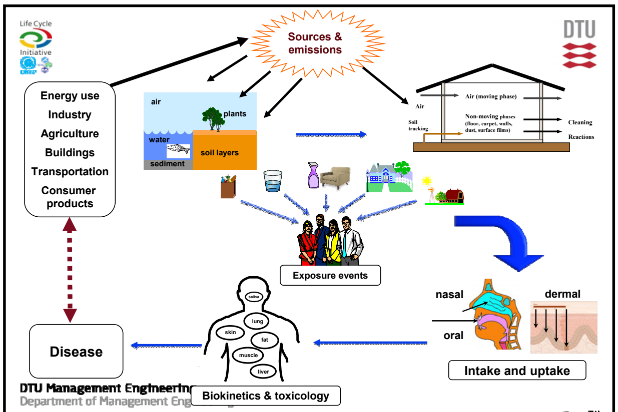
- Exposure to a contaminated medium can lead to human contact through several parallel pathways.
- Examples:
  - Pollutants in ambient (outdoor) air can contaminate indoor air, food, water, …
  - Pollutants in ground water can contaminate surface water, indoor air, food, …

Multi-route

- Pollutants enter humans through different exposure routes which combine various exposure pathways:
  - Inhalation (outdoor air, household indoor air, industrial indoor air)
  - Ingestion (drinking water, agricultural produce, meat, milk, eggs, fish, …)
  - Dermal contact (air, water, soil, cosmetics, cleaning agents, …)
- Health effects can vary with the route of intake/uptake.

Quantifying multiple exposure pathways

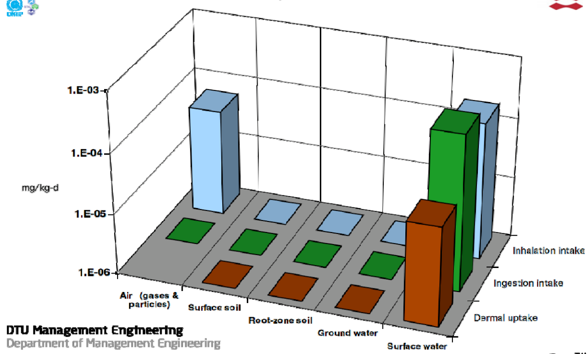




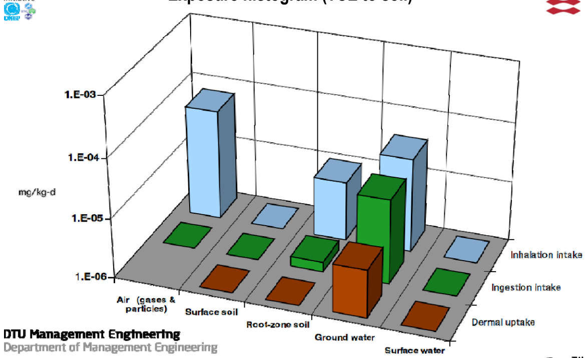
Quantifying multiple exposure pathways: Exposure matrix

	ENVIRONMENTAL MEDIA		
	AIR	**SOIL**	**WATER**
INHALATION	Outdoor air Indoor air	Soil vapors under houses Soil particles transferred to indoor air	Contaminants transferred from tap water
INGESTION	Fruits, vegetables, and grains Meat, milk, and eggs (transfer to plants to animals) Meat, milk, and eggs (inhalation by animals) *Breast milk*	Human soil ingestion Meat, milk, and eggs (soil ingestion by animals) Fruits, vegetables, and grains Meat, milk, and eggs (transfer from soil to plants to animals) *Breast milk*	Ingestion of tap water Irrigated fruits, vegetables, & grains Meat, milk, and eggs (animals consuming contaminated water) Fish and sea food *Breast milk*
DERMAL UPTAKE		Dermal contact with soil	Dermal contact in baths and showers Dermal contact while swimming

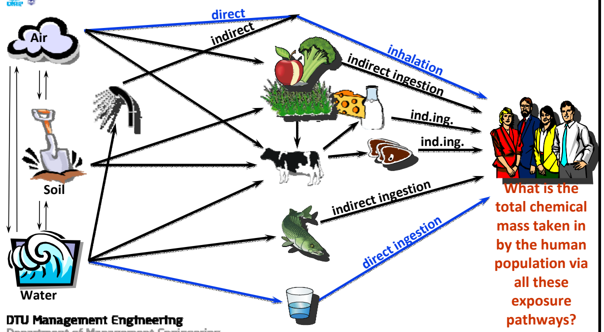
Exposure histogram (TCE to water)



Exposure histogram (TCE to soil)



Quantifying direct and indirect exposure to contaminants



Quantifying exposure: Exposure factors *XP*, the concentration-to-intake relationship

Conceptually similar to the intermedia transfer rate coefficient calculated in the fate model, the exposure factor $XP_{k,i}$ [1/*day*] is the transfer rate coefficient for exposure to contaminants in compartment *k* via exposure pathway *i* (e.g. inhalation, water ingestion, food ingestion, …):

$$XP_{k,i} = \frac{ITF_{k,i} \cdot IR_i \cdot population}{\rho_k \cdot V_k}$$

$ITF_{k,i}$ = C_i/C_k = Intermedia transfer factor from compartment *k* to medium *i* [kg_k/kg_i]
IR_i = Individual human intake rate of *i* [kg_i/day]
ρ_k = Density of compartment *k* [kg_k/m_k^3] (irrelevant if IR_i in [m^3/day])
V_k = Volume of compartment *k* [m_k^3]

The total exposure factor $XP_{k,tot}$ for compartment *k* is then given as the sum of alldirect and indirect exposure factors:

$$XP_{k,tot} = \sum_{i-direct} XP_{k,i-direct} + \sum_{i-indirect} XP_{k,i-indirect}$$

Rosenbaum, R.K., Margni, M., Jolliet, O., (2007). A flexible matrix algebra framework for the multimedia multipathway modeling of emission to impacts. Environment International 33, 624-634.

Direct exposure: Exposure factor $XP_{k,direct}$

The exposure factor $XP_{k,direct}$ [1/day] is the rate coefficient for direct exposure to contaminants in compartment *k*, through consumption of drinking water or inhalation of air. Here $ITF_{k,i} = C_i/C_k = 1$ since $i = k$, meaning that the compartment is directly ingested.

$$XP_{air,direct}\,[1/day] = \frac{IR_{air}\,[m^3/day] \cdot \text{population}}{V_{air}\,[m^3]}$$

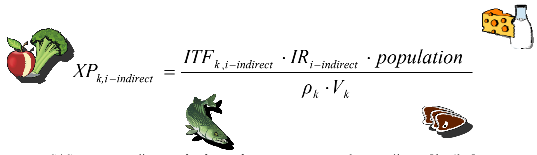
$$XP_{water,direct}\,[1/day] = \underline{\hspace{6cm}}$$

The inverse of $XP_{k,direct}$ is a residence time, reflecting the average time required for the population in compartment *k* to take in the volume of the respective compartment (inhale the volume of air or drink the volume of water.

Rosenbaum, R.K., Margni, M., Jolliet, O., (2007). A flexible matrix algebra framework for the multimedia multipathway modeling of emission to impacts. Environment International 33, 624-634.

Indirect exposure: Exposure factor $XP_{k,indirect}$

$XP_{k,indirect}$ [1/day] is the rate coefficient of indirect exposure to a contaminant in compartment *k* through consumption of an exposure medium *i* that was contaminated from compartment *k*.



$$XP_{k,i-indirect} = \frac{ITF_{k,i-indirect} \cdot IR_{i-indirect} \cdot population}{\rho_k \cdot V_k}$$

$ITF_{k,i}$ = C_i/C_k = Intermediate transfer factor from compartment k to medium i [kg_k/kg_i]
IR_i = Individual human intake rate of i [kg_i/day]
ρ_k = Density of compartment k [kg_k/m_k^3] (irrelevant if IR_i in [m^3/day])
V_k = Volume of compartment k [m_k^3]

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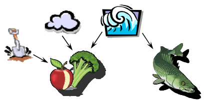
Indirect exposure: Intermedia transfer factors $ITF_{k,i}$

$ITF_{k,i}$ quantifies the transfer efficiency for a contaminant from an environmental compartment *k* to an exposure medium *i*. Various definitions and measures are used to model it, which can be found in literature. Some examples:

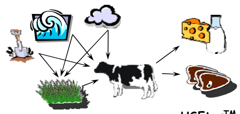
- Bioconcentration factor ($BCF_{k,i}$) at steady-state:

$$BCF_{k,i} = \frac{C_i(\text{chemical conc. in exp. medium } i)}{C_k(\text{chemical conc. in compartment } k)}$$



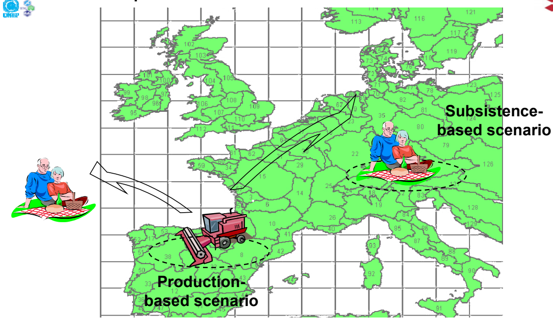
- Biotransfer factor (BTF_i) – measure of bioaccumulation at steady-state:

$$BTF_i = \frac{C_i(\text{chemical conc. in exp. medium } i)}{I_{chem.}(\text{animal chemical intake})}$$



Rosenbaum, R.K., McKone, T.E., Jolliet, O., (2009). CKow: A Dynamic Model for Chemical Transfer to Meat and Milk. Environmental Science and Technology 43, 8191–8198.

Indirect exposure: Production-based vs. subsistence scenarios



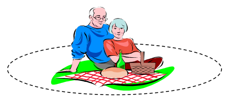
Pennington, D.W., Margni, M., Ammann, C., Jolliet, O., 2005. Multimedia fate and human intake modeling: Spatial versus nonspatial insights for chemical emissions in Western Europe. Environmental Science and Technology 39, 1119-1128.

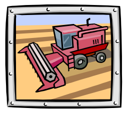
Indirect exposure: Production-based scenario

Usual exposure models used for environmental risk assessment: individual or cohort risk + conservative assumptions

« Subsistence scenario »
- receptor perspective,
- consumed food produced in the same region

« Production scenario »
- Chemical transfer to food = f(production area)
- Tracks long-range chemical transport via food





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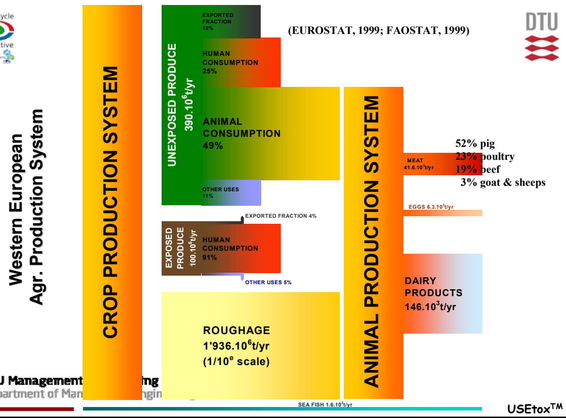
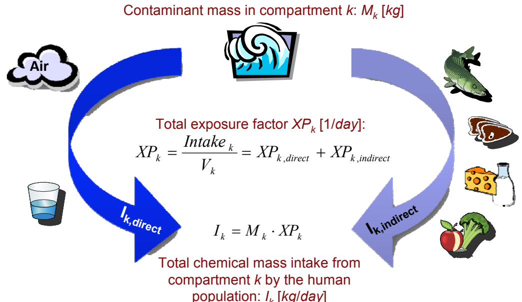


Total intake of the human population via all exposure pathways I_k

Contaminant mass in compartment *k*: M_k [*kg*]



Total exposure factor XP_k [1/*day*]:

$$XP_k = \frac{Intake_k}{V_k} = XP_{k,direct} + XP_{k,indirect}$$

$$I_k = M_k \cdot XP_k$$

Total chemical mass intake from compartment *k* by the human population: I_k [*kg/day*]

Rosenbaum, R.K., Margni, M., Jolliet, O., (2007). A flexible matrix algebra framework for the multimedia multipathway modeling of emission to impacts. Environment International 33, 624-634.

Combining fate and exposure: Intake fraction *iF*, the emission-to-intake/uptake relationship

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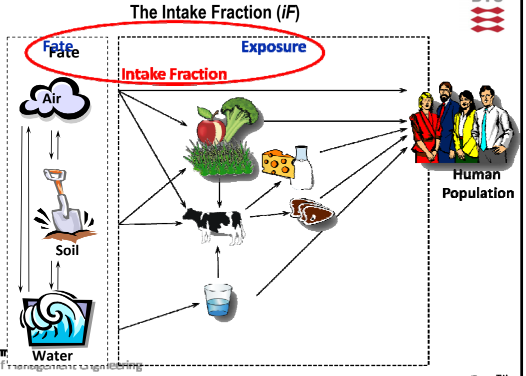
The Intake Fraction (*iF*)



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Intake fraction (*iF*) for outdoor exposure

$$iF = \frac{\sum_k M_k \cdot XP_k}{S} = \frac{\text{Population Intake}}{\text{Total Emissions}} = \frac{\int_{T_1}^{\infty} \left[\sum_{k=1}^{P} \{ C_k(t) \cdot In_k(t) \} \right] dt}{\int_{T_1}^{T_2} S(t)\, dt}$$

M_k = Mass in compartment k [g]
XP_k = Exposure factor via compartment k [$1/day$]
S = Emission rate to a compartment [g/day]
C_k = Concentration in compartment k [g/m^3]
In_k = Intake rate [$m^3/person*day$], e.g. breathing rate
P = Population [$persons$]

Bennett, D. H., Margni, M., McKone, T. E., & Jolliet, O. (2002). Intake Fraction for Multimedia Pollutants: A Tool for Life Cycle Analysis and Comparative Risk Assessment. *Risk Analysis, 22(5), 903-916.*
Bennett, D. H., McKone, T. E., Evans, J. S., Nazaroff, W. W., Margni, M. D., Jolliet, O., et al. (2002). Defining Intake Fraction. *Environmental Science and Technology, 36(9), 207A-211A.*

Intake fraction (*iF*) for indoor exposure

$$iF = \frac{IR}{V \cdot m \cdot k_{ex}} \cdot N$$

iF = population intake fraction of a chemical [-]
IR = daily inhalation rate of air of an individual [m^3/day]
N = number of people exposed [-]
V = volume of the exposure area [m^3]
k_{ex} = air exchange rate of the volume in the exposure area [-]
m = mixing factor [-]

Hellweg, S., Demou, E., Bruzzi, R., Meijer, A., Rosenbaum, R. K., Huijbregts, M. A. J., McKone, T. E. (2009). Integrating Indoor Air Pollutant Exposure within Life Cycle Impact Assessment. Environmental Science and Technology, 43(6), 1670 – 1679.

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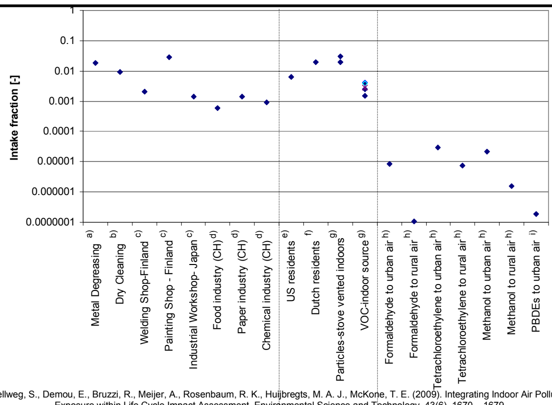

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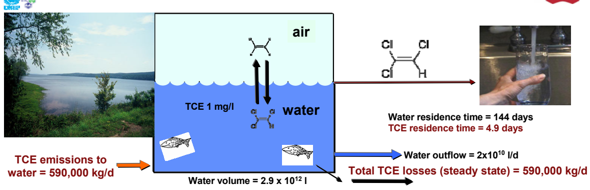
Occupational indoors | Household | Outdoors

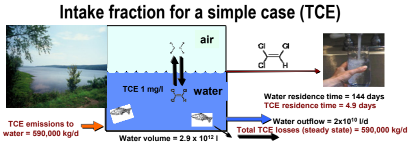
Intake fraction for a simple case (TCE)



Consider a lake that contains 1 mg/l of TCE and provides 2 l/d of drinking water to a population of 1 million people whose average weight is 70 kg:

- How many kg of TCE per day does this population of 1 million consume from the lake?
- What is the characteristic time of intake (CTI) for this lake (how many days does it take for a million people to consume the volume of the lake)?
- What is the intake fraction?
- Use the ratio of TCE residence time to CTI to determine iF.

Intake fraction for a simple case (TCE)



Fate Factor

$F_{ww} = M_{ww}/S_w$

$= \frac{2.9 \times 10^{12}\ L \times 1 mg/L\ 10^{-6}\ kg/mg}{590{,}000\ kg/d}$

$= 4.9\ d$

Exposure Factor

$XP_{w,dw} = Intake_w/Volume_w$

$= \frac{2\ L/d \times 1 \times 10^6\ people}{2.9 \times 10^{12}\ L}$

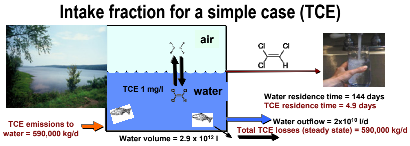
$= 6.9 \times 10^{-7}/d$

$iF_{ww} = FF_{ww} * XP_{w,dw}$

$= 4.9\ day \times 6.9E\text{-}7\ day^{-1}$

$= 3.4E\text{-}6$

Intake fraction for a simple case (TCE)



Fate factor matrix FF

	Air	Water
Air	aa	aw
Water	wa	4.9 day

Exposure factor matrix XP

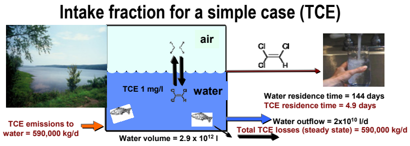
	Air	Water
Inhalation	--	--
Drinking water	--	6.9E-7 day^{-1}
Fish	--	--

iF = XP * FF

Intake fraction matrix iF

	Air	Water
Inhalation	--	--
Drinking water	--	3.4E-6 kg/kg
Fish	--	--

Intake fraction for a simple case (TCE)



Fate factor matrix FF

	Air	Water
Air	aa	aw
Water	wa	4.9 day

Exposure factor matrix XP

	Air	Water
Inhalation	--	--
Drinking water	--	6.9E-7 day^{-1}
Fish	--	3.8E-7 day^{-1}

Intake fraction matrix iF

	Air	Water
Inhalation	--	--
Drinking water	--	3.4E-6 kg/kg
Fish	--	1.9E-6 kg/kg
Total	--	5.3E-6 kg/kg

TCE *iF* versus Benzene *iF*

Fate factor matrix *FF*

TCE

	Air	Water
Air	aa	cc
Water	bb	4.9 day

Benzene

	Air	Water
Air	aa	cc
Water	bb	3.2 day

Exposure factor matrix *XP*

TCE

	Air	Water
Inhalation	--	--
Drinking water	--	6.9E-7 day^{-1}
Fish	--	3.8E-7 day^{-1}

Benzene

	Air	Water
Inhalation	--	--
Drinking water	--	6.9E-7 day^{-1}
Fish	--	1.8E-7 day^{-1}

Intake fraction matrix *iF*

TCE

	Air	Water
Inhalation	--	--
Drinking water	--	3.4E-6 kg/kg
Fish	--	1.9E-6 kg/kg
Total	--	5.3E-6 kg/kg

Benzene

	Air	Water
Inhalation	--	--
Drinking water	--	2.2E-6 kg/kg
Fish	--	5.6E-7 kg/kg
Total	--	2.8E-6 kg/kg

Emissions to and exposure for both air and water

Exposure factor XPki = Intake(ki)/Volume(k)

	Air	Water	
Inhalation	6.0E-05	--	1/day
Drinking water	--	6.7E-07	1/day
Fish	--	3.8E-07	1/day

Exposure Factor
XP_{ki}

Fate factor Fkj = Mkj/Sj

Emission to:

Fate in:	Air	Water	
Air	0.17	0.16	day
Water	0.0047	4.9	day

Emission to:

Fate in:	Air	Water
Air	Faa	Faw
Water	Fwa	Fww

Fate Factor
F_{ki}

k refers to an environmental medium (air water)
j refers to the environmental medium receiving an emission S
i refers to an exposure pathway--inhalation, drinking water, fish, etc

Intake fraction iF(ij) = Fkj*XPik

	Air emissions: Air	Air emissions: Water	Water emissions: Air	Water emissions: Water
Inhalation	1.0E-05	--	9.7E-06	--
Drinking water	--	3.14E-09	--	3.29E-06
Fish	--	1.8E-09	--	8.8E-09
Total iF		1.0E-05		1.3E-05

Intake Fraction
iF

Exposure factor XPki = Intake(ki)/Volume(k)

	Air	Water	
Inhalation	6.0E-05	--	1/day
Drinking water	--	6.7E-07	1/day
Fish	--	3.8E-07	1/day

Exposure Factor
XP_{ki}

Emissions to and exposure for both air and water

Fate factor Fkj = Mkj/Sj

Emission to:

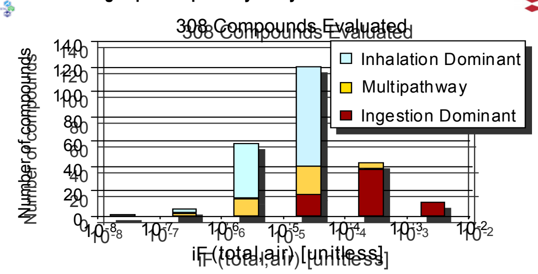
Fate in:	Air	Water	
Air	0.17	0.16	day
Water	0.0047	4.9	day

Emission to:

Fate in:	Air	Water
Air	Faa	Faw
Water	Fwa	Fww

Fate Factor
F_{ki}

Dominating exposure pathways vary between different chemicals



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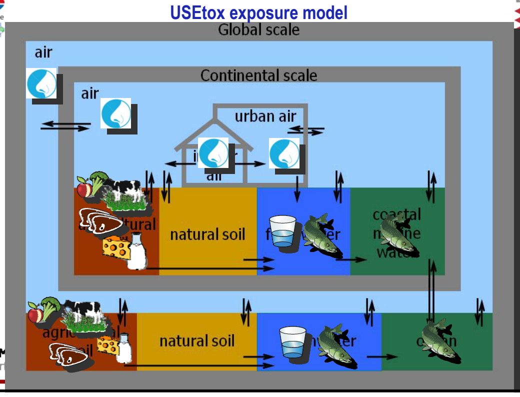
USEtox exposure model



The USEtox human *XP* and *iF* matrices (TCE)

XP [d^{-1}] (exposure medium)	urban air: airU	continental compartments: airC	fr.waterC	seawaterC	nat.soilC	agr.soilC	global compartments: airG	fr.waterG	oceanG	nat.soilG	agr.soilG
air	4.51E-04	1.30E-06	0	0	0	0	1.70E-07	0	0	0	0
drinking water	0	0	2.07E-06	0	0	0	0	7.94E-07	0	0	0
exposed produce	0	1.08E-09	0	0	0	1.68E-12	1.41E-10	0	0	0	6.44E-13
unexposed produce	0	0	0	0	0	1.14E-07	0	0	0	0	4.40E-08
meat	0	1.73E-11	5.62E-11	0	0	9.83E-13	2.26E-12	2.16E-11	0	0	3.78E-13
dairy products	0	2.43E-11	1.76E-10	0	0	2.42E-12	3.18E-12	6.75E-11	0	0	9.28E-13
fish	0	0	2.98E-07	5.77E-09	0	0	0	1.15E-07	5.37E-11	0	0

iF (exposure medium)	urban air emission: airU	continental emissions: airC	fr.waterC	seawaterC	nat.soilC	agr.soilC	global emissions: airG	fr.waterG	oceanG	nat.soilG	agr.soilG
air	2.95E-05	5.44E-06	4.81E-06	9.80E-07	4.72E-06	4.72E-06	1.16E-06	1.03E-06	1.29E-07	1.01E-06	1.01E-06
drinking water	2.64E-09	2.59E-09	9.89E-06	4.66E-10	2.02E-07	2.02E-07	5.54E-10	3.80E-06	6.13E-11	7.73E-08	7.73E-08
exposed produce	4.48E-09	4.52E-09	4.00E-09	8.14E-10	3.92E-09	3.94E-09	9.69E-10	8.54E-10	1.07E-10	8.40E-10	8.48E-10
unexposed produce	2.67E-10	2.69E-10	2.38E-10	4.84E-11	2.33E-10	1.37E-06	5.76E-11	5.08E-11	6.37E-12	5.00E-11	5.26E-07
meat	7.18E-11	7.24E-11	3.33E-10	1.30E-11	6.82E-11	8.00E-11	1.55E-11	1.17E-10	1.72E-12	1.55E-11	2.01E-11
dairy products	1.01E-10	1.02E-10	9.31E-10	1.84E-11	1.05E-10	1.34E-10	2.19E-11	3.42E-10	2.42E-12	2.55E-11	3.66E-11
fish	5.82E-10	5.76E-10	1.44E-06	2.24E-07	2.95E-08	2.95E-08	1.09E-10	5.49E-07	2.64E-09	1.12E-08	1.12E-08

iF *(aggreg.)*	airU	airC	fr.waterC	seawaterC	nat.soilC	agr.soilC	airG	fr.waterG	oceanG	nat.soilG	agr.soilG
inhalation	2.95E-05	5.44E-06	4.81E-06	9.80E-07	4.72E-06	4.72E-06	1.16E-06	1.03E-06	1.29E-07	1.01E-06	1.01E-06
ingestion	8.15E-09	8.13E-09	1.13E-05	2.25E-07	2.36E-07	1.61E-06	1.73E-09	4.35E-06	2.82E-09	8.94E-08	6.16E-07

USEtox exposure model input data

Substance specific data (see worksheet "Substance data"):

- Bioaccumulation factor in root crops BAF_{root}
- Bioaccumulation factor in leaf BAF_{leaf}
- Biotransfer factor in meat BTF_{meat}
- Biotransfer factor in milk (dairy products) BTF_{milk}
- Bioaccumulation factor in fish BAF_{fish}

Exposure model parameters for continental and global scale respectively (see worksheet "Landscape data"):

- Human population
- Human breathing rate
- Water ingestion
- Production-based food ingestion for exposed produce, unexposed produce, meat, dairy products, freshwater fish, marine fish

Exposure model parameters for urban and indoor air (hounselhold/industrial) exposure:

- Human population/average room occupation
- Human breathing rate

Concluding Points

- While the fate model provides the contaminant mass in each compartment,
- the exposure model estimates the contaminant intake of the human population due to the chemical mass in the environment.
- Combing fate and exposure, the intake fraction estimates the fraction of an emission which is ultimately taken in by the population. It is obtained from the multiplication of exposure factors (*XP*) and fate factors (*FF*) or the respective matrices containing these factors.
- Exposure happens via many direct and indirect pathways in parallel and varies dependiong on the exposure magnitude, duration, and frequency.

Further reading (USEtox)

- Rosenbaum, R.K., Bachmann, T.K., Gold, L.S., Huijbregts, M.A.J., Jolliet, O., Juraske, R., Koehler, A., Larsen, H.F., MacLeod, M., Margni, M., McKone, T.E., Payet, J., Schuhmacher, M., Van de Meent, D., Hauschild, M.Z., (2008). USEtox - The UNEP/SETAC-consensus model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in Life Cycle Impact Assessment. International Journal of Life Cycle Assessment 13, 532-546.
- Hauschild, M.Z., Huijbregts, M.A.J., Jolliet, O., MacLeod, M., Margni, M., Van de Meent, D., Rosenbaum, R.K., McKone, T.E., (2008). Building a model based on scientific consensus for Life Cycle Impact Assessment of Chemicals: the Search for Harmony and Parsimony. Environmental Science and Technology 42, 7032–7037.
- Rosenbaum, R.K., Margni, M., Jolliet, O., (2007). A flexible matrix algebra framework for the multimedia multipathway modeling of emission to impacts. Environment International 33, 624-634.
- Hellweg, S., Demou, E., Bruzzi, R., Meijer, A., Rosenbaum, R.K., Huijbregts, M.A.J., McKone, T.E., (2009). Integrating Indoor Air Pollutant Exposure within Life Cycle Impact Assessment. Environmental Science and Technology 43, 1670 - 1679.

Further reading (UNEP-SETAC LCA-toxicity expert workshops)

- Diamond, M.L., Gandhi, N., Adams, W.J., Atherton, J., Bhavsar, S.P., Bulle, C., Campbell, P.G.C., Dubreuil, A., Fairbrother, A., Farley, K., Green, A., Guinee, J., Hauschild, M.Z., Huijbregts, M.A.J., Humbert, S., Jensen, K.S., Jolliet, O., Margni, M., McGeer, J.C., Peijnenburg, W.J.G.M., Rosenbaum, R.K., van de Meent, D., Vijver, M.G., (2010). The clearwater consensus: the estimation of metal hazard in fresh water. International Journal of Life Cycle Assessment 15, 143-147.
- McKone, T.E., Kyle, A.D., Jolliet, O., Olsen, S.I., Hauschild, M., (2006). Dose-Response Modeling for Life Cycle Impact Assessment - Findings of the Portland Review Workshop. International Journal of Life Cycle Assessment 11, 137-140.
- Jolliet, O., Rosenbaum, R.K., Chapmann, P., McKone, T., Margni, M., Scheringer, M., van Straalen, N., Wania, F., (2006). Establishing a framework for Life Cycle Toxicity Assessment: Findings of the Lausanne review workshop. International Journal of Life Cycle Assessment 11, 209-212.