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Environmental Risk Assessment of Chemical Substances

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Abstract. According to the OECD, it is estimated that some 70 000 synthetic chemicals are in daily use. This number is still growing. Some of these products (e.g. polychlorinated biphenyls or chlorofluorocarbons) have gained great public attention due to their unexpected undesirable long-term impact on the ecosystem. The industrialized nations have therefore implemented and enforced stringent laws, in order to control the use of potentially harmful substances.

It is an almost impossible task to have the EU Base Set available for all existing substances. The EU and other organizations like OECD have therefore put together priority lists of potentially harmful high-volume chemicals which are assessed by experts. The last couple of years, a tremendous amount of work has been done to develop computer-based modeling systems to predict the environmental behavior and distribution of chemical substances.

There are models around (e.g. Mackay, USES, TGD EU, and others) to describe *environmental distribution* (Predicted Environmental Concentration (PEC)) of nonionic and nonpolar substances. For a first assessment, only a few physical properties (MP, BP, SOL, and possibly pK_a) are needed. For ionic and/or polar substances, expert know-how is required.

For *environmental toxicity* (Predicted No Effect Concentration (PNEC)), however, the situation is far more complex. There are different modes of action for each trophic level (algae, crustacea, fish). Computer models with Quantitative Structure-Activity Relationship (QSAR) offer a scientifically attractive tool to predict aquatic toxicity and biodegradation. There are no models that are applicable to heterogeneous chemical classes without expert know-how. Further progress can therefore be expected.

The result of an ERA for perchloroethylene with USES is presented, and the problems of the adequacy of the model parameters explained. Here too, a further improvement is addressed.

QSARs are attractive tools to design products with improved environmental compatibility at the research stage even before the first synthesis. In order to achieve such an ambitious aim, QSAR models that also include expert rules and evaluated results and their dependence on molecular structures will have to be further developed.

1. Introduction

A few decades ago, the chemical industry could develop and market almost any product, provided that there was a demand in the market and it was tested according to the existing laws.

It is estimated by the OECD that some 70 000 synthetic (mostly organic) chemicals are in daily use. A lot of them like,

drugs, cosmetics, or food additives, are not of environmental relevance. But some of them are in the public focus, because they have caused unexpected long-term damage to the ecosystem, e.g. polychlorinated biphenyls (PCBs) or chlorofluorocarbons (CFCs).

In order to control production and marketing of chemicals with potential risks, the industrialized nations have tightened up and enforced the laws regulating marketing and use of new and existing chemicals. The chemical industry fully accepts and supports the underlying target to ensure that the application of its existing or new substances as recommended leads to environmental concentrations that do not harm man and/or the environment. Furthermore, these aspects are being increas-

ingly considered in research and development of new products or processes.

Restricted financial and personal resources make it impossible to provide all the missing data for existing chemicals. Therefore, universities, national and supranational organizations as well as professional bodies representing the chemical manufacturers have taken up the challenge to contribute to the further improvement of methods and models that predict environmental behavior and will fill this gap. This publication seeks to give an overview about the state of the art of the methods and models currently applied in Western Europe.

2. Regulatory Situation

Production and marketing of chemicals in the European Union (EU) are covered by a Council Regulation on the evaluation and control of the risk of existing substances and a Commission Directive laying down the principles for assessment of risks to man and the environment of substances notified. Additional national/supranational regulations apply for cosmetics, direct and indirect food additives, pharmaceuticals, agrochemicals, biocides, and a few other areas of application. However, in this paper we will concentrate on the situation in the European Union and restrict ourselves to the chemicals covered by the dangerous goods directive [1] and its amendments, e.g. dyes and chemicals for the textile industry (> 40% of new notifications).

2.1. The PEC/PNEC Concept in the EU

The EU regulations require that an Environmental Risk Assessment (ERA) be carried out on new substances and on selected existing chemicals. Technical Guidance Document (TGD) [2] gives a detailed guideline on how to conduct an ERA. Because some important points are still under discussion, enforcement is planned after a period of probably two years. In the meantime, the Competent Authorities and the applicants can gain experience. When the Technical Guidance Document addresses regulatory specialists, a more basic introduction in this large and expanding area of ERA can be found in (Leeuwen and Hermens [3]).

The procedure for the ERA of a compound consists of three steps

- exposure assessment → PEC,
- hazard identification → PNEC,
- risk characterization → PEC/PNEC ratio.

Basically the concentration in the environment (Predicted Environmental Con-

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centration or (PEC)) is compared with the highest concentration at which no effects on organisms or ecological systems are expected to occur (the Predicted No Effect Concentration (PNEC)). This is done separately for different environmental compartments (aquatic, terrestrial, and atmospheric). For existing chemicals, *exposure assessment* (determination of environmental concentrations) can be performed either by monitoring, representative laboratory measurements, or calculations. Alternatively the environmental concentrations of a new chemical can be calculated from its (estimated) consumption volume, the proposed application method thus leading to the PEC. Furthermore, the EC guideline suggests models with the different modes of distribution (point source or widely dispersed) and default values for the most important fields of application.

The PNEC in an environmental compartment can be derived from the lowest result from laboratory toxicity tests with different species or organisms (*hazard identification*). Depending on the data availability (acute and/or chronic tests, different trophic levels), the EU Technical Guidance Document suggests an appropriate Assessment Factor (AF) between 10 and 1000 that takes the overall uncertainty into account.

The risk assessment should be carried out with all available data. The most realistic information should be given preference. Usually, field results will override lab results and lab results are preferred to estimations.

The key value for *risk characterization* is the PEC/PNEC ratio. If this ratio is below 1, then there is no immediate concern for the chemical in question. As an ERA is an iterative process, a PEC/PNEC ratio greater than 1 will be with additional information and/or further testing. If a ratio below 1 is not achievable, risk reduction measures and/or sales restrictions can be enforced.

2.2. Existing Chemicals in the EU (EINECS)

Existing chemicals are listed in EINECS (European Inventory of Existing Chemical Substances). Other countries have similar lists, e.g. TSCA (Toxic substances control act) in the USA. For high-volume products, (>1000 tons per year) the suppliers have had to provide all available ecological and toxicological information. The nonconfidential part of this information is accessible on a compact disc [4]. National and international bodies and organizations have created concern or priority lists of products where the

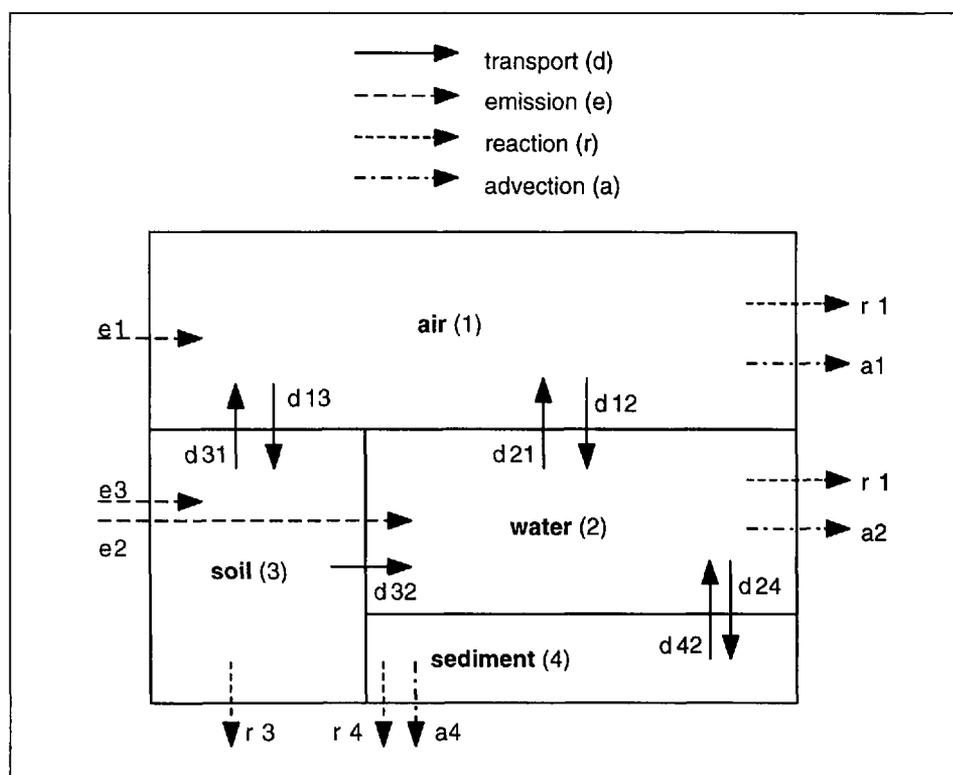


Fig. 1. Unit world (multimedia) model according (Mackay level III [13])

(eco-)toxicological data will be reviewed and assessed [5], and if necessary, the suppliers will be asked for additional information and/or testing. Should the risk assessment pose a risk to man or the environment, manufacture, marketing and, use could be restricted.

2.3. New Chemical Substances in the EU (ELINCS)

New chemicals have to pass a notification process. The chemical industry fully understands and accepts the principles laid down, but the time- and resource-consuming procedure of this notification hamper innovation. To prepare the EU documentation for a new chemical [6-7] takes 8-18 months and testing costs of CHF 150 000-200 000 for the notification procedure. After a successful notification process, the chemical will be listed in ELINCS (European List of Notified Chemical Substances). Substances considered dangerous to man and/or the environment have to be labeled adequately and may be faced with sales restrictions. Depending on the production and sales volumes, further information has to be presented. The test programs (> 100 to < 1000 t/a: level 1 program and > 1000 t/a: level 2 program [8]) consist of additional physicochemical, ecological, and toxicological tests supplemented by environmental and exposure risk assessments. For high-volume products (> 1000 t/a) the total testing expenses can easily exceed to CHF 2 Mio.

3. Models to Calculate PECs

For a preliminary assessment of the environmental distribution, the environmental compartments soil, aquatic, sediment, air, and biota have to be considered as shown in Fig. 1. Furthermore, the mode of environmental distribution has to be known. It can be a point source for chemicals used in manufacturing plants or ubiquitous distribution for consumer products.

A first assessment can be performed with a few physicochemical parameters like molecular weight (MW), water solubility (SOL), and melting and/or boiling point (MP, BP). However, these preliminary assessments are usually restricted to nonpolar, nonionogenic organic substances. A lot of data can be found in handbooks, data bases, and/or publications or can be estimated (see Table 1).

Once the selected parameters are available, the data resulting from the above-mentioned estimation procedures have to be assessed without bias before they are used for the calculation of PECs. In the next step, the release of the chemicals will be treated in environmental distribution models (see below) leading to the predicted environmental concentrations for each compartment. EU Technical Guidance Document [2] provides a sensible basis for this procedure, the underlying background, and the assessment. Nevertheless, the manual conduction of a full risk assessment is a time- and resource-consuming exercise.

Table 1. Some Important Environmental Parameters and Estimation Methods

Parameter	Source of data	Parameter estimation method	Restrictions(pitfalls of estimation)
Water solubility (SOL)	Commercial data bases [9] and printed sources [10]	May be estimated from Pow with various available regression equations (e.g. [11])	Ionic substances may strongly vary with pH
Vapor pressure (VP)	Commercial data bases [9] and printed sources [10][12]	Various methods available. For VP in the solid state from MP or of liquids from BP [13]	Not valid for salts
Acid dissociation constant (pK_a)	Commercial data bases [9] and printed sources [14]	Usually estimated from programs which are based on linear free-energy relationship (LFER) [15]	
Octanol/water partition coefficient (Pow)	Commercial data bases [9] and printed sources [10][14]	Estimated from molecular fragment method programs (e.g. CLOGP [16] from Biobyte)	No cationic substances and only free acids. Does not consider pH dependence of ionic substances
Organic carbon/water partition coefficient (Koc)	Commercial data bases [9] and printed sources [10][17]	Estimated from Pow [18]	Mainly for nonionic and nonpolar substances
Bioconcentration factor (BCF)	Commercial data bases [9] and printed sources [19]	Estimated from Koc, SOL, and perhaps MW [2][20]	see Koc
Henry's Law Constant (H)	Commercial data bases [9] and printed sources [10]	Estimated from VL, SOL, and MW (EC 1488/94 [2])	No salts
Aerobic biodegradation	Commercial data bases [9] and printed sources [21]	Methods for estimation from structure are available (TOPKAT [22], or e.g. [23])	Reliability of estimation questionable

Table 2. Short Assessment of the Selected PEC Models

Name	Operating System	Content
AQUASIM [24]	Apple McInt/Win	Mathematical modeling, simulation, and data analysis of aquatic systems including sensitivity analysis
EC-ERA [2]	Document	Detailed technical guidance document for an Environmental Risk Assessment (PEC/PNEC) in the environmental compartments
E4CHEM [25]	DOS	9 independent modules to estimate PEC values in different environmental compartments
HAZCHEM [26]	DOS	Computer program mainly based on the parameters according to the EU Technical Guidance Document
Mackay [27]	DOS	Programs to estimate PECs with fugacity models in a simple unit world concept
MASAS [28]	Apple McInt	Mathematical modeling of the fate of anthropogenic substances in aquatic systems
USES [29]	DOS	Computer program mainly based on the parameters according to the EU Technical Guidance Document

For this reason computerized models that represent the environment on a local or regional/national scale have been developed to allow a quick calculation of the environmental distribution. Some of the publicly available modeling systems are briefly described in Table 2.

Unfortunately, most of the models are programmed within DOS and therefore have the known disadvantages of the DOS environment, namely user-unfriendliness crucial stability of the system and compli-

cated print procedures. Indeed, there is always a handbook available and it is highly advisable to study the built-in default values in order to comprehend and judge the data. Additionally, some of the programs are 'black boxes' with screens for the input and the result. For an inexperienced user it is almost impossible to appreciate whether the figures are plausible or not.

For this reason, the regional scale models (e.g. Mackay, HAZCHEM, USES)

should be seen as support tools that lead to a preliminary assessment. A refinement can be achieved by applying models that represent the environment on a local scale (e.g. MASAS, AQUASIM). Further improvements come from additional information about the chemical itself, e.g. information on hydrolysis, photolysis, biodegradation, and a better understanding/characterization of the application processes.

Mackay is a simple program that handles the fugacity models in a unit world concept. With reference to equilibrium or steady-state conditions, different levels can be considered, Mackay level III (equilibrium in the compartment, steady state between the compartments) being the one most commonly chosen. Its strong point is that it demonstrates the mechanism of the environmental distribution of the investigated chemical without considering any effects but degradation processes.

E4CHEM is based on a Mackay level III type model but adds information on releases and application types. Additionally, it allows the estimation of (physico-)chemical parameters. The program consists of nine modules for these estimations that have to be chosen on the basis of expert knowledge of the underlying concepts.

HAZCHEM and USES are mainly based on the EU Technical Guidance Document [2] and the software available at the time period of the development of the two pro-

grams. These software packages are expert systems that combine three different elements: release into the environment, distribution in the environment on a local and regional scale (regional scale: Mackay level III type models), and consideration of eco-toxicological data. They support and simplify the above-described EU risk assessment, but do not replace expert know-how and unbiased judgment.

AQUASIM and *MASAS* are two models that represent a local environment in a highly detailed way and thus differ from the unit world models described above. Dynamic modeling and sensitivity analysis is possible, and even elements of expert systems are included. They thus represent another generation of models that seek to simulate the investigated environment more adequately and are programmed in a most user-friendly way. However, even though these models include detailed local information (e.g. photolysis, hydrolysis, adsorption/desorption, hydraulics, topography), they are limited to the evaluation/simulation of rivers, lakes, groundwater, and oceans.

4. Models to Determine PNECs

The Predicted No Effect Concentration (PNEC) is usually derived from acute and/or chronic toxicity tests. For a preliminary assessment, Quantitative Structure-Activity Relationship (QSAR) models can also be applied.

The hazard characterization approach is simple, the selected PNEC is intended ensure that the inhabitants of the aquatic, terrestrial, and atmospheric compartments are not impaired by an anthropogenic chemical substance. However, the limited test results available lead to an uncertain situation that is considered in the Technical Guidance Documents by the introduction of so-called assessment factors.

4.1. QSAR for Aquatic Toxicity

QSARs are estimation methods that predict certain effects or properties of chemical substances based on their chemical structure. There is extensive published information available [30].

QSARs are not intended to replace testing but to support preliminary assessments and assist the optimization of test strategies. They can be applied for several toxicological or ecological endpoints, e.g. aquatic toxicity as well as for physico-chemical parameters, e.g. octanol/water partition coefficients.

For *nonpolar* (aliphatic, aromatic hydrocarbons, both halogenated and non-

Table 3

Trophic level	Standard organisms	Method [32]	Result
Primary producers	green algae	OECD 201	EC 50/72 h ^{a)}
Primary consumers	Daphnia species	OECD 202	EC 50/48 h ^{a)}
Secondary consumers	trout, zebrafish, others	OECD 203	LC 50/96 h ^{b)}

^{a)} EC: Effect Concentration

^{b)} LC: Lethal Concentration; 50 indicates that 50% of the investigated organisms were affected in the respective test.

halogenated ethers, alcohols, etc.) and *polar* (anilines, phenols, aromatic nitro compounds, and even aliphatic amines) *narcotics*, the toxicity can be derived from the octanol/water partition coefficient Pow [2]. Ionic substances like salts or cationic compounds and polymers react differently and therefore require different models. *Escher et al.* [31] described such a model with respect to the uptake, speciation and uncoupling activity of substituted phenols in biological membranes.

Ecological or toxicological data can be derived from either molecular fragments or the specific endpoint. Results achieved with TOPKAT—a QSAR method which is based on the aquatic toxicity of molecular fragments—are only satisfactory for unspecific toxicological effects, e.g. narcosis. Additionally, it is therefore vital to have QSAR models based on the specific endpoint.

4.2. Aquatic Toxicity Tests and Assessment Factors

New products to be notified in the EU have to undergo a given set of short-term aquatic tests. To assess the acute aquatic toxicity, tests on three trophic levels have to be conducted. Depending on the amounts produced, additional chronic assays may be necessary (Table 3).

In addition, the *Respiration Inhibition Test* (OECD 209) for activated sludge is required in order to assess any influence on the biological stage in sewage treatment plants.

These tests are usually not all available for existing products. To close this gap with aquatic tests would by far exceed the available resources. Here, the use of QSARs will complement the data base.

To establish an *aquatic PNEC*, the result from the most sensitive test species has to be extrapolated with the appropriate assessment factor to compensate for the uncertainty.

The extrapolation has to consider

- the biological variance of the species in the respective trophic level,
- the short-term to long-term extrapolation,

– the laboratory to field extrapolation.

In the event of three acute test assays, an assessment factor of 1000 will be applied to the lowest LC_{50} or EC_{50} value. If additional chronic test results from all three trophic levels are available, the respective factors can be reduced to 10. Finally, for results from multispecies or field studies, the assessment factors can even be below 10. The Technical Guidance Document provides a procedure to identify the appropriate assessment factor [2].

While the aquatic compartment is covered by approved and established testing methods, the situation is less conclusive for sediments and the terrestrial compartment. As the selection of representative organisms and standardized sediments is still under discussion, the *PNEC for sediment dwellers* can be derived from the aquatic compartment by the equilibrium partitioning method [2]. In principle, the same situation applies for the terrestrial compartment. The only commonly accepted tests are the 'Earthworm, Acute Toxicity Tests' (OECD 207) and 'Terrestrial Plants, Growth Tests' (OECD 208). To calculate the *PNEC for soil*, the equilibrium partitioning method can again be applied [2].

5. Risk Characterization by Assessment of the PEC/PNEC Ratios

5.1. Preliminary Risk Characterization

An Environmental Risk Assessment is an iterative process. At the beginning, only the chemical structure and the melting and/or boiling point may be available. In a first step, it is advisable to search in data bases [33] and publicly accessible literature for information that is available or has been estimated according to Table 1.

Based on this information, a preliminary, quick, and simple risk assessment can be performed by considering at least the following parameters,

- *chemical structure* to estimate chemical reactivity and Pow ,
- solubility in water,

QSARS on aquatic toxicity are usually based on the narcotic effect of molecular fragments only. Many products like dyes, process chemicals for paper, textiles, and detergents that are ionic in character and may have different modes of action. In order to really improve the predictability of QSARS, an approach based on molecular fragments and their different endpoints is required. Another approach consists of predicting homologue series.

QSARS on biodegradability. The biodegradation of chemical substances is one of the key factors for assessing the impact of environmental exposure. The accepted test methods require a package of different time-consuming assays. Ultimate biodegradation under environmental conditions is a sequence of many complex processes that requires expert know-how. (Q)SARs that cover a wide variety of chemical structures are distinguished by a combination of expert rules based on structural parameters and evaluated data. Although a lot of work has already been done [36], further progress is needed.

User-friendly computer modeling that simulates the environmental compartments more adequately by including expert systems. There is a strong need to enhance the scope of multimedia models, so that they describe local conditions more adequately.

A further improvement of the predicting tools will make it possible to design products with improved environmental compatibility even at the start of desk research, and therefore shorten time and expenses to market. A truly promising outlook!

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- [1] 67/548/EEC: Council Directive of June 27, 1967 on the approximation of laws, regulations, and administrative provisions relating to the classification, packaging, and labelling of dangerous substances.
- [2] Technical Guidance Documents in support of the Commission Directive 93/67/EEC on Risk Assessment for New Notified Substances and the Commission Regulation (EU) 1488/94 on Risk Assessment for Existing Chemicals.
- [3] C.J. van Leeuwen, J.L.M. Hermens, 'Risk assessment of chemicals: an introduction', Kluwer, Dordrecht, 1996.
- [4] Joint Research Center (JRC) Environment, 'IUCLID, International Uniform Chemical Information Data Base', EU Commission, Ispra (Italy), 1996.
- [5] Commission Directive 1488/94/EEC of June 28, 1994 laying down the principles for assessment of risks to man and the environment of existing chemicals in accordance with Council Directive (EC) 793/93.
- [6] Council Directive 92/32 of April 30, 1992 amending for the seventh time Directive 67/548/EEC on the approximation of the laws, regulations, and administrative provisions relating to the classification, packaging, and labelling of dangerous substances.
- [7] Commission Directive 93/67/EEC of July 1993 laying down the principles for assessment of risks to man and environment of substances notified in accordance with Council Directive 67/548/EEC.
- [8] Council Directive 92/32 of April 30, 1992 amending for the seventh time Directive 67/548/EEC on the approximation of the laws, regulations, and administrative provisions relating to the classification, packaging, and labelling of dangerous substances, Annex VIII.
- [9] K. Voigt, H. Rohleder, 'Datenquellen für Umweltchemikalien', 2. Aufl., Ecomed, München, 1990; K. Voigt, R. Brüggemann, *Chemosphere* **1995**, *31*, 3585.
- [10] D. Mackay, W.Y. Shiu, K.C. Ma, 'Illustrated Handbook of Physical-Chemical Properties and Environmental Fate for Organic Chemicals', Vol. 1-4, Lewis, Chelsea, MI, 1992.
- [11] W.J. Lyman, W.F. Reehl, D.H. Rosenblatt, 'Handbook of Chemical Property Estimation Methods', American Chemical Society, Washington, DC, 1990.
- [12] T. Boublik, V. Fried, E. Hála, 'The Vapor Pressure of Pure Substances', Elsevier, Amsterdam, 1984.
- [13] D. Mackay, A. Bobra, D.W. Chan, W.Y. Shiu, *Environ. Sci. Technol.* **1982**, *16*, 645, and D. Mackay, 'Multimedia Environmental Models', Lewis, Chelsea, MI 1991.
- [14] C. Hansch, A. Leo, 'Exploring QSAR, Fundamentals and Applications in Chemistry and Biology', ACS Professional Reference Book, American Chemical Society, Washington, DC, 1995.
- [15] E.P. Serjeant, B. Dempsey, 'Ionisations Constants of Organic Acids in Aqueous Solution', Pergamon, New York, 1979.
- [16] MEDCHEM from Biobyte Inc., Version 1.55.
- [17] R.P. Schwarzenbach, J. Westall, *Water. Sci. Technol.* **1985**, *17*, 39.
- [18] S.W. Karickhoff, *Chemosphere* **1981**, *10*, 833.
- [19] S.E. Bysshe, 'Bioconcentration Factor in Aquatic Organisms', in 'Handbook of Chemical Property Estimation Methods', W.J. Lyman, W.F. Reehl, and D. H. Rosenblatt, Eds. American Chemical Society, Washington, DC, 1990.
- [20] D.W. Connell, 'Bioaccumulation in Aquatic Systems - Contribution to the assessment', in 'Proceedings of an International Workshop', VCH, Weinheim, 1990, 133.
- [21] P.H. Howard, R.S. Boethling, W.F. Jarvis, W.M. Meylan, E.M. Michalenko, 'Handbook of Environmental Degradation Rates', Lewis, Chelsea, MI, 1991.
- [22] TOPKAT (C) HDI, 'Models for aerobic biodegradation, acute toxicity to Fathead Minnow and Daphnia Magna', Version 1.5, Health Design Inc., New York, 1986-1990.
- [23] R.S. Boethling, P.H. Howard, W. Meylan, W. Stiteler, J. Beauman, N. Tirado, *Environ. Sci. Technol.* **1994**, *28*, 459.
- [24] P. Reichert, *Water. Sci. Technol.* **1994**, *30*, 21.
- [25] R. Brüggemann, U. Drescher-Kaden, B. Münzer, 'E4CHEM - A Simulation Program for the Fate of Chemicals in the Environment', GSF-Forschungszentrum, GSF - Bericht 2/96, 1996.
- [26] HAZCHEM, a Mathematical Model For Use in Risk Assessment of Substances, European Center for Ecotoxicology and Toxicology of Chemicals, ECETOC, Brussels, Belgium, 1994.
- [27] D. Mackay, 'Multimedia Environmental Models - The Fugacity Approach', Lewis Publishers, Chelsea, MI, 1991.
- [28] U.M. Ulrich, D.M. Imboden, R.P. Schwarzenbach, *Environmental Software* **1995**, *10*, 177.
- [29] RIVM, VROM, WVC, 'Uniform System for the Evaluation of Substances (USES)', Version 1.0, Ministry of Housing, Spatial Planning and the Environment, The Hague, NL, 1994.
- [30] H.J.M. Verhaar, W. Mulder, J.L.M. Hermens, 'QSAR for ecotoxicity', in: Overview of structure-activity relationship for environmental endpoints, Part 1: General outline and procedure', in 'Report of the project QSAR for Prediction of Fate and Effects of Chemicals in the Environment', European Commission contract EVSV-CT92-0211, 1995.
- [31] B.I. Escher, M. Snozzi, R.P. Schwarzenbach, *Environ. Sci. Technol.* **1996**, *30*, 3071.
- [32] Organisation of Economic Cooperation and Development (OECD), OECD guidelines for the testing of chemicals, CD-ROM, OECD, Paris, 1995-1996.
- [33] K. Voigt, H. Rohleder, 'Datenquellen für Umweltchemikalien, 2. Aufl.', Ecomed, München, 1990; K. Voigt, R. Brüggemann, *Chemosphere* **1995**, *31*, 3585.
- [34] D. Aegerter, 'Toxizitätsbewertungen in Produkt-Risikoanalyse und Ökobilanzierung am Beispiel von vier Technologien der Textilreinigung', Diplomarbeit an der Abt. XB der ETH-Zürich, Zürich, 1996.
- [35] M.M. Ulrich, S.R. Müller, H.P. Singer, D.M. Imboden, R.P. Schwarzenbach, *Environ. Sci. Technol.* **1994**, *28*, 1674.
- [36] D. Gamberger, D. Horvatic, S. Sekusak, A. Sabljic, *Environ. Sci. & Pollut. Res.* **1996**, *3*, 224.