COMPARATIVE EVALUATION OF CHEMICAL RANKING AND SCORING METHODOLOGIES

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Prepared by

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LIST OF ACRONYMS

AALAC: ambient aquatic life advisory concentration
ARET: Accelerated Reduction/Elimination of Toxics
ADI: allowable daily intake
ATSDR: Agency for Toxic Substances and Disease Registry
AWQC: aquatic water quality criteria
BAF: bioaccumulation factor
BCF: bioconcentration factor
BP: boiling point
BUA: Beratergremium für Umweltrelevante Altstoffe
CAG: carcinogen assessment group
CCHTE: chemical category human toxicity estimate
CFC: chlorofluorocarbon
CMR: Critical Materials Register
DfE: Design for the Environment
EC: European Communities
EC_{50}: the median effect concentration; the concentration at which 50% of the test population exhibit a specified response during a specified time period
ED_{10}: estimated dose associated with a lifetime increased cancer risk of 10%
EEC: European Community Commission
ELU: Environmental load units
EMPPL: Effluent Monitoring Priority Pollutants List
EPA: United States Environmental Protection Agency
EPS: environmental priority strategies
ERRP: ecological risk reduction potential
GWU: George Washington University
HA: health advisory
HEAST: Health Effects Assessment Summary Tables
HHSATR: human health structure activity team rank
HPV: high production volume
HRRP: human risk reduction potential
HRS: Hazard Ranking System
HWQC: human health water quality criteria
IARC: International Agency for Research on Cancer
IC_{50}: inhibitory concentration for 50% test population
IRIS: Integrated Risk Information System
ITC: Interagency Testing Committee
K_{ow}: octanol-water partition coefficient
LC_{50}: median lethal concentration; the concentration at which 50% of the test population die during a specified time period
LCA: life cycle assessment
LD_{50}: lethal dose for 50% test population
LD_{lo}: lethal dose to some value < 50%

LIST OF ACRONYMS, continued

LET: lethality
LOAEL: lowest observable adverse effect level
MATC: maximum acceptable toxicant concentration
MED: minimum effective dose
MOE: Ministry of the Environment (Ontario)
NA: not applicable
NAAQS: national ambient air quality standard
NEL: no effect level
NFPA: National Fire Protection Association
NOAEL: no observable adverse effect level
NOEC: no observable effect concentration
NOEL: no observable effect level
NOx: nitrous oxides
NPL: National Priority List
NTP: National Toxicology Program
OECD: Organization for Economic Cooperation and Development
PGR: population growth rate
q_1*: cancer potency slope factor
QSAR: quantitative structure-activity relationship
RfC: reference concentration
RfD: reference dose
RQ: reportable quantity
SAR: structure-activity relationship
SARA: Superfund Amendments and Reauthorization Act
SATR: structure activity team rank
SIDS: screening information data set
SRS: Site Ranking System
TD_{lo}: total dose resulting in a sublethal effect
TPQ: threshold planning quantity
TRI: Toxics Release Inventory
TSCA: Toxic Substances Control Act
TSCA CSSC: TSCA chemical scoring system category
UCR: unit cancer risk
URF: unit risk factor
UT: University of Tennessee (Knoxville, Tennessee)
VOC: volatile organic compound
WMS: Wet Milieugevaarlijke Stoffen
WOE: weight of evidence

SECTION 1: INTRODUCTION

Between 60,000 and 100,000 of the over 8,000,000 chemicals listed by the Chemical Abstracts Services Registry are commercially produced and are potential environmental pollutants. Some kind of risk-based evaluation for these chemicals is often required to evaluate the impacts of chemical use or releases, for regulatory action, and to set priorities for pollution prevention. The time and resources, however, are not reasonably available to test *all* of these chemicals for their potential health and environmental effects. During the last decade there have been vast improvements in the methods used to test chemicals for toxicity and environmental fate and to interpret these data within a risk assessment framework. We have not, however, developed generally accepted and widely used tools to better enable us to set priorities and focus limited resources on selecting those chemicals for study that would yield the greatest environmental benefits.

Risk-based ranking and scoring systems can be used to focus attention and resources on the largest potential hazards. Risk-based chemical ranking and scoring combines an assessment of both the toxic effects of chemicals (human and/or environmental) and the potential exposure to those chemicals to provide a relative evaluation of risk. Along with toxicity and exposure, ranking and scoring systems may include other environmental impacts (e.g. ozone depletion) and some measure of economic impact and/or societal value.

Although numerous ranking and scoring systems have been or are being developed, there is currently no scientific consensus on risk ranking methods. Chemical risk ranking has received the most attention, and several systems have been used, for example, to determine which chemicals should be included in various regulatory pollutant lists. To facilitate development of a framework for overall human health and environmental risk ranking, this report presents an evaluation of existing chemical ranking and scoring systems. Approximately fifty systems are compared and evaluated in terms of:

- the purpose and application of the ranking and scoring system;
- the human health criteria and endpoints included;
- the criteria and endpoints included for environmental effects;
- whether measures of exposure are included;
- the data selection approach[1] and handling of missing data;

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[1] "Data selection approach" is a term used here to describe the methods used to build a comparable data set for a specific measurable characteristic across a set of chemicals of interest. As an example, to characterize the bioconcentration potential for a set of 100 organic compounds, measured bioconcentration factors are selected first for all chemicals where this information is available. For all other chemicals, a bioconcentration value is estimated from the octanol-water partitioning coefficient or from water solubility data.

- the use of aggregation and weighing of different health and environmental impacts;
- methods of accounting for chemical potency and severity of effects; and
- inclusion of other impacts or issues.

An evaluation of the important issues inherent to the development of any consensus ranking and scoring system is presented, and important similarities and differences among the systems evaluated are discussed.

In this document, following the introduction, Section 2 presents the methods used by the evaluated systems. This includes a list and summary of the systems, a more detailed description of the systems, and a description of important elements and applications of ranking systems. Section 3 contains a discussion, based on the analysis of systems in Section 2, of the application of risk assessment principles to chemical ranking and scoring, similarities and differences among the systems, and general strengths and weaknesses of the evaluated systems. Section 4 presents conclusions and suggestions for future work.

SECTION 2: METHODS

2.1 SUMMARY OF SYSTEMS

Fifty-one ranking and scoring systems have been reviewed for this report (listed in Table 1). A summary is provided for each of these in Appendix A. The systems selected for evaluation span a wide range of methodologies and levels of complexity (from simple and straight-forward to fantastically elaborate). Evaluating this variety of systems is intended to provide a representative sampling of the approaches to chemical ranking and scoring and the issues involved in developing a standardized (or consensus) framework.

It is necessary to distinguish *chemical* ranking and scoring systems from other risk ranking systems such as those that primarily rank sites (e.g. potential sites for listing on the National Priorities List) or issues (e.g. risk from hazardous waste sites versus air pollution, etc.). The majority of ranking and scoring systems that we have evaluated are based on a chemical-specific approach, which involves ranking, scoring, or categorizing a list of chemicals based on chemical-specific attributes. A system is considered a *chemical* ranking or scoring system if it meets the following criteria:

- it ranks or scores a list of chemicals;
- it results in a relative ranking or scoring, not quantitative measure(s) of risk;
- it includes measures of either toxicity alone or toxicity and exposure; or
- if it is a subsystem of a site or issue ranking method, the approach ranks sites or issues based on an initial chemical-specific evaluation.

Thirteen of the fifty-one systems reviewed here did not meet these conditions. The following systems reviewed did not meet the criteria of a chemical scoring or ranking system as defined above:

- *CERCLA Hazard Ranking System (HRS)* (EPA 1990): a site ranking system;
- *Modified Hazard Ranking System* (Hawley & Napier, 1985): a site ranking system;
- *A Groundwater Pollution Priority System* (Hutchinson & Hoffman): a site ranking system;
- *EPA Unfinished Business Report* (Morgenstern et. al., 1987): used to rank environmental issues which pose societal risks;
- *Coastal Hazardous Waste Site Review* (Beckvar & Harris, 1985): a site ranking system;
- *Site Ranking System (SRS) for Chemical and Radioactive Waste* (Rechard et. al., 1988, 1991): a site ranking system;
- *Evaluating Contamination Potential of Surface Impoundments* (Silka & Swearingen, 1978): a site ranking system;

TABLE 1. List of Ranking and Scoring Systems Evaluated

System no. [a]	System Name or Title	Reference
1	TRI Environmental Indicators Methodology (draft)	Abt Associates, Inc., 1992
2	ATSDR, "CERCLA Section 104 Third Priority List"	ATSDR, 1992
3	Existing Chemicals of Environmental Relevance	Behret, 1989a
4	Existing Chemicals of Environmental Relevance II, Selection Criteria and Second Priority List	Behret, 1989b
5	Review of Region VII TRI Strategy	Bouchard, 1991
6	Candidate Substance List for Bans or Phase-outs	Socha et al, 1992
7	Criteria Identifying High Risk Pollutants	BNA, 1991
8	A Classification System for Hazardous Chemical Wastes	Crutcher & Parker, 1990
9	CERCLA Hazard Ranking System (HRS)	EPA, 1990
10	Identifying Chemical Candidates for Sunsetting: George Washington University	Foran & Glenn, 1993
11	Existing Chemicals: Systematic Data Collection and Handling for Priority Setting	Gjøs et al., 1989
12	Substances and Preparations Dangerous for the Environment: A System for Classification, Labeling and Safety Data Sheets	Gustafsson & Ljung, 1990
13	Notes on Ranking Chemicals for Environmental Hazard	Halfon & Reggiani, 1986
14	Application of the Hazard Ranking System to the Prioritization of Organic Compounds Identified at Hazardous Waste Remedial Action Sites	Hallstedt et al., 1986
15	Modified Hazard Ranking System (mHRS); A Ranking System for Hazardous Waste Sites with Mixed Radioactive and Hazardous Wastes	Hawley & Napier, 1985
16	A Groundwater Pollution Priority System (GWPPS)	Hutchinson & Hoffman, 1983
17	The Great Lakes Water Quality Agreement (GLWQA) Annex 1, Lists 1,2,3	IJC, 1989

TABLE 1. List of Ranking and Scoring Systems Evaluated

System no. [a]	System Name or Title	Reference
18	Chemical Scoring by a Rapid Screen of Hazard (RASH) Method	Jones et al., 1987
19	Systematic Approach for Environmental Hazard Ranking of New Chemicals ("Schmallenberg")	Klein et al., 1988
20	WMS Scoring System	Könemann & Visser, 1988; Timmer et al., 1988
21	Benchmark Comparisons	Laskowski et al., 1982
22	Michigan Critical Materials Register (MCMR)	Michigan DNR, 1987
23	USEPA Unfinished Business Report: A Comparative Assessment of Environmental Problems	Morgenstern et al., 1987
24	Chemical Scoring System for Hazard and Exposure Identification	O'Bryan & Ross, 1988
25	Effluent Monitoring Priority Pollutant List (EMPPL)	Environment Ontario, 1987, 1988
26	Coastal Hazardous Waste Site Review	Beckvar & Harris, 1985
27	Site Ranking System (SRS) for Chemical and Radioactive Waste	Rechard et al., 1988; Rechard et al., 1991
28	A Practical Method for Priority Selections and Risk Assessment Among Existing Chemicals	Sampaolo & Binetti, 1986, 1989
29	UT Chemical Ranking System (draft)	Davis et al., 1993
30	A Manual for Evaluating Contamination Potential of Surface Impoundments	Silka & Swearingen, 1978
31	The EPS Enviro-Accounting Method	Steen & Ryding, 1992
32	Defense Priority Model (FY 1993 Version)	U.S. DOD, 1991
33	Hazardous Air Pollutants: Proposed Regulations Governing Constructed, Reconstructed and Modified Major Sources	EPA, 1993b (40 CFR 63)
34	Ranking System for Clean Water Act Section 307(a) List of Priority Pollutants	Poston & Prohammer, 1985; Cornaby et al, 1986

TABLE 1. List of Ranking and Scoring Systems Evaluated

System no. [a]	System Name or Title	Reference
35	CERCLA Section 102 Reportable Quantity Ranking Process	EMS, 1985; EPA, 1989c
36	The Source Category Ranking System	Radian Corp., 1990
37	Sax Toxicity Ratings (or Hazard Index)	Sax & Lewis, 1989
38	Examination of the Severity of Toxic Effects and Recommendations of a Systematic Approach to Rank Adverse Effects	Environ 1986
39	Screening Procedure for Chemicals of Importance to the Office of Water	EPA, 1986
40	Measuring Air Quality: The New Pollutants Standards Index	EPA, 1978
41	Ranking the Relative Hazards of Industrial Discharges to POTWs and Surface Waters	Abt Assoc., 1991
42	Targeting Pollution Prevention Opportunities Using the 1988 TRI	ICF, 1990
43	EPA Design for the Environment Program Use Cluster Scoring System (also called: Chemical Use Clusters Scoring Methodology)	EPA, 1993a
44	Screening Methodology for Pollution Prevention Targeting	EPA (date unknown)
45	Toxic Chemical Release Inventory Risk Screening Guide	EPA, 1989a
46	TSCA's TRI Chemical Risk Assessment Pre-Screening Methodology	EPA (date unknown)
47	Priority Setting of Existing Chemicals ("Schmallenberg")	Weiss et al., 1988
48	Multi-Media Environmental Pollutant Assessment System (MEPAS), formerly the Remedial Action Priority System (RAPS)	Whelan et al., 1987; Droppo et al., 1989; Strenge et al., 1989; Whelan et al., 1992
49	Canadian Accelerated Reduction/Elimination of Toxics (ARETS) Scoring Protocol	CLC, 1992; Canadian ARET, 1993
50	Risk Assessment Guidance under CERCLA, screening chemicals of potential concern	EPA, 1989d

TABLE 1. List of Ranking and Scoring Systems Evaluated

System no. [a]	System Name or Title	Reference
51	EC Proposal for Priority Setting of Existing Chemical Substances (Draft)	van der Zandt & van Leeuwen, 1992

(a) System numbers are used as a shorthand method of tracking the systems. They were based on a preliminary alphabetical list of references, but at this time are essentially an arbitrarily assigned number.

- *The EPS Enviro-Accounting Method* (Steen & Ryding, 1992): developed for life cycle impact assessment;
- *Defense Priority Model* (U.S. DOD, 1991): a site ranking system;
- *Examination of the Severity of Toxic Effects* (Environ Corp., 1986): not chemical specific;
- *Ranking the Relative Hazards of Industrial Discharges to POTWs and Surface Waters* (Abt Assoc., 1991): a site ranking system;
- *Targeting Pollution Prevention Opportunities Using the 1988 TRI* (ICF, 1990): a site ranking system; and
- *Multi-media Environmental Pollutant Assessment System (MEPAS)* (Whelan et. al., 1987; Droppo et. al., 1989; Strenge et. al., 1989; Whelan et. al., 1992): a site ranking system.

For the sake of completeness, and to illustrate the diversity among what are called risk ranking systems, these thirteen systems are also summarized in Appendix A.

2.2 DETAILED DESCRIPTION OF SYSTEMS

Descriptions of the fifty-one systems have been distilled into two-page summaries (Appendix A) that include the following information:

- system name or title;
- publication references;
- the intended user of the system;
- the purpose or application;
- chemicals addressed or used for demonstration;
- summary of method or algorithm;
- an outline of the criteria, subcriteria and endpoints used; and
- data selection approach.

Several other surveys of existing (primarily *chemical*) ranking and scoring systems have been identified:

- Waters et. al. (1993) describes seventeen ranking and scoring systems, including nine methods for ranking existing sites and eight "various chemical and substance ranking methodologies";

- Foran and Glenn (1993) analyze eight "existing chemical scoring systems" in detail, and include summary tables of effects criteria, endpoints, and scoring methods for the screening systems analyzed;

- ICF (1993) provides detailed summaries and comparisons of five chemical scoring systems with brief descriptions of fifteen additional systems in a bibliography;

- Abt Associates, Inc. (1992) summarizes, in some detail, twenty-one U.S. Environmental Protection Agency (EPA) ranking systems. An additional thirteen "ranking and indexing efforts" from outside of the EPA are described briefly. All of the systems surveyed make use of TRI data;

- The Organization for Economic Cooperation and Development (OECD, 1986) describes fifteen ranking and scoring systems in some detail and lists an additional fifty "known priority ranking systems" by system name, developer, and intended user of the system. Full references for the fifty systems were not included;

- Environ Corp. (1986) describes thirty-four "chemical ranking schemes", including eleven from the EPA, eight from other federal agencies, four state ranking schemes, two "degree of hazard" ranking schemes, three from international agencies, two "other ranking schemes", and four carcinogen ranking schemes; and

- Hushon and Kornreich (1984) summarize thirty-four "existing chemical scoring systems" in a table that includes the system title, purpose, developer(s), user(s), criteria used for scoring, algorithms used, substances scored, and references.

When all of the systems described by these authors are included, a total of 147 ranking and scoring systems have been identified. A complete listing of these is provided in Appendix B, with the system name, the developers and intended users of the system, the purpose or application of the system, and the system approach (where the information was available).

2.3 DESCRIPTION OF IMPORTANT ELEMENTS AND APPLICATIONS OF RANKING SYSTEMS

Important components of any chemical ranking and scoring system include:

- the purpose and application of the ranking and scoring system;
- the human health criteria and endpoints included;
- the criteria and endpoints included for environmental effects;
- whether measures of exposure are included;
- the data selection approach and handling of missing data; and
- the use of aggregation and weighing of different impacts.

Other issues addressed include major ecological impacts, chemical mixtures, application to life cycle assessment (LCA), and economic and social considerations. These are discussed below with examples of various approaches used by the evaluated systems.

2.3.1 Purpose and Application of Chemical Ranking and Scoring Systems

Chemical ranking and scoring systems are typically used as screening tools for a rapid assessment of relative chemical hazards. They consider the toxic effects of chemicals and some measure of exposure, but are not intended to serve the same purpose as a quantitative risk assessment.

The purpose or intended use of the ranking and scoring system affects all of the aspects of the system, including the human health and environmental impacts considered, the use of aggregation and weighing, and how missing data are handled. Chemical ranking and scoring systems have been developed for the broad purposes of regulatory action, priority setting, and impact evaluations. Each of these is discussed below.

Regulatory Action

The need for the regulation of chemicals of concern has been the driving force behind the development of many of the chemical ranking and scoring systems evaluated. Examples of this application are described below:

The *CERCLA Section 102 Reportable Quantity Ranking Process* (EMS, 1985; EPA, 1989) established reportable quantities (RQs) through a scoring process that takes into account environmental and human health hazards of chemicals on the CERCLA list. RQs are threshold quantities at which certain chemical releases must be reported to the EPA.

The *Michigan Critical Materials Register (CMR)* (MDNR, 1987) ranking process results in a list of chemicals that may threaten water quality in Michigan. Chemicals included in the register are considered to pose a high degree of environmental concern, and companies must report their use and discharge of these chemicals.

The *Ontario Ministry of the Environment (MOE) Candidate Substance List for Bans or Phase-outs* (Socha et. al., 1992) is a ranking system that identifies chemical substances for release reduction, bans, or phase-outs.

The George Washington University (GWU) scoring system (Foran and Glenn, 1993) is intended to serve as a tool for pollution prevention in the Great Lakes region through the identification of chemical substances for Sunsetting (bans or phase-outs) and other activities.

Priority Setting

Several ranking and scoring systems have been developed specifically for assessing chemical hazards for priority setting for non-regulatory purposes. For example:

The *EPA Design for the Environment Program (DfE) Use Cluster Scoring System* (EPA, 1993) is aimed at measuring potential health and environmental risks of chemicals that are used in industry clusters (i.e., certain common industrial processes) as a way of evaluating the benefits of substitutes for those chemicals. The relative risk scores are provided to industry as a means of encouraging the voluntary adoption of pollution prevention measures.

The *Wet Milieugevaarlijke Stoffen (WMS) Scoring System* (Könemann and Visser, 1988; Timmer et. al., 1988) was developed by the Directorate General for Environmental Protection of the Netherlands Ministry of Housing, Physical Planning, and the Environment. It was intended for use in industry, government, and academia for the selection of a limited number of chemicals as priorities for further investigation.

The *Agency for Toxic Substances and Disease Registry (ATSDR) System* (ATSDR, 1992): The Superfund Amendments and Reauthorization Act (SARA) of 1986 required the ATSDR to prepare a list, in order of priority, of the hazardous substances commonly found at National Priority List sites that pose the most significant potential human health threats. Substances on this priority list become candidates for the preparation of toxicological profile reports prepared by ATSDR.

The University of Tennessee (UT) Center for Clean Products and Clean Technologies chemical ranking system (Davis et. al., 1993) prioritizes chemicals for safe substitutes assessments. The system has also been used for impact evaluation, as discussed below, and for scoring of TRI releases from chemical production facilities.

Impact Evaluation

Other scoring systems have been developed to evaluate the potential impacts of chemical releases.

The *Toxics Release Inventory (TRI) Environmental Indicators Methodology* (Abt Assoc., 1992) is intended to evaluate TRI releases and derive a value to indicate the overall impacts of those releases by all facilities and to each environmental medium. Annual calculations of the indicator numbers allow a comparison of potential TRI impacts from year to year.

The *UT ranking system* (Davis et. al., 1993) has been modified to allow a comparative assessment of the potential hazard or risk posed by aggregate TRI chemical releases and transfers from an entire state or from facilities (Kincaid and Bartmess, 1993). The modified system was used to assess, on a relative basis, the potential impacts from chemical releases for the five states with greatest releases (Tennessee, Texas, Louisiana, Indiana, and Ohio) and is being used to score TRI releases from chemical production facilities.

The *New Pollutant Standards Index* (EPA, 1978) was developed for use by local and state air pollution control agencies to provide a simple method for reporting daily air pollutant concentrations and to inform the public about the potential health effects associated with these concentrations. The index is calculated from a measured air pollutant concentration and its national ambient air quality standard, and is characterized with terms such as "good" or "unhealthful".

Another aspect of impact assessment is within the field of life cycle assessment (LCA). The methods for conducting life cycle impact assessment are currently being developed (SETAC, 1993). Chemical ranking and scoring methods with a focus on impact assessment have the potential to be applied to this emerging technology. LCA is discussed further in section 2.3.7.

2.3.2 Human Health Criteria and Endpoints

In order to assess the potential or actual hazard associated with a particular chemical substance, chemical ranking and scoring systems may include criteria for scoring the toxicity of a chemical to terrestrial mammals, non-mammalian terrestrial species, aquatic organisms, and/or plants. The toxicity of chemicals to these organisms is used to evaluate potential effects to human health and the environment. Acute, subchronic and chronic mammalian toxicity data are often used as surrogates for human health effects. Ecological effects typically include acute, subchronic and chronic toxicity to terrestrial mammals, non-mammalian terrestrial species, aquatic organisms and plants. Although some ranking and scoring systems include bioaccumulation and/or persistence in the environmental effects category, these are discussed within the framework of this paper as factors affecting exposure.

Overview of Human Health Effects

Human health effects include many responses in humans caused by chemical exposure. Epidemiological data may be used to characterize health effects, but laboratory mammalian toxicity data are most often included in chemical ranking and scoring systems. The numbers and types of endpoints used to assess potential health effects vary significantly.

Criteria for evaluating health effects often include toxicity resulting from varying durations of exposure. Those effects resulting from acute, sub-chronic and chronic exposure are commonly included in chemical ranking and scoring systems. A brief description of each of these types of effects is listed below:

Acute Effects. Acute toxicity tests usually involve a single dose and a 14-day observation period. These tests are most commonly conducted on the mouse or rat, but other species, such as the dog or rabbit, may be used. Acute effects are often characterized by lethality, commonly reported as the mammalian median lethal dose or concentration (LD_{50} or LC_{50}). This is the dose or concentration required to elicit lethality in 50% of the animals tested. Non-lethal acute effects are sometimes included as well. Skin or eye irritation and sensitization are examples of such effects. Routes of administration commonly preferred include oral, dermal and inhalation exposure. Some systems use data from other routes of exposure in the absence of preferred data.

Sub-chronic Effects. The most common test duration is 90 days for these tests, but the exposure time may vary. The main goal of these studies is to determine the no-observed-effect-level (NOEL) and to identify the specific organs affected after repeated doses of the test substance. These tests are usually conducted on the rat or the dog by an oral route of administration, but other species and routes may be used (Klaassen and Eaton, 1993).

Chronic Effects. These are long-term (longer than 3 months) studies designed to assess the cumulative toxicity of chemicals (Klaassen and Eaton, 1993). Chronic test data are often utilized in chemical scoring systems. Chronic health effects may be evaluated on the basis of a wide variety of toxicological endpoints. Carcinogenicity, mutagenicity, teratogenicity, reproductive toxicity, and other chronic toxic effects are often included in chemical scoring systems. General chronic effects may be characterized by RQs, reference doses (RfDs), threshold planning quantities (TPQs), the minimum effective dose (MED), or other measures.

A brief description of chronic effects often assessed in chemical ranking and scoring is provided below:

Carcinogenicity. Chemical carcinogens are substances which cause cancer in humans or other animals. Carcinogenicity is often evaluated on the basis of weight-of-evidence classifications developed by the EPA and/or strength-of-evidence classifications by the International Agency for Research on Cancer (IARC). Weight-of-evidence classification considers all long-term animal and relevant human studies as well as metabolism, pharmacokinetic and mechanistic information, structure-activity relationships (SARs) and other studies involving biochemical or physiological function. Strength-of-evidence classification may refer to the magnitude of conviction about the results of an experiment. For example, the National Toxicology Program (NTP) classifies each carcinogenic bioassay according to the amount and type of data from an experiment (Scala, 1993). The strength-of-evidence scheme developed by IARC excludes mechanistic information relating to the relevance to humans of bioassay data which show evidence of carcinogenesis in animals. This scheme does not consider all relevant data. For these reasons, the IARC classification scheme is considered to be based on strength-of-evidence rather than weight-of-evidence (Ashby et. al., 1990).

Sometimes one or both of the EPA and IARC classifications are combined with a measure of potency, usually the slope factor (q_1^*) or the ED_{10} in chemical ranking and scoring systems. Potency refers to the relationship between the dose and the response. The slope factor is an upper bound estimate of the probability of a response per unit intake of a chemical over a lifetime. It is used to estimate the probability of an individual developing cancer resulting from a lifetime exposure to a carcinogen (EPA 1989b). This is the potency factor normally used in EPA risk assessments. The ED_{10} is the estimated dose associated with a lifetime cancer risk increase of 10 percent. This is used in establishing RQs under CERCLA Section 102.

Mutagenic Effects. Mutagenesis occurs when chemicals cause changes in the genetic material which can be transmitted during cell division (Klaassen and Eaton, 1993). Several procedures, both *in vitro*

and *in vivo*, have been developed to test chemicals for possible mutagenicity. Tests for mutagenicity are often used to screen for potential carcinogenesis because the initiation of chemical carcinogenesis is believed to be a mutagenic occurrence (Klaassen and Eaton, 1993). Like carcinogenicity, mutagenicity is often evaluated according to weight-of-evidence classification which is sometimes combined with a measure of potency and/or severity. Mutagenic effects may also be of interest in terms of genetic alterations in the next generation.

Reproductive Toxicity. This refers to the occurrence of adverse effects, resulting from exposure to chemical or physical agents, on the male or female reproductive system. These may include effects on fertility, gestation, or lactation, among others (Klaassen Eaton, 1993). These effects are usually scored according to some type of weight-of-evidence and/or potency and severity.

Teratogenic Effects. Teratogenicity occurs when exposure to some chemical or physical agent induces defects during the development of an organism from conception to birth (Klaassen and Eaton, 1993). Teratogenicity is sometimes considered separately from other reproductive effects. Likewise, these effects are often scored on the basis of weight-of-evidence and/or some measure of potency and/or severity.

Neurotoxicity. This includes adverse effects on the nervous system caused by chemical exposure which may be structural and\or functional and may include behavioral changes and learning disabilities.

Several chemical ranking systems include toxicity scoring criteria based not on specific toxicological endpoints, but on indices that combine or scale one or more toxicological endpoints, such as:

- RQ: A hazardous substance, under CERCLA, released in a quantity above this amount must be reported to the National Response Center, the State Emergency Response Commission and the Local Emergency Planning Committee;

- RfD: An estimated daily exposure to the human population that is likely to be without appreciable risk or adverse effects in a lifetime, expressed in mg/kg/day; and

- TPQ: The amount of an extremely hazardous substance present at a facility above which the emergency planning notification must be provided to the State Emergency Response Commission and the Local Emergency Planning Committee.

Endpoints Used for Human Health Effects

Member countries of the OECD have undertaken the investigation of approximately 600 high production volume (HPV) chemicals. A data set has been established which is necessary to provide an initial screening of health and environmental risks. The Screening Information Data Set (SIDS) is the minimum information needed for deciding whether or not a HPV chemical should be considered of low current concern, considered for further information gathering or testing, or a candidate for further review with possible action to reduce risks posed by the chemical (Auer, 1992). This represents an effort to standardize, on an international basis, the basic experimental data needed to characterize the potential health and environmental effects of chemicals.

The SIDS database (Auer, 1992) includes the following toxicological data:

- acute toxicity;
- repeated dose toxicity;
- genetic toxicity (two endpoints, generally point mutation and chromosomal aberrations); and
- reproductive toxicity (including fertility and developmental toxicity).

The endpoints used to score human health and ecological effects are presented in Appendix C and in Table 2. (The use of criteria and endpoints is discussed further in section 3.2.1.) Although most chemical ranking and scoring systems evaluated were designed with human health protection in mind, most of them do not clearly distinguish between endpoints included to assess human health from those used to characterize toxicity to other terrestrial mammals. Often a score for 'general toxicity' is determined. The manner in which systems evaluate health effects varies dramatically among the many different systems. As can be seen, the specific endpoints selected to represent health effects are numerous.

The *Nordic System* (Gjøs et. al., 1989) scores health effects based on data pertaining to acute mammalian toxicity, irritation, sensitization, general toxicity, genotoxicity, carcinogenicity and reproduction damage/teratogenicity.

The *EPA DfE Use Cluster Scoring System* (EPA, 1993) assigns a human health hazard ranking for chemicals. This system assigns a score on the basis of criteria such as the RfD, RQ, or the TPQ, among others. The carcinogenic properties of each chemical are also scored and the higher of the two scores is selected as the human health hazard potential score.

TABLE 2. Endpoints Used for Scoring Environmental and Human Health Effects

Endpoint	System Number for Method Using this Endpoint [a]
Plant Toxicity	**(8 systems)[b]**
phytotoxicity in higher plants (qualitative)	28
qualitative effects (algae)	28, 47
aquatic, terrestrial IC_{50}	17
EC_{50}	6, 22, 25, 47, 49
NOAEL/NOAEC	6, 25, 49
Aquatic Toxicity	**(26 systems)**
AWQC (acute or chronic)	1, 9, 42, 45
AALAC (ambient aquatic life advisory concentration)	1, 9
NOAEL	1, 6, 10, 25, 49
acute LC_{50}	1, 2, 3, 4, 5, 6, 9, 10, 11, 12, 17, 19, 20, 22, 24, 25, 28, 29, 34, 35, 39, 49
acute LD_{50}	17
acute EC_{50}	3, 4, 10, 11, 12, 17, 19, 20, 22, 24, 28,
subchronic or chronic EC_{50}	6, 25, 34, 49
subchronic or chronic MATC	6, 22, 25, 34, 49
NOEL/NOEC	20, 24, 29
aquatic toxicity RQ	41, 42
population growth rate (PGR) (algae)	5
lethality (LET) (algae)	5
acute and prolonged fish, Daphnia toxicity	47
Terrestrial (non-mammal) Toxicity	**(8 systems)**
subchronic or chronic effects	6
acute LC_{50}	22
acute LD_{50}	10, 22, 28
chronic NOAEL	10
severity and effective dose	22
subchronic or chronic NOEL	25, 49
acute toxicity (bird, earthworm)	47

TABLE 2. Endpoints Used for Scoring Environmental and Human Health Effects

Endpoint	System Number for Method Using this Endpoint [a]
unspecified	11
Mammalian Toxicity[c]	**(19 systems)**
acute LD_{50}	2, 3, 4, 6, 7, 10, 11, 12, 17, 19, 20, 24, 25, 28, 29, 34, 35, 49
acute LC_{50}	2, 3, 4, 6, 7, 11, 12, 17, 24, 25, 28, 35, 49
subacute NOEL/NEL	19, 20, 28
subchronic or chronic NOAEL	6
skin or eye irritation	19, 28
skin or eye sensitization	19, 28
severity and effective dose	24
subchronic or chronic NOEL	25, 49
subchronic or chronic LOAEL	17
subchronic or chronic LD_{lo} and TD_{lo}	34
acute, subchronic, and chronic toxicity (rat)	47
General Ecological Effects	**(7 systems)**
ecological disruption	10
ecosystem recovery potential	23
ecological effects benchmarks	32
AWQC	43
aquatic toxicity RQ	43
team rank chemical category	43
ecotoxicity	44
ecological effects RQ	45
effect on fertility (mammals, birds, plants, etc)	47
Systemic (Non-carcinogenic) or General Health Effects	**(30 systems)**
acute LD_{50} and LC_{50}	9, 29, 37
NOAEL and LOAEL	1, 43
LOEL	7
10-day health advisory (HA)	5
max. concentration level	8

TABLE 2. Endpoints Used for Scoring Environmental and Human Health Effects

Endpoint	System Number for Method Using this Endpoint [a]
severity and effective dose	10
number of "highly toxic" chemicals	16
potency, relative potency	18, 23
other toxic effects	35
type of effect	35, 36, 37, 38
unspecified	46
chronic MED	1, 2, 35
RfD/RfC	1, 5, 7, 9, 23, 33, 42, 43, 45, 48, 50
chronic toxicity severity rating (R_v)	2
systemic mammalian toxicity	10
irritation	11, 47, 51
sensitization	11, 47, 51
general acute or chronic toxicity	5, 8, 11, 33, 36, 44, 51
chronic ADI	27, 32
RQ (acute, chronic, cancer)	33, 41, 42, 43, 45
NAAQS	40
TPQ	42, 43, 45
neurotoxicity	29, 44
Toxic Substances Control Act chemical scoring system category (TSCA CSSC)	43
HWQC	43
chemical category human toxicity estimate (CCHTE)	43
human health structure activity rank (HHSATR)	43
Carcinogenicity/Mutagenicity/Genotoxicity[c]	**(36 systems)**
carcinogenicity	
weight, amount, or type of evidence; or probability	1, 2, 4, 6, 7, 9, 10, 17, 20, 22, 24, 25, 29, 33, 35, 39, 43, 44, 49
potency or slope factor (q_1* or CPF)	1, 9, 42, 43, 50
ED_{10}	1, 9, 10, 33, 35
qualitative potency or effects	2, 3, 4, 23, 25, 34, 48, 49

TABLE 2. Endpoints Used for Scoring Environmental and Human Health Effects

Endpoint	System Number for Method Using this Endpoint [a]
CERCLA hazard rank	7
carcinogen (yes or no)	11, 20, 47
URF (unit risk factor)	5, 7, 45
UCR	27
cancer potency RQ	41, 43
EEC guidance	28
unspecified endpoint	36, 51
number of carcinogens	16
mutagenicity	
weight, amount, or type of evidence	1, 4, 17, 22, 51
severity or dose	1
effects	3, 4, 34
EEC guidance	28
bacterial or short-term tests	19, 20
mutagen (yes or no)	29, 47
genotoxicity	
weight, amount, or type of evidence	1, 17, 24
severity or dose	1
genotoxin (yes or no)	11
Developmental/Reproductive Toxicity	**(19 systems)**
unspecified	36, 44
weight, amount, type of evidence	1, 10, 22, 24, 51
severity, dose	1, 10
teratogenic effects	6, 34
effective dose	6, 17, 22, 25, 49
LOEL	7
developmental or reproductive toxin (yes, no)	11, 29, 39, 47
teratogen, EEC guidance	28
teratogenesis and fetotoxicity	38

TABLE 2. Endpoints Used for Scoring Environmental and Human Health Effects

Endpoint	System Number for Method Using this Endpoint [a]
Physical Hazard and Other Properties	**(15 systems)**
ignitability, flash point	2, 11, 22, 28, 35, 37
boiling point	2, 11, 28, 35, 51
reactivity, explosivity	2, 11, 22, 28, 35, 37
corrosivity	22
odor/taste and appearance	22
pH	22
molecular weight	28, 48
melting point	28
relative density	28
vapor pressure	28, 48, 51
surface tension	28
water solubility	28, 48
fat solubility	28
oxidizing properties	28
ecological risk reduction potential (ERRP)	43
human health risk reduction potential (HHRRP)	43
radionuclide dose factors	15, 48
welfare effects (recreation, aesthetics etc.)	23
gross alpha	16
Sax toxicity rating	14, 16
presence on CAA Amendments list	42
low Kow	51
other dangers not covered by specific criteria	12

(a) refer to Table 1 for the corresponding systems
(b) the number of systems listed in parentheses indicates how many of the evaluated systems consider some endpoint in the listed category
(c) criteria could apply to ecological and/or human receptors, depending on the system. Often, this distinction is not clear in the system documentation.

The *CERCLA HRS* (EPA, 1990) evaluates human health effects based on acute toxicity and two categories of chronic toxicity, which include cancer and non-cancer toxicological responses. The non-cancer score is based on the RfD, and the score for carcinogenicity is based on the q_1^*. The higher of the two chronic toxicity scores is the score assigned for human toxicity. Acute toxicity data are used to score human toxicity only in the absence of RfD and q_1^* data.

The *Ontario MOE Candidate Substances List for Bans or Phase-outs system* (Socha et. al., 1992) includes mammalian acute lethality, sublethal effects on mammals and chronic effects such as teratogenicity, genotoxicity/mutagenicity and carcinogenicity for evaluating human health effects.

Not only is there a wide variation of endpoints selected for assigning a score or scores in the area of human health effects, but the preference given to these endpoints may vary as well. For example, the *HRS* (EPA, 1990) prefers chronic toxicity data over acute data, whereas many other scoring systems include both. Often, the purpose or application of the system affects the choice of criteria to be considered.

Potency and Severity of Effects

Potency. The dose required to elicit a toxic effect is referred to as potency. Data regarding the potency of chemicals in test organisms are more frequently used to assess acute rather than chronic effects to terrestrial and aquatic plants and animals. For acute toxicity endpoints such as lethality, the dose required to elicit the effect (i.e. potency) is commonly reported (e.g. LC_{50}). Data regarding the potency of chemicals required to elicit chronic effects such as mutagenicity or carcinogenicity, however, are often limited.

Many ranking and scoring systems assign scores, particularly for carcinogenicity, based only on the weight of evidence that the chemical causes the effect in humans. Examples include:

- *Michigan CMR* (MDNR, 1987);
- *German Existing Chemicals of Environmental Relevance* List I and II (BUA; Behret, 1989a,b); and
- The *MOE Candidate Substance List for Bans or Phase-outs* (Socha et. al., 1992).

It is helpful to distinguish between a highly potent carcinogen and a moderately potent one, but the availability of potency data is limited. A few systems include both weight-of-evidence and potency data. For example, *GWU* (Foran and Glenn, 1993) assigns a score according to a matrix which includes a weight-of-evidence classification as well as the potency factor ($1/ED_{10}$) that has been used to assign reportable quantities for carcinogens by the CERCLA Section 102 program. In the *EPA DfE Use Cluster Scoring System* (EPA, 1993) weight-of-evidence is combined with the reportable quantity potency factor or the q_1^*. The *CERCLA HRS* (EPA, 1990) assigns values based on weight-of-evidence and the q_1^* or an estimate based on the ED_{10}.

Severity. Severity is a function of both the *type* and *magnitude* of the effect. The type of effect (e.g. a specific biochemical effect) reflects the mechanism of action as well as the target organ of a particular chemical. The magnitude of the effect (e.g. the percent change from normal of the biochemical effect) reflects the dose-response properties associated with a chemical (Environ, 1986).

Currently, there is no widely accepted method for incorporating severity into chemical ranking and scoring systems and many systems do not include measures of severity at all. This may yield misleading results. For example, two chemicals may have exactly the same NOEL of 0.3 mg/kg/day for neurotoxicity. Assigned scores based on the NOEL would be the same for these two chemicals, even though at similar doses one may cause a temporary narcotic effect and the other long-term irreversible brain damage. Below are examples of two systems that do include severity when scoring substances:

The *Toxic Substances Control Act (TSCA) System* (O'Bryan and Ross, 1988) includes severity in several parameters. For example, for nonlethal acute toxicity, the dose score is multiplied by the severity score to arrive at a final score in this category. The severity of effects are scored according to whether the effect is life-threatening or severe, moderately serious, mild, or no effects are observed at high doses.

The *Michigan CMR* (MDNR, 1987) also includes severity in several parameters. For example, a score for "other toxicity" (chronic or subchronic) to terrestrial animals includes severity ranging from adverse effects to severe effects. Examples of each effect classification are provided to guide decisions in response to the question of how severe is the effect. For example, "moderate effects" include effects such as degenerative or necrotic changes with no apparent decrement of organ functions; or reversible, slight changes in organ function.

2.3.3 Criteria and Endpoints for Environmental Effects

Overview of Environmental Effects

Ecological effects resulting from chemical exposure may occur in populations of organisms from many trophic levels. These include both terrestrial mammalian and non-mammalian species, aquatic organisms, and plants. Most ranking systems evaluate ecological effects through the use of toxicity test data. Typically, surrogate species are selected for use in the evaluation of the potential environmental hazards of chemicals.

When including toxicity information in a chemical ranking and scoring system, it is important to specify the following information regarding the endpoints to be considered (EPA, 1989d):

- organism tested or observed;
- nature of the effect;
- concentration or dose needed to produce the effect;
- duration of exposure needed to produce the effect; and

- environmental conditions under which the effects were observed.

Similar to tests used for evaluating human health effects, the durations for testing chemicals of ecological concern include acute, sub-chronic and/or chronic exposure periods. Observations include lethality as well as sub-lethal effects. Lethal doses directly disrupt important physiological functions and result in death. Sub-lethal toxicity may have long-term physiological or behavioral impacts on a population.

Terrestrial effects. Terrestrial organisms commonly considered by chemical ranking and scoring systems to be important receptors include mammals, non-mammals and plants. Most scoring systems do not make a distinction between mammalian toxicity and human health effects. At least two of the chemical ranking and scoring systems examined use the same endpoint for human health effects as was used to characterize terrestrial mammalian toxicity (rodent acute toxicity). Terrestrial non-mammalian data are usually derived from tests on avian species such as the mallard duck or ring-neck pheasant. Data for terrestrial plants are sometimes included, but such data are limited. Other organisms may be included as surrogates, but unfortunately, there is not a large data base of information regarding the effects of chemicals on most terrestrial organisms.

Aquatic effects. The aquatic receptors of interest in most chemical ranking and scoring systems include non-mammalian aquatic organisms and plants. The most common surrogates for evaluating the toxic potential of chemicals include fish, *Daphnia* and algae. There is a fairly large data base of information regarding the toxicity of chemicals to these organisms. The majority of available data are from short-term toxicity tests performed on these species, but in reality there is often greater concern regarding the effects of long-term exposure and effects. Additionally, the types of organisms most often tested are not necessarily those about which there is the most concern. Due to standardized test methods and data availability, however, it is reasonable to include these commonly tested organisms in chemical ranking and scoring systems.

The endpoints most frequently included in ranking and scoring systems for aquatic toxicity are the LC_{50} and the EC_{50}. The LC_{50} describes lethality and the EC_{50} describes the concentration at which there are observed effects in 50% of the test population. The effects may be behavioral or physiological and may indicate immobilization or changes in growth and reproduction, among others. Other endpoints, such as the no-observable-adverse-effect-level (NOAEL) or regulatory standards such as ambient water quality criteria (AWQC) may be included.

In the absence of data, there are over fifty high-quality quantitative structure-activity relationships (QSARs) for estimating biological effects in these three organisms (Clements, 1993). QSARs are discussed further in section 2.2.5.

Endpoints used for Environmental Effects

Endpoints used for environmental effects for each system are presented in Appendix C and are summarized in Table 2. (The use of criteria and endpoints is discussed further in section 3.2.1.) The following examples illustrate some of the types of data used to evaluate ecological effects:

The *Schmallenberg System* (Klein et. al., 1988; Weiss et. al., 1988) was developed by a group of French and German officials and scientists and uses many endpoints to assess ecological effects, including acute, subacute and chronic effects in algae, plants, earthworms, birds and fish.

The *GWU system* (Foran and Glenn, 1993) includes acute and chronic toxicity to aquatic organisms as well as terrestrial and avian species.

The *EPA Toxics Release Inventory Environmental Indicators Methodology* (Abt Assoc., 1992) scores ecological effects based on a matrix of aquatic toxicity and bioaccumulation. Aquatic toxicity is scored according to the LC_{50}, life cycle/chronic NOAEL, or other measures such as the Acute or Chronic Ambient Water Quality Criteria (AWQC). Bioconcentration is based on the water solubility, log K_{ow}, or bioconcentration factor (BCF).

The *EPA DfE Use Cluster Scoring System* (EPA, 1993) scores ecological hazard based on the AWQC (acute and chronic) or Aquatic Toxicity Reportable Quantities.

The *Michigan Critical Materials Register* (MDNR, 1987) scores acute and chronic effects on aquatic organisms (fish, invertebrates, amphibians), acute and chronic effects on terrestrial animals, and plants.

The SIDS database (Auer, 1992) includes the following ecotoxicological data:

- acute toxicity to fish;
- acute toxicity to daphnids;
- acute toxicity to algae; and
- terrestrial toxicity (if significant exposure in terrestrial environment or if aquatic toxicity testing is not possible).

2.3.4 Measures of Exposure

As stated earlier, chemical ranking and scoring systems span a wide range of complexity. The simplest level is to use toxicity data alone. When exposure is considered, the systems become more complex. In fact, the level of complexity is primarily a function of the degree of sophistication used to estimate exposure. In a quantitative risk assessment, a dose to each receptor from each potential pathway is estimated on a site-specific basis using measured or modeled concentrations for each potentially contaminated environmental medium. This approach represents a high degree of sophistication and is not used in most chemical ranking and scoring systems. In a simpler approach, production or use volume or TRI emission data are often used as surrogates for dose. An intermediate level of

sophistication might employ a multimedia fate and transport model to estimate the distribution of chemicals in the environment based on release data.

Many factors affect the potential for exposure to a chemical. These factors generally relate to properties of the chemical, characteristics of the human or environmental receptors of concern, amount of the chemical available for exposure, and the behavior (fate, transport) of the chemical in the environment. Appendix C and Table 3 present the measures of exposure used by the ranking systems evaluated. This is also discussed further in section 3.2.1. Examples of the use of these various measures for exposure follow.

The *WMS Scoring System* (Könemann and Visser, 1988; Timmer et. al., 1988) assigns scores for environmental exposure according to use volume, percentage release to the environment, degradation in air, soil and/or water, relative occurrence in these media and bioconcentration. Exposure via products is also scored, and this includes use patterns, exposure frequency and intensity of exposure.

The *GWU system* (Foran and Glenn, 1993) assesses exposure according to the bioaccumulation, persistence, and release or production volume.

The *Michigan CMR* (MDNR, 1987) scores chemical exposure according to bioaccumulation, persistence, and a few physicochemical properties such as flammability, reactivity, and corrosivity.

The *Effluent Monitoring Priority Pollutants List (EMPPL)* (Environment Ontario, 1987, 1988) includes environmental persistence, bioaccumulation and detection in the environment.

The *German Beratergremium für Umweltrelevante Altstoffe (BUA) System* (Behret, 1989a,b) includes bioaccumulation, persistence and production volume.

The *EPA Toxics Release Inventory Environmental Indicators Methodology* (Abt Assoc., 1992) uses facility-specific data and generic fate, transport, and exposure models to estimate a "surrogate dose", or the amount of chemical an individual might be exposed to. A separate evaluation is conducted for each release pathway allowing comparisons across media. The level of uncertainty is included in the scoring for exposure. Exposure of aquatic life is obtained by estimates of the ambient water concentration.

Table 3. Endpoints Used for Scoring Exposure

Endpoint	System Number for Method Using this Endpoint [a]
Degradation or Transformation Potential	**(25 Systems)[b]**
degradability in air, water, soil and/or sediment ($t_{1/2}$)	3, 4, 6, 9, 10, 20, 21, 22, 24, 25, 34, 48, 49
biodegradation	8, 19, 47
transformation	24, 45
oxidation	34
photolysis	9, 35, 47
hydrolysis	8, 9, 29, 34, 35
BOD 1/2 life, BOD_5/COD, BOD_{28}, BOD/ThOD	11, 12, 28, 29, 35
volatilization half-life	9
log K_{ow}	9, 43
qualitative degree of persistence/ expert judgement	16, 43
source existence (yrs)	16
EPA persistence rating scale	14
Mobility/Partitioning	**(30 Systems)**
adsorption (K_d, K_{oc})	8, 21, 34, 45
water solubility	1, 9, 11, 21
log K_{ow} (P, P_{ow})	1, 3, 4, 6, 9, 11, 12, 19, 20, 21, 22, 24, 25, 28, 34, 43, 47, 49, 51
BCF	1, 3, 4, 6, 9, 12, 17, 20, 22, 24, 25, 29, 39, 43, 49
BAF (some systems consider BCF=BAF)	10, 17, 22, 34
molecular weight (regarding bioconcentration)	11, 51
bioconcentration (yes/no)	45
vapor pressure	21
initial partitioning/transport	19, 24, 45, 47, 48, 51
evaporation	22
volatilization	9, 45
site-specific characteristics	16, 32
leaching potential	21
environmental transfer factors (e.g. soil to plants)	48

Table 3. Endpoints Used for Scoring Exposure

Endpoint	System Number for Method Using this Endpoint [a]
environmental spread/degree of mobility (qualitative)	28, 16
Estimated Dose, Environmental Occurrence, Concentration, or Releases (37 Systems)	
Dose estimate	
human exposure potential (mg/kg/day)	1
theoretical daily dose	2
estimated daily intake	32
chemical concentration, frequency or occurrence	
exposure to contaminant or medium containing contaminant	2
exposure via migration pathway	9
projected levels in various media/compartments	19, 46, 47,
estimated ambient concentrations	1, 7, 23
frequency of occurrence/application	2, 14, 21, 23, 34
occurrence in air/soil/water	3, 4, 20, 27, 39
measured concentrations	15, 26, 32, 40, 50
concentration of chemical introduced	21
Use, production amounts, release or emission data	
number of sites of discharge/use	34, 43
emission source data	36, 45
emissions estimates (rate,type,release height, temp.,flow rate,vent diameter)	36
TRI releases/transfers	5, 29, 42, 46
national emissions data (various sources)	7
release to environment (annual)	10, 24, 34, 41, 43, 44, 45
production volume	10, 11, 12, 19, 21, 24, 44, 51
import volume	11, 12, 51
waste volume	16
use volume	10, 20, 43
quantity on the market	28
release reduction potential	43

Table 3. Endpoints Used for Scoring Exposure

Endpoint	System Number for Method Using this Endpoint [a]
Exposure Frequency or Intensity (Receptor Characteristics) (11 Systems)	
use pattern	19, 20, 51
population size/number potentially exposed	1, 23, 24, 27, 28, 32, 43
land use	32
distance from site	32
presence of critical environments	32
intensity of exposure	20, 23, 24
length of exposure	23
probability of exposure	24
frequency of exposure	20, 23
plurality of exposure	28
geographical extent of exposure (ecological)	23

(a) refer to Table 1 for the corresponding systems
(b) the number of systems listed in parentheses indicates how many of the evaluated systems consider some endpoint in the listed category

The SIDS database (Auer, 1992) includes the following data to assess sources and levels of exposure:

- production ranges (metric tons per annum);
- categories and types of use;

and environmental fate and pathways:

- aerobic biodegradability;
- abiotic degradability (hydrolysis and photodegradation by estimation); and
- estimates of environmental fate, pathways and concentrations (including Henry's Law constant, aerosolization, volatilization, soil adsorption and desorption).

2.3.5 Missing Data, Data Selection Approach

Due to the extensive time and resources required to perform thorough testing of each of the thousands of chemicals in commerce, the available data necessary for complete assessment of the hazards of these chemicals are limited. Therefore, chemical ranking and scoring systems must somehow work in the absence of complete data sets for every chemical. An overview of the approaches for assigning values to criteria or endpoints used by the ranking systems evaluated can be found in Appendix C. Four general approaches were identified:

1. Assign one endpoint per criteria being assessed and estimate missing data (e.g. use oral LD_{50} for rats for acute human toxicity criteria). In the *UT system* (Davis et. al., 1993) there is only one endpoint specified for each criterion, and missing data are estimated using QSARs, surrogate chemicals, or other structure-activity relationships (SARs).

2. Choose data from a hierarchy of endpoints, listed in order of preference, based on data quality, appropriateness of test, etc. The *Chemical Use Cluster Scoring Methodology* (EPA, 1993) uses a data hierarchy based on data quality for scoring the toxicity components. Preference is given to high quality data as specifically defined in the document. Data of medium or low quality may be used in the absence of high quality data. When scoring non-carcinogens, the RfD and RQ are classified as "high quality" data whereas chronic and sub-chronic NOAELs are "medium quality". If multiple data are available within the high quality classification, then the data yielding the highest score (i.e. most conservative or health-protective) is used.

3. Choose the most conservative value from a pool of different endpoints. The *GWU System* (Foran and Glenn, 1993) is an example of a system where a group of endpoints could be considered for a given criterion, and the data yielding the most conservative (health-protective) result are chosen. If multiple data are available for a particular criterion (e.g. acute mammalian toxicity), then the data resulting in the highest score are used. One drawback that should be noted for such a system is that it does not encourage further testing of compounds, because it is unlikely that a score for a chemical can be lowered by filling data gaps.

4. Assign cutoff (or trigger) values to a large number of criteria and select a chemical if one or a specified number of the criteria are met. Several systems designed to select chemicals for regulatory action or for further study do not provide an overall score for a chemical. Rather, a chemical is selected if it meets certain criteria. Examples of this type of system include the *Michigan CMR* (MDNR, 1987), where a chemical is selected for regulatory action if it receives a certain score; and the *Candidate Substance List for Bans or Phase-Outs* (Socha et. al., 1992), where certain cut-off values are used to determine if a substance is to be considered as "persistent", "bioaccumulative" and/or "toxic". The primary list consists of substances considered to be all three of these.

For approaches where required data are not available, it is necessary to somehow estimate the missing data. SARs, QSARs, default values, and/or ad hoc expert judgement have been used in the absence of experimental data. SARs and QSARs are often used in many chemical scoring and ranking systems to estimate chemical properties for which data are lacking. SARs qualitatively relate known data from a chemical with similar molecular or molecular fragment structure, and therefore similar expected biological activity or other properties, to the chemical with missing data. QSARs are obtained primarily through regression analysis which results in mathematical equations representing correlations. Chemical structure or physicochemical properties, such as molecular weight and octanol-water partitioning coefficients, are typically compared with chemical toxicity or fate (Hermans, 1989). The limitations of these methods must be weighed against the impact of missing data on the results of a chemical ranking or scoring system.

Examples of systems that use SARs QSARs for predicting the effects of chemical exposure are discussed below.

The *Schmallenberg system* (Klein et. al., 1988; Weiss et. al., 1988) defines the minimum data set required for priority-setting. Data on mutagenesis and acute aquatic toxicity are essential and may be estimated by QSARs when necessary. Other important missing data can be estimated from QSARs, but any information, even if it is semi-quantitative in nature is considered.

The *German (BUA) scoring system* (Behret, 1989a,b) assigns negative scores where data are unavailable. These scores are based largely on SARs. The use of negative scores occurred for only a few chemicals evaluated by this system.

The *UT system* (Davis et. al., 1993) requires a quantitative assessment for many of the endpoints included in the algorithm. This is obtainable through the use of expert judgement, SARs or QSARs for estimation.

The *EPA DfE Use Cluster System* (EPA, 1993) allows a score for human health hazard potential to be assigned by a structure activity team. Ecological hazard potential may be scored according to QSAR concentrations of concern.

Another approach to filling data gaps results in the assignment of default values in the absence of data or reliable QSARs or SARs. The *European Communities (EC) system* (van de Zandt and van Leeuwen, 1992) uses default values and flags the data to identify when default values are used.

A few systems use expert judgement to give qualitative or semi-quantitative scores to chemicals (e.g. high, med., low). An example of a system using this approach is the *EPA Unfinished Business Report* (Morgenstern et. al., 1987). The project was described as being based on "informed judgement". Quantitative information available within the EPA was collected on the various environmental problems addressed, but because the qualitative judgement was extensive, the study results were not considered to be scientifically "reproducible".

2.3.6 Aggregation and Weighing

The majority of the chemical ranking and scoring systems reviewed include human health and environmental effects as well as exposure parameters. The manner in which these parameters are combined to give an overall ranking or risk categorization varies tremendously and significantly effects the final result. Scores may be added, multiplied, divided or not combined at all. Scores may be weighted differently for human versus environmental effects (e.g. *Screening Methodology for Pollution Prevention Targeting*, EPA, date unknown), acute versus chronic effects (e.g. EPA, 1990) or exposure via water versus exposure via air (e.g. Klein et. al., 1988; Weiss et. al., 1988). Examples of various aggregation and weighing methods follow.

Chemical selection in the *Michigan CMR* (MDNR, 1987) is based on combinations of scores in the various parameters. For example, selection for the Register may occur if a chemical scores a "5" in two or more criteria. These criteria include all of the health, environmental and exposure parameters where none are considered more important than the others.

The Nordic system (Gjøs et. al., 1989) selects chemicals with a score of "high" in an effects category (health or environmental) regardless of the exposure score or chemicals with an effect score of "medium" and an exposure score of "high".

The *WMS Scoring System* (Könemann and Visser, 1988; Timmer et. al., 1988) calculates ten scores for ten different combinations of exposure and effects. Examples of such combinations include 1) Exposure via air *and* general toxicity for mammals, carcinogenicity, and mutagenicity; and 2) Exposure via products *and* general toxicity for mammals, carcinogenicity, and mutagenicity.

In the *MOE Candidate Substance List for Bans and Phase-outs* (Socha et. al., 1992) substances are selected on the basis of combinations of scores in toxicity, persistence and bioaccumulation. For example, a substance is placed on the primary list if it scores a "10" in any one of the seven toxicity categories *and* has a persistence of a half-life of 50 days *and* it has a bioconcentration factor of more than 500.

In the *ATSDR Priority List* (ATSDR, 1992) scores are assigned for each of three criteria: frequency of detection at National Priorities List (NPL) sites, toxicity, and potential for human exposure. The total score is simply the sum of the scores assigned for each of these parameters.

Once scores are obtained for each of the various exposure and effects parameters, chemicals may be placed into categories, such as selected or non-selected chemicals, or they may be ranked in order of priority.

Categorization may be accomplished by determining an overall concern score of high, medium or low, or by selecting chemicals according to combinations of numerical scores in the exposure and effects categories. For example:

The *Schmallenberg system* (Klein et. al., 1988; Weiss et. al., 1988) scores chemicals and places them in one of three categories: immediate action, observation, or no action.

The *GWU Method* (Foran and Glenn, 1993) assigns scores of high, medium or low in several toxicity categories, release and production, persistence, and bioaccumulation. A chemical is selected as a candidate for Sunsetting if 1) it scores "high" in any toxicity category and "high" in release and production (excluding pesticides) or 2) it scores "high" in any acute or chronic toxicity category and "high" in persistence or bioaccumulation (including pesticides).

The *WMS Scoring System* (Könemann and Visser, 1988; Timmer et. al., 1988) categorizes chemicals into three areas of priority by plotting an image point on a two-dimensional diagram. The image point is determined after each chemical has been assigned a rank for exposure and effects.

The *MOE Candidate Substances List for Bans or Phase-outs* (Socha et. al., 1992) assigns numerical scores for environmental transport, persistence and bioaccumulation as well as seven categories for toxicity. Specific combinations of scores in these categories result in the inclusion of the chemical on the primary or secondary list for appropriate action.

The scoring systems which are designed to rank chemicals often include an algorithm for combining individual scores for toxicity and exposure in order to determine an overall score which represents a relative indicator of hazard for each chemical. These
ranking systems then prioritize chemicals in order of their potential hazard to human and environmental health. For example:

The *UT Method* (Davis et. al., 1993) uses an algorithm which includes both additive and multiplicative parameters to determine an overall hazard value for each chemical. The chemical rank indicates its hazard relative to the other chemicals that are scored.

The *ATSDR Method* (ATSDR, 1992) places 275 substances in order of hazard potential based on the total score. The total score is obtained by the following formula:

Total score = NPL frequency + Toxicity + Potential for human exposure

The *EPA DfE Use Cluster Scoring System* (EPA, 1993) arrives at an overall chemical score as follows:

Chemical score = Human risk reduction potential+Ecological risk reduction potential+EPA interest level

The average chemical score for the entire cluster is then added to the cluster score for pollution prevention potential to give an overall cluster score which forms the basis for prioritizing clusters.

Whether a method results in categorization or ranking of chemical substances will depend on the specific goals of the system. Systems developed for regulatory objectives frequently categorize chemicals by selecting those that pose the greatest potential threat for regulation and/or monitoring. Systems for prioritization for other purposes may rank chemicals in order to focus research or other activities on those chemicals highest on the list.

2.3.7 Other Issues

Other issues that can be considered in chemical ranking and scoring include:

- indirect ecological impacts, such as greenhouse gases, acid rain, eutrophication, and stratospheric ozone depletion;
- effect of chemical mixtures;
- application to life cycle assessment, specifically, life cycle impact assessment; and
- social or economic impacts.

Indirect Ecological Impacts

The release of chemicals into the environment can have direct effects on human health and the environment, but indirect effects may result as well. Certain substances are known to affect abiotic components of the environment and ultimately result in large scale ecological disruption. For example, a few substances (e.g. carbon dioxide) are considered "greenhouse gases" because they are believed to have the potential to change the global climate. Other examples of chemicals that may cause these indirect impacts are sulfur and nitrous oxides, which contribute to acid rain, chlorofluorocarbons (CFCs), which contribute to stratospheric ozone depletion, and nitrous oxides and volatile organic compounds (VOCs) which contribute to tropospheric (low atmosphere) ozone formation. Another example is eutrophication of surface waters caused by excess nutrient inputs.

Most chemical ranking and scoring systems do not include these types of indirect impacts as scoring criteria. The hazards posed by substances causing these effects have not been quantified in such manner that they can be easily included. This is not to say that the risks are not significant or that they should be ignored in chemical scoring. Ayres (1993), in an analysis of the relationship between natural resources and economic growth, concludes by asserting that "those activities that are most likely to interfere with natural climatological and nutrient cycling processes" should be of primary importance to both economic development and environmental protection policy.

Foran and Glenn (1993) list several reasons why there is no mechanism currently available for predicting or quantifying large scale ecological disruption. First, due in part to a lack of understanding of how hazardous compounds affect the structure and function of ecosystems it is difficult to predict the adverse impacts at an ecosystem or global level. Additionally, hazardous substances may interact with components of ecosystems, but due to a lack of understanding of the fate and transport characteristics of these substances, their effects on ecosystems are difficult to predict. It is important to have information about the use and release patterns of a chemical in order to predict large-scale ecological disruption, but this information is not generally available when a chemical is created and tends to change over time.

The *GWU system* (Foran and Glenn, 1993) considers evidence for ecological disruption when selecting candidates for Sunsetting. The data available are mostly derived from studies of effects in natural ecosystems, but other chemical-specific studies may be considered as well. Laboratory studies or theoretical evaluations that suggest ecological disruption potential must be supported by predicted use and release patterns of the substance.

The *TRI Environmental Indicators Methodology* (Abt Assoc., 1992) has not yet included scoring criteria for these effects, but it notes a major EPA project aimed at determining the risks associated with CFCs and their alternatives. The model is complicated but could perhaps be used to evaluate the risks posed by the emissions of these substances. Methods are also suggested for developing an indicator for tropospheric ozone. This would involve identifying all VOCs reported in the TRI that are considered to be ozone precursors and to sum the releases of these compounds from each facility.

Alternatively, policy changes which would require reporting of VOCs and nitrous oxides (NOx) as a group would help in the development of an indicator. The developers of the system are also examining models designed to determine the exposure resulting from particle deposition to evaluate the risks posed by airborne chemicals which are deposited into other media, such as surface water.

Because chemical ranking and scoring systems have focused on direct toxicity to humans and other organisms in the environment, indirect, large-scale impacts such as those discussed above have rarely been taken into account. Impact assessment approaches have been developed, and the challenge will be to incorporate these with the direct toxicological impacts. The field of life cycle assessment, discussed below in section 2.3.7.3 is one place where this challenge is being addressed.

Effect of Chemical Mixtures

The majority of toxicity tests are conducted for single chemicals, usually at high doses. Organisms in the environment, however, are more typically exposed to low levels of several chemicals rather than to one chemical at a time. Chemicals may interact with one another to elicit effects that are different from the combined effects of the individual chemicals. The effects may be additive, where the total effects approximately equal the sum of the individual chemical effects; synergistic, where the total effects are greater than the additive effects; or antagonistic, where the total effects are less than the additive effects. Other types of chemical interaction can also occur that result in unanticipated effects. There are limited data regarding the effects of chemical mixtures. One data source developed by the EPA (MIXTOX) contains summary information from and literature citations on studies of toxicological interactions, primarily for binary mixtures (EPA, 1992).

The chemical ranking and scoring systems evaluated do not consider the effects of chemical mixtures. Because they are not usually site-specific, they are designed to evaluate the general potential harm from substances on a chemical by chemical basis without regard to the effects of mixtures. It is difficult to predict the effect of chemical mixtures on humans and environment. If incorporation of mixture toxicity into chemical ranking and scoring systems is a goal, however, there is some evidence to suggest that real world situations involving many organic chemicals are likely to result in approximate additive toxicity (McCarty and MacKay, 1993).

Life Cycle Assessment

Recently, much attention has been focused on the methodology of LCA, a holistic approach to evaluating the human health and environmental burdens associated with a product or process life cycle. LCAs are tools for evaluating the effects on the environment associated with products, processes or activities (SETAC, 1993). A full LCA includes a quantitative inventory of resource and energy inputs and pollutant outputs and some form of impact assessment. A life cycle impact assessment is a process for assessing the potential and actual effects of environmental loadings identified in the inventory (SETAC, 1993). Chemical ranking and scoring could become an essential element in the development of tools for assessing the impacts to health and the environment from chemical releases throughout the life cycle of products.

LCA has several uses, although its uses are more limited if some form of impact assessment is not included. LCA can be used for internal product improvements, for designing new products, for setting public policy on products and materials, and for environmental labeling. Clearly, the different uses of LCA create different needs for impact assessment. An LCA used for internal product improvement, for example, might simply use the inventory component and operate on a "less-is-best" approach. An LCA used for setting public policy on materials or products would need to include some framework for assessing and comparing the significance of environmental releases and resource and energy use of the different products and materials being compared.

One of the systems evaluated was developed for life cycle impact assessment. The *EPS-Enviro-Accounting Method* (Steen and Ryding, 1992) was developed to assess the health and ecological effects associated with the entire life-cycle of a product, process, or activity. The main objective of the *EPS Method* is to provide one overall economic measure of resource depletion and potential health and environmental impacts throughout a life cycle.

In this system, values are assigned to impacts on the environment in terms of five 'safe-guard subjects' (human health, biodiversity, production, resources & aesthetic values) according to willingness to pay to restore them to normal status. Emissions, use of resources, and other human activities are then valued according to their estimated contribution to the changes in these safeguard subjects. The information on environmental impacts originates from LCA-based inventory of the materials/process under study.

Economic Considerations

Chemical ranking and scoring systems are usually designed to be fairly quick and simple, limiting the time and resources required for assessment to a minimum. It is usually beyond the scope of these systems to determine potential economic impacts caused by releases of a particular chemical.

One system that does include economic considerations is the *EPS Enviro-Accounting system* (Steen and Ryding, 1992) which is intended for life cycle impact assessment. Impacts on five safeguard subjects are valued on a relative scale which is based on the willingness to pay for avoiding undesired effects. Environmental load units (ELUs) which are standard monetary values, are assigned accordingly to score impacts. As another example, the *Unfinished Business Report* (Morgenstern et. al., 1987) considers monetary estimates of damage when categorizing environmental problems as they relate to welfare effects.

Social Values

Economic impacts can be included under the broader category of social welfare or social values. SETAC (1993, p. 20) outlines a variety of "social welfare impact categories"; some of these issues or impacts possibly relevant to chemical ranking and scoring include:

- demographic impacts, including fertility and mortality, morbidity, migration;
- sociopolitical impacts, including legal, governmental;
- social impacts, including quality of life;
- community impacts, including land use, physical appearance of community, community satisfaction;
- sociocultural impacts, including social justice, aesthetics, environmental values; and
- psychosocial impacts, including anxiety or stress.

Only a few systems include social considerations, per se, in the scoring or selection criteria. One example, The *Michigan Critical Materials Register* (MDNR, 1987) includes aesthetic considerations such as taste, odor and appearance as criteria for scoring chemicals within one parameter. The *Unfinished Business Report* (Morgenstern et. al., 1987), although not specifically a chemical ranking system, ranks issues related to social welfare such as recreation, losses in aesthetics and non-user values. The *EPS Enviro-Accounting method* (Steen and Ryding, 1992) includes aesthetic values as one of the five safeguard subjects for which impacts are evaluated.

SECTION 3: DISCUSSION

3.1 RISK ASSESSMENT PRINCIPLES APPLIED TO CHEMICAL RANKING AND SCORING

Chemical ranking and scoring systems are typically intended to be fairly simple and quick methods for determining the health and environmental hazards posed by the use and release of chemical substances. Although not intended to provide a quantitative assessment of risk, the majority of the systems reviewed do rely on the basic principles of risk assessment for chemical ranking and scoring.

Chemical risk is a product of both toxicity and exposure. Most chemical ranking and scoring systems include measures of both toxicity and exposure and, in this way, are similar to quantitative risk assessment methods. The major difference is the extent to which the exposure assessment is performed.

Exposure assessment in a quantitative risk assessment involves an analysis of contaminant releases, identification of exposed populations, identification of all potential exposure pathways, and estimation of exposure point concentrations and contaminant intakes. The exposure assessment results in an estimate of the magnitude, frequency and duration of actual or potential human exposures through various pathways expressed as a total dose. None of the chemical ranking and scoring systems reviewed include a detailed site-specific quantitative risk assessment, although the *(TRI) Environmental Indicators Methodology* (Abt Assoc., 1992) approaches this level of detail.

The system developed by Jones et. al. (1988) is one of the few systems that does not include any exposure assessment. The stated purpose of the system, however, is to estimate only the relative toxicological potency for hazardous substances rather than overall hazard. Another example is the method developed by the EPA (1993b) for demonstrating the relative hazard of emissions under section 112(g) of the Clean Air Act. As required, offsetting emission decreases must be considered "more hazardous" than emission increases. For categorizing emissions, toxicity criteria alone are considered. The Sax Toxicity Ratings (Sax and Lewis, 1989) is also based only on chemical properties posing a physical hazard and toxicological characteristics. The other systems reviewed include some measure of exposure, although the endpoints used to characterize exposure vary significantly.

The final step in a baseline risk assessment is risk characterization. Here, chemical toxicity data are combined with potential exposure levels for the receptors of interest at a site to arrive at a quantitative estimate of the risk that receptors will suffer adverse effects. Such site-specific characterization is not generally performed in chemical ranking and scoring, but most of the systems reviewed do combine toxicity and exposure in some manner to score, select, or prioritize chemicals. As discussed in Section 2.3.6, the manner in which toxicity and exposure are combined for an overall assessment also varies significantly.

3.2 SIMILARITIES AND DIFFERENCES AMONG SYSTEMS REVIEWED

3.2.1 Most Common Effects and Exposure Endpoints Used

The effects and exposure categories specified by the systems were difficult to compare. They were divided, as best could be done, into categories of commonly recognized criteria for presentation in Tables 2 and 4 and in Appendix C. More information is available in Appendix A , where the criteria, subcriteria, and endpoints as defined by each system are outlined. Some criteria and endpoints were commonly used in many systems while others were unique to a particular system. The most commonly listed endpoints for major classes of effects criteria include:

- *carcinogenicity*, *mutagenicity*, *genotoxicity*, most often characterized by the weight, type, or amount of evidence that a chemical would elicit that effect;
- *systemic (non-carcinogenic) or general health effects*, most commonly characterized by chronic or subchronic Rfd or RfC values;
- *aquatic toxicity*, most often quantified by acute LC_{50} and EC_{50} data;
- *mammalian toxicity*, most often quantified by acute LD_{50} and LC_{50} data;
- *developmental/reproductive toxicity*, again most often measured by the weight, type, or amount of evidence;
- *physical hazard*, most often characterized by ignitability, boiling point, and reactivity;
- *plant toxicity*, most commonly measured by EC_{50} data;
- *terrestrial non-mammalian toxicity*, most often characterized by acute LD_{50}; and
- *general ecological effects*, with no specific endpoint used by more than one system.

The most commonly listed endpoints for major classes of exposure criteria include:

- *degradation or transformation potential*: most commonly measured by half-life in the environment and some type of BOD data;
- *mobility and partitioning*, most often characterized by Kow and BCF;
- *estimated dose, environmental occurrence, concentration, or amount released*, most commonly measured by annual releases to environment and production volume; and
- *exposure frequency or intensity*, relates to potential receptors and usually is measured by population size or number potentially exposed.

The classes of criteria are listed in both cases in decreasing order from the most to the least often included as components of the evaluated systems.

3.2.2 Ranking versus Categorization

As mentioned in Section 2.3.6, there are two major types of chemical ranking and scoring systems; those that rank chemicals and those that categorize chemicals. Examples of categories that may be used include substances of high, medium or low concern or selected chemicals, non-selected chemicals

and chemicals for further review. Ranking systems, however, usually derive overall scores and rank chemicals relative to one another based on these scores.

In developing a consensus framework for chemical scoring, a decision must be made whether to use the system to rank chemicals, select or categorize chemicals, or rank and select chemicals. To a certain extent, this decision depends on the purpose of the system, but one disadvantage for a system that only categorizes or selects chemicals is that those selected substances cannot be further prioritized. For example, suppose such a system were used to choose a subset of chemicals that are considered to be of high concern from a regulatory perspective. If 200 chemicals meet the criteria to be considered high concern, there may need to be a means of further prioritizing these substances before regulatory policy decisions could be made. van de Zandt and van Leeuwen (1992) suggest that a ranking system is preferable to classification methods for this reason.

Three of the systems reviewed assign chemical scores which are not used to rank or categorize the chemicals. For example, the *TRI Environmental Indicators Methodology* (Abt Assoc., 1992) scores TRI chemicals to reflect the impacts of the releases and transfers. These numbers can then be compared from one year to the next to monitor changes in impacts. Chemicals are not ranked or selected.

Several systems assign chemical scores and rank the substances according to relative hazard. The priority list of substances prepared by the ATSDR (1992) is the result of ranking and scoring, in order of priority, chemicals commonly found at NPL sites.

Chemical ranking may be used for selecting chemicals for further review, regulatory action or some other activity. An example is the *Ranking System for the Clean Water Act* (Poston and Prohammer, 1985; Cornaby et. al., 1986) in which chemicals were ranked and then selected as candidates for possible inclusion on or deletion from the Priority Pollutant List. There are seven systems reviewed which result in both ranking and selection of chemicals.
Thirteen of the systems evaluated resulted in the selection or categorization of chemicals, mostly for regulatory purposes (ten systems), without first ranking them. An example of such a system is that developed by ICF (1990) for the EPA which selects chemicals as "High Priority Pollutants" if certain exposure and effects criteria are met. Another example is the *Michigan CMR* (MDNR, 1987) which is derived from scoring chemicals for various exposure and effects criteria. Chemicals are then selected for inclusion in the Register if they receive a score a "5" (the maximum score) in two or more criteria or score an additive level of "15" or greater for all criteria. Chemicals are chosen for more detailed scrutiny if other similar criteria are met.

3.2.3 Quantitative versus Qualitative Endpoints

Chemical ranking and scoring systems are basically quantitative in nature, oftentimes resulting in ranking or selection based on numeric cut-off values for various criteria. The assignment of scores for specific endpoints, however, is not always based on quantitative data. Many of the systems reviewed include a

combination of both qualitative and quantitative endpoints. Particularly for chronic health effects, such as carcinogenicity, qualitative data are essential. A large number of the systems which include carcinogenicity as a scoring criterion utilize weight-of-evidence and/or strength-of-evidence information. Sometimes, as in the *GWU system* (Foran and Glenn, 1993), these qualitative data are combined with quantitative potency estimates where available. Qualitative data are also used frequently in the absence of quantitative data for certain criteria. For example, the *BUA system* (Behret, 1989a,b) assigns negative scores where qualitative information is utilized in the absence of a desired quantitative endpoint. When there is no data such as the K_{ow} or bioconcentration factor (BCF) regarding bioaccumulation, then a score of -1 is assigned if there is no suspicion of bioaccumulation or a -2 if bioaccumulation potential is suspected. Qualitative data, such as SARs, are frequently used to fill data gaps.

3.2.4 Assigning Scores to Endpoint Data

For those systems where there is agreement on which particular endpoint to use, there still exists a variety of approaches to assign corresponding numerical scores. To illustrate this, BCF is used as an example of an endpoint included in several systems and scored in a variety of ways. Table 4 presents the numerical scores assigned to BCF or log BCF by eight systems. For comparison purposes, all BCF data are converted to log BCF and the scores are normalized on a scale of 0 to 1 corresponding to the minimum and maximum value assigned by the system. This information is also presented graphically in Figure 1.

A few items are worthy of note. First, there is a noticeable lack of agreement; the eight systems represented here use seven different schemes to assign values to BCF data. Second, the majority of systems use some kind of step function to assign values to endpoint data (i.e. if log BCF is between 3 and 4, then assign a value of x). One exception is the *UT system*, which uses a continuous linear function with upper and lower bounds. The systems that use step functions use different numbers of steps. The *BUA system* has only two; it simply assigns a minimum score if the log BCF is less than 2 and a maximum score if it is greater than 2. Several others use five steps. Finally, it can be seen that different systems assign varying levels of significance to BCF values. The BUA system considers a log BCF of 2.1 to be of maximum significance, while, for this same BCF value, the *Michigan CMR* assigns a relatively low value and the *UT system* assigns a mid-range score.

Similar evaluations could be useful for all endpoints included in a chemical ranking and scoring system, but are beyond the scope of this report.

TABLE 4. Bioconcentration Factor (BCF) Scores for Several Systems

System name (System no.)	BCF	Log BCF	Score	Normalized score [a]
Candidate Substance List for Bans or Phase-outs (6); Effluent Monitoring Priority Pollutant List (EMPPL) (25); Canadian Accelerated Reduction/Elimination of Toxics (ARET) Scoring Protocol (49)	>15,000	>4.2	10	1.0
	500 - 15,000	2.7 - 4.2	7	0.7
	20 - 500	1.3 - 2.7	4	0.4
	≤20	≤1.3	0	0
Michigan Critical Materials Register (MCMR) (22)	≥100,000	≥5	S(sufficient)	1.0 [b]
	10,000 - 99,999	4 - 5	5	0.71
	1,000 - 9,999	3 - 4	3	0.43
	100 - 999	2 - 3	1	0.14
	<1 - 99	<2	0	0
WMS Scoring System (20)		>3	2	1.0
		1.5 - 3	1	0.5
		<1.5	0	0
Chemical Scoring System for Hazard and Exposure Identification (TSCA) (24)	≥1000	≥3	9	1.0
	200 - 1,000	2.3 - 3	7	0.78
	100 - 200	2 - 2.3	5	0.56
	10 - 100	1 - 2	3	0.33
	<10	<1	0	0
TRI Environmental Indicators Methodology (1)	>10,000	>4	50,000	1.0
	1,000 - 10,000	3 - 4	5,000	.79
	100 - 1,000	2 - 3	500	.57
	10 - 100	1 - 2	50	.36
	1 - 10	0 - 1	5	.15
	<1	<0	0.5	0
Existing Chemicals of Environmental Relevance (BUA) I & II (3,4)	>100	>2	2	1.0
	<100	<2	0	0
UT Method (29)		>4	2.5	1.0
		1 - 4	0.5logBCF+0.5	(calc)
		≤1	1	0.4

(a) normalized on a scale from 0 to 1 by dividing each score by the maximum score for that system
(b) normalized assuming a maximum score of 7

Figure 1

3.3 GENERAL STRENGTHS AND WEAKNESSES OF EVALUATED SYSTEMS

A detailed critique of all fifty-one systems reviewed is beyond the scope of this report. Instead, a general discussion is presented for consideration either in choosing an existing system, or in developing a new or hybrid system. Van de Zandt and van Leeuwen (1992) suggest that a priority setting system should be:

- quick to use as a screening tool to identify priority substances for further review;
- systematic and computerized;
- transparent, with methodologies described in detail for clarity to the user
- flexible;
- accurate, avoiding too many false positives or negatives and working with available data to give consistent results;
- based on a scientifically justifiable framework and generally accepted methodologies; and
- based on exposure and effects, with emphasis on long-term effects.

These aspects, along with a few additional issues we have identified, are discussed below:

Ease of use, complexity. The EPA chemicals of potential concern selection process is simple and straight forward when concentration data are available. The required toxicity data, however, are readily available for only a limited number of chemicals. The *TRI indicators methodology* is very complex and amounts to practically conducting a quantitative risk assessment at every facility that reports TRI releases. The time and resources required is an important deciding factor in choosing or developing a method. Also, the mathematical or mechanical processes of scoring and ranking should be straight forward enough so that the system is *transparent* to the user. It should easy to understand the results given a basic knowledge of the chemicals and data used.

Flexibility. A system should have enough flexibility so the user can augment or simplify it, add or subtract components, add new data as they become available, or change the weighing for various criteria while the system maintains its integrity. The *UT system* is an example of a relatively flexible system.

Availability of data. Many systems require data that either are not readily available or frequently require estimation methods. As much of the required data as possible should be peer-reviewed. The *Use Cluster Scoring System* (EPA, 1993) draws on a number of possible endpoints, arranged in a hierarchy for high, medium and low quality data. This data selection approach allows the user to draw from a much wider range of data, and should result in fewer instances of missing data.

Comparability to other systems. Ranking and scoring results, especially when regulations are involved, should be comparable across regulatory programs and across industries. Ideally, they should also be

comparable on an international basis. One example where international comparability could be important is where trade issues are involved. Three of the evaluated systems (the *Canadian Substance List for Bans or Phase-outs*, the *EMPPL system*, and the *ARETS Scoring Protocol*) use the same scoring criteria, based on the MOE scoring criteria, although their selection processes differ slightly. Otherwise, there is little consistency among the evaluated systems.

Number of chemicals the existing system has been demonstrated on. Some systems may seem like a good idea, but may disintegrate under the pressure of a large number of chemicals. A few of the evaluated systems were presented only in theory, with no demonstration using real chemical data. Others have been demonstrated or used on hundreds of chemicals. For example, over 700 chemicals were ranked by the *CERCLA 104 Priority List system* (ATSDR, 1992), and van de Zandt and van Leeuwen (1992) addressed 2000 HPV chemicals in the *Priority Setting of Existing Chemical Substances system*.

Applicability to various classes of chemicals. Ions, metals and radionuclides pose problems that are very different from organic compounds. For example, many QSAR or SAR estimation methods do not apply to inorganic chemicals. The *CERCLA HRS system* (Hallstedt et. al., 1986) was intended only for ranking organic compounds, but has been modified to include radionuclides in the site ranking process (Hawley & Napier, 1985).

Reproducibility or subjectiveness of scoring methods. Results from a panel of experts or when qualitative estimations are used may not be reproducible at different times or when applied by different users. For example, the *WMS Scoring System* relies an a panel of experts to score chemicals; if used in another application, different experts could arrive at different scores for the same chemicals. In addition, a system should be based on scientific principles and an understanding of risk assessment methodologies.

Completeness. All potential and important effects should be included in a system. The following components should be included, or the decision not to include a component should be made clear:

- the purpose and application of the ranking and scoring system;
- the human health criteria and endpoints included;
- the criteria and endpoints included for environmental effects;
- whether measures of exposure are included;
- the data selection approach and handling of missing data;
- the use of aggregation and weighing of different health and environmental impacts;
- methods of accounting for chemical potency and severity of effects; and
- inclusion of other impacts or issues.

SECTION 4: CONCLUSIONS

This review of various chemical ranking and scoring systems demonstrates that there is currently no consensus regarding an appropriate framework for evaluating adverse impacts to human health and the environment from exposure to chemical substances. There is much variation in the degrees of sophistication, the types and numbers of endpoints incorporated, the data selection approach and the manner of weighing and/or combining scores to arrive at a final assessment.

Clearly, the purpose for which the ranking or scoring tool is intended will affect these factors. Although the intended purpose of a ranking or scoring system can influence its design, it would be useful to develop a standard framework for chemical ranking and scoring that is flexible enough to be adapted for most purposes. A standardized system for ranking and scoring chemicals is desirable for several reasons. It could assist business and regulatory agencies to target their pollution prevention efforts; enable environmental policy and business decisions to be made on similar, objective, and scientifically-based methods; provide consistency nationally across regulatory programs as well as internationally; make use of and build on previous experience gained from the development of existing systems; allow new information to be incorporated while maintaining system integrity; and save on time and expense incurred by continuing to develop new systems from scratch with every new application.

Due to the large variation among ranking systems in terms of criteria, endpoints, data selection approaches, and scoring methods, one logical way to approach a consensus on methods would require the following steps (illustrated in Figure 2):

- Develop a consensus on the overall framework for chemical ranking and scoring, including its component parts: criteria, endpoints, data selection approach, and scoring formula;

- Work toward agreement on the component parts, such as:

    - which criteria should be included in any chemical ranking and scoring system
    - which endpoint(s) should be used to measure or score that criteria
    - what data selection approach should be used to select or estimate data for the criteria
    - how should criteria scores be weighted and combined to reach an overall score or rank for each specific chemical (if an overall score per chemical is the goal)

Figure 2

- what level of sophistication in exposure estimation is appropriate - from total amounts produced, used or released, to multimedia environmental fate models, to site-specific models including estimates of dose over time

- Reassemble these elements into the agreed-upon framework, providing flexibility to use some or all of the components for specific purposes.

The process of developing the consensus framework should involve all of the significant stakeholders - government agencies, chemical manufacturers and users, environmental and consumer groups, and academic researchers. This will create greater acceptance of the results.

Given the current interest in chemical ranking and scoring, and the many potential applications, an effort to develop a consensus framework for chemical ranking and scoring would be an important contribution to reducing chemical risk.

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APPENDIX A
SUMMARIES OF RANKING AND SCORING SYSTEMS

System Summary 1

Toxics Release Inventory (TRI) Environmental Indicators Methodology

References

Abt Associates, Inc. (1992). Toxics Release Inventory Environmental Indicators Methodology. (Draft Report). By Abt Associates, for U.S. Environmental Protection Agency (EPA) Office of Pollution Prevention and Toxics.

Developed for Use by: EPA Office of Pollution Prevention and Toxics

Purpose: "The ultimate goal of the indicator effort is to devise a measure that reflects the impacts of chemical releases and transfers, which can be used to assess progress in reducing these impacts over time"

Chemicals Addressed: TRI chemicals

Summary of Method or Algorithm

Each indicator (e.g. for human health chronic impacts) is determined by 4 components:

- the quantity of the chemical released or transferred
- a toxicity adjustment
- an adjustment reflecting the size of the potentially exposed population, and
- an exposure potential adjustment

"Separate assessments are made for each unique combination of a chemical, facility and release medium. For each of these releases or transfers, one develops an indicator 'element': a unitless value proportional to the potential impact of each specific release or transfer." The TRI indicator is the sum of all indicator elements.
An indicator element is calculated for human health and ecological impacts according to the following algorithms:

<u>human health chronic indicator</u>
Indicator element $_{i,j,k}$ = Toxicity weight $_{i,j,}$ x Exposure weight $_{i,j,k}$ x Adjusted population $_{jk}$, for chemical $_{i}$; facility $_{j}$; and medium $_{k}$

<u>Ecological chronic indicator</u>
Indicator element $_{i,j,k}$ = Toxicity weight $_{i,j,}$ * Exposure weight $_{i,j,k}$,
for chemical $_{i}$; facility $_{j}$; and medium $_{k}$

Simple sum of component scores: $I = S_1 + S_2 + S_3 \ldots S_R$

where I = TRI indicator of interest
S = facility-chemical-medium specific indicator element
Then normalize simple sum to a base year to track progress

Criteria, Subcriteria, and Endpoints

Mammalian Toxicity
- Carcinogens
  - Weight of evidence
    - • EPA Risk Assessment Guidelines
    - • TSCA Chemical Scoring System Category
  - Potency
    - • EPA q_1*
    - • ED_{10}
- Non-carcinogens
  - RfDs when available, use the following if RFDs are not available
  - WOE for
    - • genotoxicity
    - • developmental effects
    - • mutagenicity (EPA)
  - - "Similar weighting systems need to be developed for neurotoxicity, reproductive toxicity and other chronic toxicity endpoints"
  - Potency (all human-adjusted)
  - • minimum effective dose (MED)
  - • lowest-observable-adverse-effect level (LOAEL)
  - • no-observable-adverse-effect level (NOAEL)

Aquatic Toxicity
- Aquatic toxicity category
  - • life cycle or chronic NOAEL
  - • LC_{50}
  - • acute Ambient Water Quality Criteria (AWQC)
  - • chronic AWQC
- Bioaccumulation
  - • water solubility (mg/L)
  - • log K_{ow}
  - • BCF

Human Exposure Potential
- • surrogate dose (mg/kg day)
- • uncertainty estimate

Ecological Exposure
- • estimated ambient water concentration

Population Size

Data Selection Approach

Note that this is a draft report. There are issues related to the specific methodology of the developed indicators and the development of additional indicators that are not yet resolved. In general, the final toxicity weight will be the highest weight it receives among all of the endpoints considered. Exposure is modelled, and the system works with data gaps. SARs may be used in some cases.

System Summary 2

The CERCLA 104 Priority List of Hazardous Substances That Will be the Subject of Toxicological Profiles

References

Agency for Toxic Substances and Disease Registry (1992). *Support Document: The CERCLA 104 Priority List of Hazardous Substances That Will Be The Subject of Toxicological Profiles.* U.S. Public Health Service, Department of Health and Human Services, Washington, D.C.

Developed for Use by: ATSDR and EPA

Purpose

As required by CERCLA section 104, the ATSDR and EPA must prepare a list, in order of priority, of substances, that are most commonly found at NPL facilities and which are determined to pose the most significant potential threat to human health. Substances on the priority list are candidates for toxicological profiles prepared by the ATSDR.

Chemicals Addressed: Over 700 substances found at three or more NPL sites

Summary of Method or Algorithm

Scores are assigned to every chemical in three categories including toxicity, frequency of occurrence at NPL sites and potential human exposure. The final score is the sum of the three scores:

Total Score =	NPL frequency score	+	Toxicity score	+	Potential human exposure score
	(1800)		(600)		(600) (300 conc) + (300 exposure)

Criteria, Subcriteria, and Endpoints

Frequency of Occurrence at NPL Sites
- Frequency as reported in ATSDR's HazDat database

Toxicity
- Reportable quantity (RQ), or
- Toxicity/Environmental Score (TES); based on RQ methodology, including:
  - Ignitability/Reactivity
  - Aquatic Toxicity
    - LC_{50}
  - Mammalian Toxicity
    - Oral LD_{50}
    - Dermal LD_{50} or
    - Inhalation LC_{50}
  - Chronic Toxicity
    - minimum effective dose (MED)
    - rating values (R_V) 1 - 10 based on severity of effect
  - Carcinogenicity
    - EPA weight-of-evidence
    - Potency (high, medium, low)
  - Biodegradation/Hydrolysis/Photolysis Adjustment

Potential for Human Exposure

Concentration
- theoretical daily dose (from measured site concentrations in HazDat database)

Exposure
- Exposure to or potential exposure to contaminant
- Exposure to or potential exposure to medium containing contaminant

Data Selection Approach

All data are required. In the absence of an RQ, a toxicity/environmental score (TES) is calculated, based on the RQ methodology. In some cases, TESs are assigned based on the RQs for structurally-similar substances if relevant data are lacking. The RQs and TESs are based on a pool of criteria, with the most conservative value determining the score. Adjustments may be made based on biodegradation, hydrolysis or photolysis.

Potential for human exposure scores are based on available concentration data (or population data in its absence) and a score for exposure or potential exposure to contaminants.

System Summary 3

Existing Chemicals of Environmental Relevance /
Beratergremium für Umweltrelevante Altstoffe (BUA)

References

Behret, H. (Ed.). (1989). *Existing Chemicals of Environmental Relevance.* GDCh-Advisory Committee on Existing Chemicals of Environmental Relevance. VCH Publishers, New York.

Developed for Use by: Society of German Chemists (GDCh)

Purpose

To select chemicals (60) which must be examined as to whether they warrant regulatory action to be taken, as provided for in 84(6) of the German Chemicals Act.

Chemicals Addressed

13 international lists including organics and inorganics
There are 2 categories of lists:

1) chemicals which occur in the environment; and
2) chemicals of industrial importance

Summary of Method or Algorithm

The selected chemicals show the highest scores for the following criteria

- Occurrence in the environment (air or water) and
- Degradability (in air or water)

and at least one of the following

- Bioaccumulation potential
- Acute aquatic toxicity
- Acute toxicity to mammals
- Indications of mutagenic or carcinogenic properties

Criteria, Subcriteria, and Endpoints

Occurrence in environment (concentration or qualitative indication)
- occurrence in water, soil
- occurrence in air

Degradability
- degradability in water (measured or qualitative indication)
- degradability in air (tropospheric half-life or qualitative indication)

Bioaccumulation
- log P_{ow}
- BCF
- qualitative indication

Acute aquatic toxicity
- LC_{50}, fish
- EC_{50}, daphnia
- qualitative indication

Acute mammalian toxicity
- oral LD_{50}
- dermal LD_{50}
- inhalation LC_{50}
- qualitative indication

Indication of Mutagenic/Carcinogenic Properties
- type of effects or qualitative indication (weight-of-evidence ratings not discussed)

Data Selection Approach

A minimum data set is needed, including occurrence, degradability and effects data. Chemicals lacking sufficient data cannot be prioritized, but are rather placed on a "waiting list". However, data for all effects criteria are not necessary due to the selection criteria. Negative scores indicate estimations or suspicion of effects. The scoring procedure follows, in principle, the procedure used by the U.S. Interagency Testing Committee.

System Summary 4

BUA Second Priority List

References

Behret, H. (Ed.). (1989). *Existing Chemicals of Environmental Relevance II, Selection Criteria and Second Priority List.* GDCh-Advisory Committee on Existing Chemicals of Environmental Relevance. VCH Publishers, New York.

Developed for Use by: Society of German Chemists (GDCh)

Purpose

To select existing substances of recognized environmental relevance in response to government authorization contained in 84(6) of the German Chemicals Act.
This is the second list with 75 substances (does not included 60 from first list).

Chemicals Addressed

13 international lists including organics and inorganics
There are 2 categories of lists:

1) chemicals which occur in the environment; and
2) chemicals of industrial importance

Summary of Method or Algorithm

Priority is given to substances with high effects potential or high environmental exposure if these substances are not degradable in water and air. Two chemical groups are selected.
Group I: substances probably not degradable with high biological effects potential, based on:

- acute aquatic, acute mammalian, or mutagenicity/carcinogenicity; and
- poor degradability in water or air

Group II: substances probably not degradable with high environmental exposure potential, based on:

- occurrence in air and hardly degradable in air
- occurrence in water and biologically non-degradable in water

Selection was further refined based on substance domestic production rate.

Criteria, Subcriteria, and Endpoints

Occurrence in environment (concentration or qualitative indication)
- occurrence in water, soil
- occurrence in air

Degradability
- degradability in water (measured or qualitative indication)
- degradability in air (tropospheric half-life or qualitative indication)

Bioaccumulation
- log P_{ow}
- BCF
- qualitative indication

Acute aquatic toxicity
- LC_{50}, fish
- EC_{50}, daphnia
- qualitative indication

Acute mammalian toxicity
- oral LD_{50}
- dermal LD_{50}
- inhalation LC_{50}
- qualitative indication

Indication of Mutagenic/Carcinogenic Properties
- type of effects or qualitative indication

(those receiving highest score are further differentiated on weight-of-evidence ratings)

Production in the Federal Republic of Germany (tons/annum)

Data Selection Approach

A minimum data set is needed for Group I selection, including at least one toxicity endpoint (most conservative, of several) and at least one of the degradability endpoints. For Group II selection, one degradability (determined by several methods) and one occurrence data point are necessary. Estimations for some endpoints may be calculated. Negative scores indicate estimations by SAR.

System Summary 5

Region VII Toxics Release Inventory
Geographic Risk Analysis System (TIGRAS)

References

Bouchard, D. (1991). *Review of Region VII TRI Strategy*. (Memo, EPA Region VII).

Developed for Use by

Region VII TRI work group ("Friends of TRI")

Purpose

To develop user-friendly tools for relative risk screening based on TRI releases for specified geographic areas. It ranks risk to both human and ecological health from TRI releases.

Chemicals Addressed

TRI chemicals

Summary of Method or Algorithm

Components of TIGRAS (Toxics Release Inventory Geographic Risk Analysis):

1. TRI/GIS interface: the user selects a base map by country or zip code, identifies stressors (currently includes only TRI data) and year or years as well as TRI release media. A map is created.
2. Risk Screening Module: includes human health risk analysis and ecological risk analysis.

Scores for human health and ecological risk are not combined for an overall score.

Criteria, Subcriteria, and Endpoints

Human health risk analysis
- Toxicity (relative toxicity parameter, RTP)
  - Acute effects
    - inhalation, non-cancer
      - • endpoint not specified
    - ingestion, non-cancer
      - • reciprocal of 10-day health advisory levels from ODW for a 10-kg child
      - • adjusted subchronic RfD (could fill data gaps)
  - Chronic effects
    - inhalation, cancer
      - • unit risk factors from IRIS, HEAST
    - ingestion, cancer
      - • unit risk factors from IRIS, HEAST
    - inhalation, non-cancer
      - • reciprocals of RfCs from IRIS, HEAST
    - ingestion, non-cancer
      - • reciprocals of RfDs from IRIS, HEAST or ODW
- Loadings
  - • Relative daily toxic loading (RDTL), where:
    RTDL = TRI release x RTP

Ecological Risk Analysis (aquatic ecology)
- Toxicity (relative toxicity parameter, RTP)
  - Acute effects
    - • 48-hr LC_{50} (daphnia, fish)
    - • LC_{50}, population growth (PGR) or lethality (LET) (algae)
- Loadings
  - • Relative daily toxic loading (RDTL), where:
    RDTL = TRI release x RTP / stream volume

Data Selection Approach

All data are not required, but only chemicals with similar data can be compared. Real data are needed to calculate relative toxicity parameters (RTPs) for all toxicity criteria, however, one RDTL will be calculated, and comparison can only be done when RDTLs are calculated from similar RTPs. Therefore data for all toxicity criteria are not required. A data hierarchy is specified for some criteria. Other data for loading (releases) and stream volume are needed. Due to lack of data, human health risk analysis will be used as a surrogate for terrestrial animals.

System Summary 6

Candidate Substance List for Bans or Phase-outs

References

Socha, A.C., T. Dickie, & R. Aucoin, R.V. Angelow, P. Kauss, and G. Rutherford (1992). *Candidate Substances List for Bans or Phase-Outs*. Ontario Ministry of the Environment. ISBN 0-7729-9764-0.

Developed for Use by

Ontario's Ministry of the Environment

Purpose

To identify substances released into or present in Ontario's surface waters which pose the greatest hazard, based on their potential to cause adverse impact on the environment.

Chemicals Addressed

800 substances known as the "MISA Primary Group", which includes inorganics, organics and pesticides.

Summary of Method or Algorithm

Chemicals are selected for inclusion on a primary list or one of three secondary lists if certain criteria are met. The primary list is composed of chemicals considered to be:

persistent: $t_{1/2} > 50$ days in water, soil, sediment or sludge;
bioaccumulative: BCF > 500 or $4.0 < \log k_{ow} < 7$;
and toxic: Receives highest score in any one toxicity category.

A substance is considered to be toxic if it meets any one criterion on a list of several criteria which generally correspond to a score of 10 from the MOE scoring criteria.

The secondary lists are:

A: toxic and persistent or bioaccumulative
B: persistent and bioaccumulative and toxicity score = 8 in at least one toxicity category
C: persistent or bioaccumulative and toxicity score = 8

Criteria, Subcriteria, and Endpoints

(Based on MOE scoring criteria)

Persistence
- t ½ in water, sediment or soil

Bioaccumulation
- fish BCF
- log k_{ow}

Toxicity

Acute lethality
- oral LD_{50}
- dermal LD_{50}
- inhalation LD_{50}
- aquatic LC_{50}

Chronic/Subchronic Toxicity

aquatic biota (different genera)
- EC_{50}
- MATC
- NOAC

terrestrial non-mammals (different genera)
- subchronic effects
- chronic effects

plants

for aqueous, air and soil media:
- NOAEL or $\leq$5% effect
- EC_{50} or >5 - 50% effect
- >50% effect

mammals

oral NOAEL, $\geq$90 days or 28-90 days

inhalation NOAEC, $\geq$90 days or 28-90 days

Teratogenicity
- observed effects (effective dose)

Carcinogenicity
- IARC or EPA Classification

Data Selection Approach

Selected chemicals are considered to be toxic, persistent and bioaccumulative. Toxicity may be determined by any one of several endpoints for acute or chronic toxicity. Data are needed for persistence in water, soil, sediment *or* sludge. Bioaccumulation (BCF) data are essential and may be estimated by log k_{ow}.

System Summary 7

Criteria for Identifying High Risk Pollutants

References

Criteria for Identifying High Risk Pollutants. *Environmental Reporter* (pp. 463-465). (BNA)(1991)Bureau of National Affairs, Inc, Washington, D.C.

Developed for Use by: EPA

Purpose

A ranking of hazardous air pollutants is required by some provisions of Section 112 of the Clean Air Act Amendments. It is intended to limit the use of off-setting reductions in emissions of hazardous air pollutants by other hazardous air pollutants.

Chemicals Addressed: Hazardous air pollutants (HAPs)

Summary of Method or Algorithm

The screening analysis evaluates hazardous air pollutants in a three-tiered approach.

Tier I: Selected chemicals for which the available health effects data for a pollutant met certain criteria:

Potential carcinogens

a) had EPA-approved potency factor

b) had high concern designation for carcinogenicity potential in CERCLA section 102

Non-carcinogens and carcinogens causing other health effects

a) had EPA-verified RfD or RfC

b) had appropriate data from RTECS

Tier II: To determine which of the remaining pollutants merited further analysis, based on standardized risk calculations

Carcinogens

- calculated on acceptable risk 'benchmark' concentration; pollutants are selected if they exceeded the benchmark at 10 tons/year

Non-carcinogens

- modelled ambient concentrations > RfC or RfD by at least 1 order of magnitude
- ambient concentration > LOEL or LD_{50} / uncertainty factor

Tier III: "Review of nation-wide emissions data"
If one or more sources exceeded the benchmarks (from Tier II) with reported emissions of a listed pollutant, the pollutant was selected as a high-risk pollutant.

Criteria, Subcriteria, and Endpoints

Health effects

Carcinogenicity

- potency factors
- weight -of- evidence (EPA)
- CERCLA Section 102 hazard ranking

Reproductive and developmental toxicity

- LOEL

Acute lethality

- LD_{50}
- LC_{50}

Systemic effects (other than acute lethality)

- inhalation RfC
- oral RfD
- LOEL (oral, inhalation or dermal)

Exposure

- estimated ambient air concentration (using EPA's Human Exposure Model)
- national emissions data

"Both human and animal studies for each health effects category were examined and data from studies involving inhalation, ingestion, and dermal routes of exposure were considered."

Data Selection Approach

A data hierarchy is specified for toxicity information. Exposure is modelled in the Tier II analysis and TRI data, or other similar data are necessary in the Tier III analysis.

System Summary 8

A Classification System for Hazardous Chemical Wastes

References

Crutcher, M.R., & F.L. Parker (1990). A Classification System for Hazardous Chemical Wastes. Superfund 90, Hazardous Materials Control Research Institute, 11th Annual National Conference, 222-225.

Developed for Use by

Those who manage and dispose of hazardous chemical wastes

Purpose

"A simple, quick method of ranking hazardous substances can be used to assist managing the disposal of these substances"

Chemicals Addressed: Six organic compounds and lead

Summary of Method or Algorithm

A hazard potential number which considers toxicity, adsorption potential and degradation potential is determined according to the following equation:

$$HPN = 10^6/(K\ Tox)$$

HPN = hazard potential number
Tox = maximum concentration level related to an adverse effect (mg/l)
K = adsorption or distribution coefficient (ml/g)

Then the degradation process is considered and the HPN may be determined by the following equation:

$$HPN = HPN_o \exp [(k_b + k_H)t]$$

HPN_o = HPN at time t_o
k_b = biological degradation rate constant (time) $^{-1}$
k_H = hydrolysis degradation rate constant (time) $^{-1}$
t = time

The HPN changes over time, allowing substances to change in their relative hazard rankings.

Criteria, Subcriteria, and Endpoints

Toxicity
- exposure concentrations established by agencies such as EPA or OSHA (based on acute or chronic, human or environmental effects)

Adsorption
- k_d

Degradation
- hydrolysis rate constant
- biodegradation

Data Selection Approach

All of the data are needed for the equations above. Therefore, the system can only be applied on chemicals with this complete data set.

System Summary 9

Revised Hazard Ranking System (HRS)

References

U.S. Environmental Protection Agency. (Dec. 14, 1990). Hazard Ranking System, Final Rule. *Federal Register* 55 (241): 51532 - 51667 (40CFR Part 300).

Developed for Use by: EPA

Purpose

To evaluate the relative potential human health and environmental threat posed by hazardous waste sites for possible including on the National Priority List (NPL).

Chemicals Addressed

A single substance expected to be the most hazardous at a site.

Summary of Method or Algorithm

This system is the principle mechanism for placing sites on the NPL. The HRS pathway scores are based on factors grouped into three categories: the likelihood of release, waste characteristics and targets. The factor category scores are multiplied and then normalized to 100 points to obtain a pathway score [e.g., the groundwater migration pathway score]. The final HRS site score is a combination of scores from four pathways: groundwater migration (S_{gw}), surface water migration (S_{sw}), soil exposure (S_s) and air migration (S_a) using a root-mean-square method:

$$S = (S_{gw}^2 + S_{sw}^2 + S_s^2 + S_a^2/4)^{1/2}$$

Criteria, Subcriteria

Groundwater Migration Pathway
- Likelihood of Release
  - •observed release, or
    potential to release containment
    - • net precipitation
    - • depth to aquifer
    - • travel time
- Waste Characteristics
  - • toxicity/mobility (human toxicity)*
  - • hazardous waste quantity
- Targets
  - • nearest well
  - • population
  - • resources
  - • wellhead protection area

Soil Exposure Pathway
- Resident Population Threat
  - Likelihood of Exposure
    - • observed contamination
  - Waste Characteristics
    - • toxicity (human)*
    - • hazardous waste quantity
  - Targets
    - • resident individual
    - • resident population
    - • workers
    - • resources
    - • terrestrial sensitive environments
- Nearby Population Threat
  - Likelihood of Exposure
    - • attractiveness/accessibility
    - • area of contamination
  - Waste Characteristics
    - • toxicity*
    - • hazardous waste quantity
  - Targets
    - • population within 1 mile
    - • nearby individual

Air Migration Pathway
- Likelihood of Release
  - • observed release, or
  - potential to release
    - gas:
    - gas containment
      - gas source type
      - gas migration potential
    - particulate:
      - particulate containment
      - particulate source type
      - particulate migration potential
- Waste Characteristics
  - • toxicity/mobility (human toxicity)*
  - • hazardous waste quantity
- Targets
  - • nearest individual
  - • population
  - • resources
  - • sensitive environments

Surface Water Migration Pathway: Overland Flow/Flood Component
- Likelihood of Release
  - • observed release, or
  - potential to release
    - by over-land flow
      - • containment
      - • runoff
      - • distance to surface water
    - by flood
      - • containment
      - • flood frequency
- Drinking Water Threat
  - Waste Characteristics
    - • toxicity/persistence*
    - • hazardous waste quantity
  - Targets
    - • nearest intake
    - • population
    - • resources
- Human Food Chain Threat
  - Waste Characteristics
    - • toxicity/persistence/bioaccumulation*
    - • hazardous waste quantity

Targets
- food chain individual
- population

Environmental Threat

Waste Characteristics
- ecosystem toxicity/persistence/bioaccumulation*
- hazardous waste quantity

Targets
- sensitive environments

Surface Water Migration Pathway: Groundwater to Surface Water Component

Likelihood of Release
- observed release, or

potential to release
- containment
- net precipitation
- depth to aquifer
- travel time

Drinking Water Threat

Waste Characteristics
- toxicity/mobility/persistence*
- hazardous waste quantity

Targets
- nearest intake
- population
- resources

Human Food Chain Threat

Waste Characteristics
- toxicity/mobility/persistence/bioaccumulation*
- hazardous waste quantity

Targets
- food chain individual
- population

Environmental Threat

Waste Characteristics
- ecosystem toxicity/mobility/persistence/bioaccumulation
- hazardous waste quantity

Targets
- sensitive environments

* For specific endpoints used to characterize toxicity, bioaccumulation and persistence, see Endpoints below

Endpoints

Bioaccumulation
- BCF
- Log K_{ow}
- water solubility

Persistence
- hydrolysis t ½
- biodegradation t ½
- photolysis t ½
- volatilization t ½
- log k_{ow}

Human Toxicity Factor Values:

Cancer
- slope factor (or 1/6 (ED_{10})
- WOE rating

Non-cancer, chronic
- reference dose (RfD)

Non-cancer, acute
- oral LD_{50}
- dermal LD_{50}
- dust or mist LC_{50}
- gas or vapor LC_{50}

Ecosystem Toxicity
- EPA chronic Ambient Water Quality Criterion (AWQC)
- EPA chronic Ambient Aquatic Life Advisory Concentrations (AALAC)
- EPA acute AWQC
- Lowest LC_{50}

(endpoints listed in order of preference)

Data Selection Approach

For human toxicity endpoints, for the substance potentially posing greatest hazard:
- if RfD and slope factor available, use worst of the two
- if either RfD or slope factor available, use available endpoint
- if neither, use acute data
- if no toxicity data available, select another chemical

For ecosystem toxicity endpoints
- The endpoints are listed above in order of preference. If no data are available, select another substance for which data are available.

For persistence
- Select the endpoint which gives the highest value (most persistent)

If there are too many data gaps, another chemical at the site will be selected for scoring.

System Summary 10

Criteria to Identify Chemical Candidates for Sunsetting in the Great Lakes Basin

References

Foran, J.A. & B.S. Glenn (1993). *Criteria to Identify Chemical Candidates for Sunsetting in the Great Lakes Basin.* The George Washington University, Environmental Health and Policy Program, Department of Health Care Sciences, Washington, D.C.

Developed for Use by

George Washington University and Pollution Probe of Toronto, Ontario, Canada

Purpose

To develop a mechanism to identify, evaluate and classify chemicals as candidates for Sunsetting in the Great Lakes Basin

Chemicals Addressed

A subset of the (approximately 800) chemicals manufactured, used, or stored in the Great Lakes Basin. The subset consisted of 19 chemicals from EPA's 33/50 list and the US/Canada IJC's Great Lakes critical pollutant list, plus 26 chemicals chosen randomly from the universe of 800 chemicals.

Summary of Method or Algorithm

Chemicals are included on the Sunset candidate list if they:

Score high in any toxicity category and
high in release and production
(excluding pesticides)
or
Score high in any toxicity category and
high in persistence or bioaccumulation
(including pesticides)

Criteria, Subcriteria, and Endpoints

Bioaccumulation
- bioaccumulation factor (BAF)

Persistence
- $t_{1/2}$ in critical medium (days)

Release and Production Volume

open systems
- amount released to environment (annual)
- production volume (annual)

closed systems
- Production or use volume (annual)

Acute aquatic toxicity
- LC_{50}
- EC_{50}

Chronic aquatic toxicity
- NOAEC

Acute terrestrial and avian (non-mammalian) toxicity
- LD_{50}

Chronic terrestrial and avian (non-mammalian) toxicity
- NOAEL

Acute lethal mammalian toxicity
- LD_{50}

Systemic mammalian toxicity
- severity
- effective dose (mg/kg/day)

Carcinogenicity
- weight -of- evidence
- potency ($1/ED_{10}$)

Reproductive and developmental toxicity
- severity and amount of evidence
- lowest effective dose (mg/kg/day)

Ecological effects;
- evidence of ecological disruption

Data Selection Approach

For the most part, the most conservative data are used in scoring each criteria as high, medium or low. Data must be available for at least one exposure parameter and one toxicity parameter for a chemical to be scored and potentially classified as a Sunset candidate.

System Summary 11

Systematic Data Collection and Handling for Priority Setting

References

Gjøs, N., M. Møller, G.S. Hægh, & K. Kolset (1989). *Existing Chemicals: Systematic Data Collection and Handling for Priority Setting*. Center for Industrial Research. Nordic Council of Ministers, Copenhagen.

Developed for Use by

General use within the European Communities (EC)

Purpose

General method of sorting and selecting chemicals. "To provide management tools for national work on control and regulations of chemicals".

Chemicals Addressed

Two lists of chemicals consisting of 42 substances in car care products and 189 substances in builders' supplies

Summary of Method or Algorithm

Categorization is based on 3 selection elements-exposure, health effects and environmental effects. Individual elements may be classified as High, Medium or Low. Chemicals are sorted into 3 selection groups:

- selected chemicals
- non-selected chemicals
- standby chemicals

The criteria for combining exposure and effects in order to assign chemicals to the 3 groups depends on the purpose of selection and may be altered by the user. One example is presented in which selected chemicals score High for effects (health or environmental) or a Medium for effects combined with a high in exposure. Non-selected chemicals scored Low for effects or Medium in effects and a Low for exposure. The standby chemicals were those for which relevant data were missing.

Criteria, Subcriteria, and Endpoints

Exposure
- Production and import volume
- Physical properties
  - boiling point
  - flash point
  - explosivity
- (use pattern and occurrence left to a later review stage)

Health Effects
- Acute toxicity
  - LD_{50} oral, rat
  - LD_{50} dermal, rat/rabbit
  - LC_{50} inhalation, rat
- Irritation (y/n)
- Sensitization (y/n)
- General toxicity (y/n)
- Genotoxicity (y/n)
- Carcinogenicity (y/n)
- Reproductive damage / Teratogenicity (y/n)

Environmental Effects
- Biodegradability
  - BOD_{28}
  - BOD_5
- Bioaccumulation
  - log K_{ow}
  - water solubility
  - molecular weight
- Toxicity, aquatic
  - LC_{50} fish
  - LC_{50} daphnia
  - LC_{50} shrimp
  - EC_{50} algae
- Terrestrial (no endpoint specified)

Data Selection Approach

All available data are used to score a chemical for each criteria. An overall score for exposure, health effects and environmental effects is based on the number of criteria scoring a certain way. For example, a chemical receives a rating of "high" for health effects if at least one of the health effects criteria receives a high rating. Therefore, the system works in the absence of data, but the use of estimation methods is encouraged (expert judgment, SARs and QSARs).

System Summary 12

Substances and Preparations Dangerous for the Environment

References

Gustafsson, L. & E. Ljung (1990). *Substances and Preparations Dangerous for the Environment: A System for Classification, Labelling and Safety Data Sheets*. Final Report from a Nordic Working Group, Nordic Council of Ministers, Copenhagen. Miljørapport: 1990:10E.

Developed for Use by

Nordic Countries

Purpose

A proposed system for classification, labeling, and safety data sheets for substances and preparations dangerous for the environment. There is already a list of substances "Hazardous to Health".

Chemicals Addressed

Applicable to all chemical products (substances and preparations), including pesticides

Summary of Method or Algorithm

Substances are classified as "dangerous for the environment" if one of the following 4 criteria are met:

1. The substance is very acutely toxic
2. The substance is acutely toxic and bioaccumulating/potentially bioaccumulating
3. The substance is acutely toxic and not readily biodegradable
4. The substance is bioaccumulating/potentially bioaccumulating and not readily biodegradable

These classifications are based on numeric cutoff values for the various endpoints (outlined below).

Criteria, Subcriteria, and Endpoints

Acute toxicity
- LC/EC_{50} fish/Daphnia/algae or
- LD_{50} oral, rat or
- LC_{50} inhalation, rat

Bioaccumulation
- BCF or
- K_{ow}

Biodegradability
- OECD 28-day test or
- BOD_5
- COD

Coverage criteria
- other immediate or long-term danger not covered by the specific criteria

Data Selection Approach

All readily available data are considered. Substances are considered "dangerous to the environment" if any one of the four conditions previously mentioned are met, based on numeric cutoff values.

System Summary 13

Vectorial Approach for Partial Ordering

References

Halfon, E., & M.G. Reggiani (1986). Notes on Ranking Chemicals for Environmental Hazard. *Environ. Sci. Technol. 20,* 1173-1179.

Developed for Use by: General use

Purpose

Method of vectorial (rather than scalar) ranking is presented

Chemicals Addressed

34 selected organic chemicals and a set of 6 chlorobenzenes

Summary of Method or Algorithm

Chemicals are ranked for environment hazard according to test results relevant to their fate and/or toxicity using a vectorial approach for partial ordering. Ranking results are based on set theory and systems analysis and are displayed graphically with Hasse diagrams.

Criteria, Subcriteria, and Endpoints

The method could apply to any set of criteria. The examples used included:
Bioaccumulation

- bioaccumulation in algae
- bioaccumulation in fish
- bioaccumulation in activated sludge
- percent retention in rats

Degradation

- mineralization rates by activated sludge (% CO_2)
- degradation by photoirradiation (% CO_2)
- percent organic fragments

Toxicity

- fish toxicity
- zooplankton toxicity
- microtox test

Data Selection Approach

Not specified

System Summary 14

Application of the Hazard Ranking System to the Prioritization of Organic Compounds Identified at Hazardous Waste Sites

References

Hallstedt, P.A., M.A. Puskar, & S.P. Levine (1986). Application of the Hazard Ranking System to the Prioritization of Organic Compounds Identified at Hazardous Waste Remedial Action Sites. *Hazardous Waste and Hazardous Materials,* 3(2), 221-232.

Developed for Use by: Those involved with hazardous waste site investigative studies, monitoring efforts or analytic method development projects.

Purpose

To analyze organic chemicals at 32 hazardous waste remedial action sites and prioritize them as potential threats to public health and the environment. One possible use would be to narrow the list of target organic compounds analyzed for in site investigations or monitoring efforts.

Chemicals Addressed

113 organic priority pollutants common to hazardous waste sites

Summary of Method or Algorithm

A combined rating factor (CRF) is obtained for each chemical scored (taken from the HRS, EPA, 1990) based on a scoring matrix:

		Persistence			
		0	1	2	3
	0	0	0	0	0
Toxicity	1	3	6	9	12
	2	6	9	12	15
	3	9	12	15	18

Toxicity is based on the Sax rating, persistence is based on an EPA rating scale. The scoring results in a combined rating factor (CRF), which is multiplied by frequency of occurrence to arrive at a total score.

Criteria, Subcriteria, and Endpoints

Toxicity
- Sax rating

Persistence
- EPA rating scale

Frequency of occurrence (percent)

Data Selection Approach

Data are needed for each of the 3 criteria. It is not specified what is done in the absence of data. All common chemical isomers were grouped together, and for groups of isomers the most conservative toxicity or persistence values were chosen.

System Summary 15

Modified Hazard Ranking System (mHRS)

References

Hawley, K.A., & B.A. Napier (1985). *A Ranking System for Hazardous Sites & With Mixed Radioactive and Hazardous Wastes*, Proceedings of the Fifth DOE Environmental Protection Information Meeting, November 6-8, 1984, published April, 1985. CONF-841187 Volume 1. U.S. Department of Energy, Office of Operational Safety, Pacific Northwest Laboratory, Richland, WA.

Developed for Use by: U. S. Department of Energy (DOE)

Purpose: It is a modification of the basic HRS which adds the capability to consider radioactive wastes

Chemicals Addressed: Radionuclides

Summary of Method or Algorithm

Modifications to the HRS were restricted to the waste characteristics section of each exposure route. Scores for radioactive waste characteristics are determined by a power function for compatibility with the existing HRS.

Modified HRS Logic Diagram:

This is done for each of five exposure routes:

- migration through air
- migration through surface water
- migration through groundwater
- exposure by fire or explosion
- direct contact with material at the site

Criteria, Subcriteria, and Endpoints

Radioactive Waste Characteristics Score, scored for each exposure route

- unit dose factor (rem/pCi/L)
- concentration (pCi/L)

Data Selection Approach

Radioactive wastes may be ranked for cases where the concentrations of the radionuclides are known, or where they may be estimated as a "potential dose."

System Summary 16

A Ground Water Pollution Priority System (GWPPS)

References

Hutchinson, W.R., & J.L. Hoffman (1983). *A Ground Water Pollution Priority System* (N.J. Geological Survey Open File, Report No. 83-4). Division of Water Resources, Trenton, NJ.

Developed for Use by: New Jersey Geological Survey

Purpose

To prioritize groundwater pollution sites. "Scores from one site can be compared to scores from other sites to determine which site most threatens human health and the environment through groundwater." Objectives:

1. Provide a simple rating method
2. Provide a checklist of factors for consideration in order to reduce review time on a groundwater pollution investigation
3. Provide a standardized evaluation system

Summary of Method or Algorithm

There are seven steps for rating the potential hazard at a site:

1. Site identification
2. Compile background information
3. Resolve problems with missing data
4. Assign rating scale levels to indicate the relative severity of a situation
5. Calculate rating factor scores
6. Calculate group subscores
7. Calculate overall score

Occurrences of groundwater contamination are scored from 0 - 100 for degree of severity based on 19 rating factors (RFs). Each rating factor is quantified on a rating scale level of 0,1,2, or 3 based on relative severity. A multiplier is assigned based on the importance of each factor to groundwater contamination.

factor score = rating scale level x multiplier
(relative severity) (importance)

$$\text{group subscore} = 100 \times \frac{\text{sum of factor scores}}{\text{maximum possible sum}}$$

$$\text{overall site score} = 100 \times \frac{\text{sum of all factor scores}}{\text{sum of all maximum possible scores}}$$

Criteria, Subcriteria, and Endpoints

Site Characteristics Rating Factors:

- Distance to nearest well
- Distance to nearest surface water
- Background groundwater quality
- Recharge
- Unsaturated zone thickness
- Unsaturated zone permeability
- Saturated aquifer thickness
- Saturated zone permeability
- Hydraulic gradient
- Depth to bedrock
- Population served by endangered aquifer

Waste Characteristics Rating Factors

- Source existence (years)
- Diversity of highly toxic chemicals and known or suspected carcinogens (number of carcinogens, highly toxic chemicals)[a]
- Toxicity (Sax levels)[a]
- Radioactivity (gross alpha particle activity)
- Persistence (qualitative degree of persistence)[a]
- In-site compound mobility (qualitative assessment of mobility)[a]
- Hazardous waste quantity (volume)
- Total waste quantity (volume)

[a] Critical factors which must be considered for evaluation

Data Selection Approach

The system is intended to be uncomplicated for application by persons of varying expertise. Sources to be used for gathering data for each of the rating factors are specified.
Due to the nature of scoring, missing values may exist for any but the 4 critical factors which are marked above with([a]) The overall site score cannot be evaluated without these.

System Summary 17

The Great Lakes Water Quality Agreement Annex, lists 1, 2, and 3

References

International Joint Commission's Binational Objective Development Committee (1989). *The Great Lakes Water Quality Agreement Standard Methods and Annex 1*, Lists of Substances.

Developed for Use by: International Joint Commission

Purpose

"These standard methods are to be used to assist in the identification of substances possessing the potential to impact the Great Lakes System."

Chemicals Addressed

Any chemicals which could adversely impact The Great Lakes System-includes inorganics, organics and pesticides.

Summary of Method or Algorithm

The development of three lists is the first phase in the process for selecting substances for which to develop specific objectives. Based on exposure and effects, these lists categorize actual or potentially hazardous chemicals. Specific criteria are defined to classify substances as present, potentially present, toxic and potentially toxic. The three lists are:

List 1: Present and Toxic
List 2: Present and potentially Toxic
List 3: Potentially present and Toxic

Substances on List 1 will be considered for development of "specific objectives." List 2 substances will be considered for further toxicological testing and may be moved to List 1 if toxic effects are exhibited. Substances on List 3 will be candidates for additional monitoring and may be moved to List 1 if detected within the Great Lakes System.

Criteria, Subcriteria, and Endpoints

Exposure
- Believed to be present
- Believed to have the potential of being discharged

Toxic Effects
- Acute effects
  - Aquatic
    - fresh water cladocerans or midge larvae
      - • LC_{50} (48-hr)
      - • LD_{50} (48-hr)
      - • EC_{50} (48-hr)
    - other freshwater fish amphibian, aquatic invertebrate
      - • LC_{50} (96-hr)
  - Mammalian
    - • oral LD_{50}
    - • inhalation LC_{50}
    - • dermal LD_{50}
- Chronic effects
  - Aquatic animal
    - •LOAEC
    - •fish BCF or BAF
  - Plants (aquatic or terrestrial)
    - • IC_{50} (inhibitory concentration - growth rate)
  - Mammals
    - Oral/inhalation toxicity
      - •LOAEL
    - Teratogenicity /embryotoxicity
      - • effective dose
    - Carcinogenicity
      - • WOE
    - Reproductive effects
      - • effective dose
    - Mutagenic/genotoxic action
      - • evidence of specific effects
    - Non-mammalian, terrestrial organisms (e.g., avian)
      - • oral LOAEL

Data Selection Approach

Chemicals are selected for inclusion on one of the three lists if certain, specific criteria for exposure and toxicity are met. Any one of several toxicity endpoints may render a classification of "toxic." There is no need to estimate missing data. However, SARs may be used to classify a substance as "potentially toxic".

System Summary 18

Rapid Screening of Hazard (RASH) Method

References

Jones, T.D., P.J. Walsh, A.P. Watson, B.A. Owen, L.W. Barnthouse, & D.A. Sanders (1988). Chemical Scoring by a Rapid Screen of Hazard (RASH) Method. *Risk Analysis*, 8(1), 99-118.

Developed for Use by: Not specified

Purpose

A method for deriving relative potency estimates for hazardous substances

Chemicals Addressed

278 chemicals were evaluated

Summary of Method or Algorithm

Relative potency values and permissible environmental concentrations are derived using RTECs and GENE-Tox as the main data sources. Relative potency is determined by comparing the effects of a chemical to the effects from a reference chemical used as a standard of comparison. One of the reference chemicals is taken as the primary standard and secondary standards are scaled to the primary standard.
Compute relative potency by:

- comparing different doses required to induce the same level of effect
- comparing different levels of effect resulting from equal doses
- also by "reasonable" comparisons

Criteria, Subcriteria, and Endpoints

Only effects are considered, not exposure potential

- chemical toxic potency (no specific endpoints are targeted)

Data Selection Approach

The "interviewing" chemical is compared to a "standard" chemical. These comparisons are based on similar tests. If there are not sufficient matches for comparison, a secondary "standard" may be selected. Missing data are not estimated. For multiple data points, the median potency was chosen as characteristic for a chemical, and the interquartile range used as the estimate of uncertainty.

System Summary 19

The Environmental Hazard Ranking System ("Schmallenberg")

References

Klein, W., W. Kördel, A.W. Klein, D. Kuhnen-Clausen, & M. Weiss (1988). Systematic Approach for Environmental Hazard Ranking of New Chemicals. *Chemosphere, 17,* 1445-1462.

Developed for Use by

European Community member states National Competent Authorities

Purpose

A computerized scoring system to assess the environmental hazard of new chemicals with classification into 3 classes: no action / observation / immediate action. Environmental assessment of chemicals under the 6th amendment of the EEC Draft Directive 67/548/EC

Chemicals Addressed

New chemicals entering the market

Summary of Method or Algorithm

Environmental hazard criteria for exposure and effects are scored, and the sum of the scores for all criteria is given as the percentage of the sum of the possible scores. This normalization is performed separately for exposure and effects criteria and for air, water, and soil. Different weights for air, water and soil media are used. For example, acute aquatic toxicity scores in air and soil are ¼ that of contamination of water. A two-dimensional image plot is constructed based on the exposure and effects percentages obtained. These plots are used to assign a chemical to one of three regulatory option categories: no action, observation, or immediate action.

Criteria, Subcriteria, and Endpoints

Exposure Potential*
- quantity in environment
  - • annual production rate
  - • use pattern
- initial partitioning
  - • tons/annum for air, water and soil
- quantity in compartment (Mackay model, level 1)
  - • tons/annum for air, water and soil
- persistence (biodegradation)
- accumulation
  - • log P_{ow}

Biological Effects*
- mutagenicity
- subacute mammalian toxicity
  - • oral, dermal or inhalative 28d. NOEL
- acute mammalian toxicity
  - • oral LD_{50} and dermal LD_{50} or inhalation LC_{50}
  - • skin irritation
  - • skin sensitization
- acute aquatic toxicity (fish or Daphnia, worst case)
  - • (lowest) effect concentration
  - • LC_{50}
  - • EC_{50}
- bioconcentration
  - • log P_{ow}

* weighted separately for air / soil / water

Data Selection Approach

All acceptable available data are utilized to determine the percentages of the maximal scores to assign in each of the exposure and effects criteria. Data may be estimated using QSARS or by extrapolation from experimental data.

WMS - Scoring System

References

Könemann, H. & R. Visser (1988). Selection of Chemicals With High Hazard Potential: Part 1: WMS-Scoring System. *Chemosphere, 17,* 1905-1919.
Timmer, M., H. Könemann, & R. Visser (1988). Selection of Chemicals With High Hazard Potential: Part 2: WMS-Scoring System. *Chemosphere, 17,* 1921-1934.

Developed for Use by

Originally intended for use in the preparation of policy on existing chemicals to be implemented under the Netherlands' Chemical Substances Act. The system may be used by government, industry, or academia for chemical selection.

Purpose

To systematically select a limited numbers of chemicals from a greater number, as needed to set priorities for further investigation and for development of environmental and health protection policies.

Chemicals Addressed

378 chemicals obtained by merging several international and national lists of hazardous chemicals or those with high exposure potential. The system appears to be applicable to nearly all chemicals in commerce.

Summary of Method or Algorithm

The system was developed using the general methodology described in a report by the OECD. The relative hazards of chemicals can be compared by determining F values where:

F = Ef / Ex
and F = ratio for a given chemical
Ef = exposure above which (unacceptable) effects are observed
Ex = actual exposure of target organisms

Different Ef and Ex values must be derived for different target systems and for the presence of a chemical in various places in the environment respectively. The target systems considered are mammals (including man) and aquatic organisms. For mammals, three types of effects are considered. The four exposure scenarios include:

- contamination of air (exposure via air)
- contamination of soil / water
- contamination of aquatic biota
- in products

There are 10 useful combinations of target systems and exposure scenarios which give 10 endscores that make up the scoring profile. The endscores reflect the difference between the maximum hazard and the scored hazard. The final selection of chemicals will vary with the application.

System Summary 20, continued

Criteria, Subcriteria, and Endpoints

Effects

Mammals

general toxicity (oral, dermal, inhalation):

- NEL
- LD_{50}

- mutagenicity (amount of evidence from short-term tests)
- carcinogenicity (evidence of carcinogenicity hazard and/or animal data)

Aquatic toxicity

- NOEC
- EC_{50}

Exposure

Environmental exposure

- use volume
- percentage release to the environment (by type of use)
- degradation in air (half-life)
- degradation in soil/water (semi-quantitative)
- relative occurrence in air Mackay model, fugacity
- relative occurrence in soil/water Mackay model, fugacity
- bioconcentration (log P, log BCF)

Exposure via products

- use pattern
- exposure frequency
- intensity of exposure

Data Selection Approach

All readily available data are supplied to at least two experts who score the chemicals independently. Significant differences are discussed and minor differences are averaged.
The experts may use SARs and QSARS for scoring.

System Summary 21

Benchmark Comparison

References

Laskowski, P.A., C.A.I. Goring, P.J. McCall, & R.L. Swann (1982). Principles of Environmental Risk Analysis: Terrestrial Environment. in *Environmental Risk Analysis for Chemicals*, R. Conway (Ed.), pp. 198-240. Van Nostrand Reinhold, New York.

Developed for Use by

(Not specified)

Purpose

"Data interpretation by benchmark comparison is accomplished by comparing a series of fundamental properties of chemicals whose environmental behavior is unknown with the standards whose environmental behavior is known." The benchmark system is used for ranking compounds.

Chemicals Addressed

It was demonstrated on 27 pesticides

Summary of Method or Algorithm

Chemicals are ranked for each of 6 criteria.
These include :

1) leaching potential
2) leaching index
3) volatility potential
4) volatility index
5) on-site exposure
6) off-site exposure

The system does not combine the criteria for an overall score. Toxicity or potential effects are not considered. Therefore, this is not a risk-based chemical ranking system. It is useful, however, to examine the exposure component of the system.

Criteria, Subcriteria, and Endpoints

Leaching Potential
Relative on-site and off-site exposure based on:

- soil t ½
- vapor pressure
- water solubility
- soil adsorption constant (k_{oc})
- octanol-water partition coefficient (k_{ow})
- volume of material manufactured
- frequency of application
- concentration of chemical introduced

Data Selection Approach

Data are needed for each endpoint in order to calculate a score for each of the six criteria.

System Summary 22

Michigan Critical Materials Register (CMR)

References

Michigan Department of Natural Resources (MDNR) (1987). *Critical Materials Register.* (Criteria and Support Documents).

Developed for Use by

Michigan Department of Natural Resources

Purpose

To prepare a "list of chemicals of high environmental concern from a water pollution control perspective which may be used, discharged and/or disposed of in Michigan". Every business within the state must file an annual report or usage/discharge of critical materials.

Chemicals Addressed

"Those with well recognized adverse effects as well as those materials which may be of specific concern in Michigan."

Summary of Method or Algorithm

Chemicals are scored for several criteria. Those chemicals selected for inclusion in the Register score:

- a "5" (the maximum score) in 2 or more criteria
- an additive level of 15 or greater

Chemicals are selected for a detailed scrutiny and identification of disposition if they score:

- a "5" in one criterion and insufficient information in all other criteria
- a combined level of "10 - 15"

Criteria, Subcriteria, and Endpoints

Acute toxicity - terrestrial animals
- oral LD_{50}
- dermal LD_{50}
- inhalation LC_{50}

Acute toxicity - aquatic
- LC_{50}
- EC_{50}

Carcinogenicity
- weight-of-evidence

Mutagenicity
- weight-of-evidence (includes several endpoints)

Reproductive/developmental toxicity
- weight-of-evidence
- effective dose

Other toxicity - terrestrial animals (sub-chronic, chronic or acute)
- severity
- effective dose

Other toxicity - aquatic organisms (chronic)
- MATC (based on full or partial life cycle tests)

Phytotoxicity
- EC_{50}

Bioaccumulation
- BCF
- BAF
- log k_{ow}

Physical and chemical properties and environmental fate
- flammability: NFPA rating
- reactivity: NFPA rating
- corrosivity: pH
- aesthetics
  - taste / odor
  - appearance
- environmental distribution and fate
  - persistence in soil/water ($t_{1/2}$)
  - hydrolysis (H $t_{1/2}$)
  - evaporation (E $t_{1/2}$)

Data Selection Approach

Due to the nature of the selection process, data gaps may exist. There is a data hierarchy specified for some criteria. Often times, the most conservative of several scores within a criterion is selected or the geometric mean of multiple acceptable test results may be used for scoring (aquatic acute toxicity). Detailed guidelines for scoring are provided.

System Summary 23

Unfinished Business: A Comparative Assessment of Environmental Problems

References

Morgenstern, R., D. Clay, G. Emison, R. Hanmer, & M. Williams (1987). *EPA Unfinished Business Report: A Comparative Assessment of Environmental Problems, Volume 1*. U.S. Environmental Protection Agency, Washington, D.C. (EPA/230/2-87/025a)

Developed for Use by: EPA

Purpose

This system was used for ranking problems, or issues, rather than chemicals. The objective was to rank the relative risks associated with major environmental problems to support long-term EPA priority-setting.

Chemicals Addressed

(Not for chemical ranking/scoring)

Summary of Method or Algorithm

Four work groups were established to rank 31 environmental problems according to the following risk types:

- cancer risks
- non-cancer health risks
- ecological effects
- welfare effects

An overall rank including all risk types was not obtained, but rather a ranking of environmental problems within each risk type category. Similar methods for estimating risk were applied across the four areas whenever possible. The ranking relied heavily on professional judgement, with an emphasis on consensus within the work groups.

Criteria, Subcriteria, and Endpoints

Cancer risk
- exposure
- potency (carcinogen assessment group estimates)
- population exposed

Non-cancer risk
- exposure
- potency (ambient concentration / RfD)

Ecological Risk
- geographical extent of exposure
- intensity of exposure
- length of exposure
- frequency of exposure
- other factors
- ecosystem recovery potential

Welfare effects
- soiling and other material damages
- recreation
- natural resource damage
- damages to other public and commercial property
- damage to groundwater supplies
- losses in aesthetics and non-user values

Data Selection Approach

The ranking was performed through a combination of quantitative and qualitative assessment. Professional judgement was used whenever quantitative information was not available.

System Summary 24

Chemical Scoring System for Hazard and Exposure Identification

References

O'Bryan, T.R. & R.H. Ross (1988). Chemical Scoring System for Hazard and Exposure Identification. *J. Toxicol. Env. Health, 1,* 119-34.

Developed for Use by

EPA, Office of Toxic Substances (OTS)

Purpose

Provide a mechanism to systematically screen chemicals for additional scientific evaluation. "The purpose of scoring is to identify, from a large number of existing chemicals, those chemicals that may warrant further investigation."

Chemicals Addressed

Compounds of toxicological and environmental interest to the EPA. Approximately 100 CHIPS chemicals (those for which Chemical Hazard Information Profiles have been prepared for the EPA) and 100 petroleum substances.

Summary of Method or Algorithm

The system combines objective guidelines with professional judgement to evaluate chemicals. Chemicals can be scored on eleven parameters for exposure and effects. All or any combination of parameters may be scored, depending on data availability. Scores for each criteria are not combined for an overall score; the entire set of scores are presented in a scoring profile for each chemical and the scoring profiles are presented graphically.

Criteria, Subcriteria, and Endpoints

Oncogenicity
- amount/type of evidence

Genotoxicity
- amount/type evidence

Developmental toxicity
- amount/type of evidence

Acute lethality (mammalian)
- inhalation LC_{50}
- dermal LD_{50}
- oral and other LD_{50}

Nonlethal acute toxicity (mammalian)
- severity of effects
- effective dose (mg/m^3 or mg/kg)

Subchronic/chronic toxicity (mammalian)
- severity of effects
- effective dose (mg/m^3 or mg/kg/day)

Aquatic toxicity
- acute LC_{50} or EC_{50}
- life-cycle or chronic NOEL

Bioconcentration
- BCF
- log P

Chemical production volume
- kg or lbs

Occupational exposure
- number of workers potentially exposed
- probability of workers exposure
- intensity of workers exposure
  - measured concentration
  - vapor pressure

Consumer exposure
- number consumers potentially exposed
- frequency of consumer exposure
- intensity of consumer exposure

Environmental exposure
- pounds released annually

Environmental fate
- ½ life
- transport
- transformation

Data Selection Approach

Chemicals are scored independently by two experts who may use all readily available data and SARs for scoring. Differences in scores of more than one point are resolved. The scoring may be performed on any or all of the criteria, depending on data availability. Scores are not added, weighted or combined.

System Summary 25

The Effluent Monitoring Priority Pollutants List (EMPPL)

References

Environment Ontario (1987). *The Effluent Monitoring Priority Pollutants List.* Ontario Ministry of the Environment, Hazardous Contaminants Coordination Branch. ISBN 0-7729-2784-7

Environment Ontario (1988). *The Effluent Monitoring Priority Pollutants List, 1988 Update.* Ontario Ministry of the Environment, Hazardous Contaminants Coordination Branch. ISBN 0-7729-5450-X

Developed for Use by

Ontario Ministry of the Environment

Purpose

To develop a list of chemicals "which have been detected or are potentially present in Ontario municipal and industrial effluents which pose a hazard to the receiving environment." This will provide a basis for "chemical specific monitoring regulations under the MISA program".

Chemicals Addressed

Chemicals detected in effluents or surface water and chemicals not yet detected but which would be of concern if present.

Summary of Method or Algorithm

A chemical is selected for promotion to the EMPPL if it is present or potentially present in Ontario, and if it meets or exceeds any one of a number of "concern levels" in various other parameters (including persistence, bioaccumulation and toxicity). These parameters are scored using the MOE criteria.

Criteria, Subcriteria, and Endpoints

Persistence
- t ½

Bioaccumulation
- BCF
- log k_{ow}

Acute lethality
- oral LD_{50}
- dermal LD_{50}
- inhalation LD_{50}
- aquatic LC_{50}

Chronic/subchronic

Non-mammals

aquatic
- EC_{50}
- MATC
- NOAEL

terrestrial
- subchronic NOEL
- chronic NOEL

plants (aquatic and terrestrial)
- NOAEC
- EC_{50}

Mammals
- oral NOEL
- inhalation NOEL

Mutagenicity/Genotoxicity
- positive results (test system specified)

Teratogenicity
- effective dose (mg/kg/day)

Carcinogenicity
- criteria rely on amount and type of evidence

Data Selection Approach

The data search strategy is in two levels. Both levels utilize both printed and computer-accessed information for every chemical. Sufficient information for scoring each of the adverse effects parameters is obtained. This may not require searches on both levels. The data selection approach is specified for each of the criteria. For example, preference is given to toxicity data based on route, test duration, species, or the most conservative value. For bioconcentration, BCF values are preferred over K_{ow} and the most conservative value for persistence is selected. Data gaps remaining after a level II search are documented. QSARs, SARs, and expert judgement may be used. This system functions in the absence of data.

System Summary 26

Coastal Hazardous Waste Site Review

References

Beckvar, N. & L. Harris (1992). *Coastal Hazardous Waste Site Review, September, 1992*. Hazardous Materials Response and Assessment Division, NOAA/ORCA, Seattle, WA.

Developed for Use by

National Ocean and Atmospheric Administration (NOAA)

Purpose

To select sites (on the NPL or proposed for inclusion) for further investigation that could affect natural resources; to determine the potential for injury to the resources evaluate clean-up alternatives; and to carry out restoration actions. This initial assessment is to provide an overall guide to the potential for injury to NOAA trust resources resulting from a site.

Chemicals Addressed

(Not for chemical ranking/scoring)

Summary of Method or Algorithm

The reviews examine:

1) site exposure potential (qualitative information)
2) NOAA trust habitats and species
3) site-related contamination (maximum concentration of contaminants)

Data from each site are screened against standard comparison values, depending on the media. Such standards used are:

- Ambient water quality criteria
- Selected soil averages
- Effective Range-Low (ER-L) values

The primary concern is with chronic effects.

Criteria, Subcriteria, and Endpoints

Site-specific data

Data Selection Approach

Site-specific, measurable data are needed for comparisons against standard values.

System Summary 27

SRS: Site Ranking System for
Hazardous Chemical and Radioactive Waste

References

Rechard, R.P., G.F. Wilkinson, & J.D. Schreiber (1991). *User's Manual for SRS88: Site Ranking System for Chemical and Radioactive Waste* (SAND87-2815, UC-721). Sandia National Laboratories, Albuquerque, NM.

Rechard, R.P., M.S.Y. Chu, & S.L. Brown (1988). *SRS: Site Ranking System for Hazardous Chemical and Radioactive Waste* (SAND86-2994, DOE/HWP-26). Sandia National Laboratories, Albuquerque, NM.

Developed for Use by: U.S. Department of Energy

Purpose

To perform a ranking of hazardous waste sites based on relative human health risks and primarily using information that already exists on the sites. (Primarily *site* ranking, with simple chemical ranking as an initial screening step.)

Chemicals Addressed

Major waste components of sites. Minor waste components are initially screened out based on amount, concentration and toxicity.

Summary of Method or Algorithm

The ranking process involves the following steps:

- collect site data
- rank wastes at a site by quantity and toxicity
- describe contaminant release pathways of concern
- evaluate engineered features at a site
- identify target populations for pathways of concern
- score site characteristics based on contaminant migration (ground-water, surface water, air pathways)
- combine individual scores to obtain a pathway score
- combine pathway scores to obtain a site score
- rank sites relative to other scored sites

The risks posed by contaminant release from hazardous waste sites is determined by:

population x exposure x toxicity

Criteria, Subcriteria, and Endpoints

Target population
- log of population at risk

Chronic toxicity
- unit cancer risk (UCR) for carcinogens and radionuclides
- allowable daily intake (ADI) for noncarcinogens

Groundwater pathway
- mass of hazardous material initially left at site
- effectiveness of engineered barriers
- effectiveness of site features
- chemical decay rate

Surface water pathway
- method of waste placement
- soil cover and hydraulic structures
- time frame of interest
- decay rate at site

Air pathway
- method of waste placement
- time frame of interest
- decay rate at site

Data Selection Approach

Default scores are assigned for missing site data. Best estimates of chemical or site properties are to be used, rather than conservative upper limits.

System Summary 28

A Practical Method for Priority Selections and Risk Assessments Among Existing Chemicals

References

Sampaolo, A. & R. Binetti (1986). Elaboration of a Practical Method for Priority Selections and Risk Assessment Among Existing Chemicals. *Reg. Toxicol. & Pharmacol, 6,* 129-154.

Sampaolo, A. & R. Binetti (1989). Improvement of a Practical Method for Priority Selections and Risk Assessments Among Existing Chemicals. *Reg. Toxicol. & Pharmacol.*, 10, 185-195.

Developed for Use by: General use

Purpose

A system, for different purposes, for assessment and priority selection of existing chemicals. It has been included as the official method in the Italian decree for the implementation of the EC directive 82/501, particularly for calculating the toxicity risk in case of accident.

Chemicals Addressed

Method validated on 80 substances including inorganics, organics and pesticides

Summary of Method or Algorithm

This system may be used for:

- Assessment of intrinsic properties
- Identification of data needs
- Risk assessment
- Priority assessment in selecting chemicals for further study

Depending on the purpose, there are different equations which result in scores for:

1) priority for personal direct exposure
2) priority for environmental exposure
3) risk for personal direct exposure
4) risk for environmental exposure
5) general risk index
6) application to specific effects (emphasis on types of effects)
7) adapted formulas for use for EC directive

The equations include additive and/or multiplications parameters, depending on the objective.

Criteria, Subcriteria, and Endpoints

Physicochemical properties
- molecular weight
- melting point
- boiling point
- relative density
- vapor pressure
- surface tension
- water solubility
- fat solubility
- flammability
- explosive properties
- oxidizing properties

Toxicological properties

Acute toxicity
- oral LD_{50}
- inhalation LC_{50}
- skin LD_{50}
- irritation (skin and/or eye) EEC "guide on classification and labelling"
- sensitization (EEC guide)

Sub-acute, subchronic, chronic toxicity
- no-effect level (oral, inhalation, cutaneously)
- mutagenicity (EEC guide)
- carcinogenicity (EEC guide)
- reproduction/teratogenicity (EEC guide)

Ecotoxicological properties
- acute LC_{50}, fish
- acute EC_{50}, *Daphnia*
- acute oral LD_{50}, birds
- toxicity for higher plants (qualitative phytotoxicity)
- effects on algae

Multiplier parameters
- quantity on market
- plurality of direct exposure
  - personal exposure
  - domestic exposure
  - professional exposure
- environmental spread
- persistence
  - BOD
  - ThOD
- bioconcentration (log P)
- size of risk population

Data Selection Approach

Scoring criteria are provided for both cases where data are available and unavailable. In the absence of data, scores are assigned on the basis of SAR or other properties of the chemical (fat solubility, qualitative information, etc.).

System Summary 29

Chemical Ranking for Potential Health and Environmental Impacts

References

Davis, G.A. et al (1994). Chemical Hazard Evaluation for Management Strategies: A Method for Ranking and Scoring Chemicals by Potential Human Health and Environmental Impacts. University of Tennessee (UT), Center for Clean Products and Clean Technologies, Knoxville, TN.

Developed for Use by

University of Tennessee Center for Clean Products and Clean Technologies

Purpose

"To examine the components of chemical ranking and scoring systems, propose a detailed scheme for chemical ranking, and to recommend a set of priority chemicals for safe substitutes analysis"

Chemicals Addressed

The top 99% releases and transfers from 1989 TRI (organics and inorganics) and several high-volume pesticides.

Summary of Method or Algorithm

An unweighted hazard value is obtained for each chemical based on health, environmental and exposure criteria.

The algorithm (not weighted by releases) is:

Total Hazard Value = (Human Health Effects + Environmental Effects) x Exposure Factor

where:

Human Health Effects = $a\mathrm{HV}_{\mathrm{OR}} + b\mathrm{HV}_{\mathrm{INH}} + c\mathrm{HV}_{\mathrm{CAN}} + d\mathrm{HV}_{\mathrm{NC}}$ and
Environmental Effects = $a\mathrm{HV}_{\mathrm{MAM}} + e\mathrm{HV}_{\mathrm{FA}} + f\mathrm{HV}_{\mathrm{FC}}$
Exposure Factor = $g\mathrm{HV}_{\mathrm{BOD}} + h\mathrm{HV}_{\mathrm{HYD}} + i\mathrm{HV}_{\mathrm{BCF}}$
$\mathrm{HV}_{\mathrm{OR}}$ = hazard value for acute oral toxicity (human)
$\mathrm{HV}_{\mathrm{INH}}$ = hazard value for acute inhalation toxicity (human)
$\mathrm{HV}_{\mathrm{CAN}}$ = hazard value for carcinogenicity (human)
$\mathrm{HV}_{\mathrm{NC}}$ = hazard value for chronic, noncarcinogenic toxicity (human)
$\mathrm{HV}_{\mathrm{MAM}}$ = hazard value for acute oral toxicity (other mammalian)
$\mathrm{HV}_{\mathrm{FA}}$ = hazard value for acute toxicity to fish
$\mathrm{HV}_{\mathrm{FC}}$ = hazard value for chronic toxicity to fish
$\mathrm{HV}_{\mathrm{BOD}}$ = hazard value for acute oral toxicity (other mammalian)
$\mathrm{HV}_{\mathrm{HYD}}$ = hazard value for acute toxicity to fish
$\mathrm{HV}_{\mathrm{BCF}}$ = hazard value for chronic toxicity to fish
a ... i = term weighting factors

A weighted hazard value is obtained based on releases and transfers as reported in the 1989 TRI and pesticide usage data.
The same algorithm above is used, but release weighting factors (RWFs) are applied to the individual hazard values.

The release weighting factors were calculated as follows:

$RWF_{a,w,t}$ = ln (releases to air, water or total) - 10

The release-weighted hazard values were obtained as follows:

$wHV_{OR} = (HV_{OR})(RWF_w)$
$wHV_{INH} = (HV_{INH})(RWF_a)$
$wHV_{CAN} = (HV_{CAN})(RWF_t)$
$wHV_{NC} = (HV_{NC})(RWF_t)$
$wHV_{MAM} = (HV_{MAM})(RWF_w)$
$wHV_{FA} = (HV_{FA})(RWF_w)$
$wHV_{FC} = (HV_{FC})(RWF_w)$

where

${}_wHV_x$ = release-weighted hazard value for term x
RWF_w = water release weighting factor
RWF_a = air release weighting factor
RWF_t = total release weighting factor

A weighted hazard value is obtained based on releases and transfers as reported in the 1989 TRI.

Criteria, Subcriteria, and Endpoints

- Health Effects
  - Acute
    - oral LD_{50}
    - inhalation LC_{50}
  - Chronic
    - carcinogenicity
      - EPA WOE
      - IARC strength-of-evidence
    - non-carcinogenic effects
      - chronic toxicity (adverse effects other than cancer)
      - developmental toxicity
      - mutagenicity
      - neurotoxicity
      - reproductive toxicity
- Environmental Effects
  - Terrestrial effects
    - oral LD_{50} (rodent)
  - Aquatic effects
    - acute LC_{50} (fish)
    - chronic NOEL (fish)
- Exposure Parameters
  - Persistence
    - BOD ½ life
    - hydrolysis ½ life
  - Bioaccumulation
    - BCF
- Release weighting
  - TRI releases and transfers

Data Selection Approach

One endpoint for each criterion is required, with preference given to data for a particular species or test duration for most health and environmental effects. When multiple, preferred data are available, the most conservative value is selected. Data are needed for every endpoint and may be estimated by QSARs or SARs where appropriate. Some data gaps remain where estimations are not possible. A sensitivity analysis is performed to evaluate the effects of the data gaps.

System Summary 30

A Manual for Evaluating Contamination Potential of Surface Impoundments

References

Silka, L.R., & T.L. Swearingen (1978). *A Manual for Evaluating Contamination Potential of Surface Impoundments*. (EPA 570/9-78-003). Environmental Protection Agency Office of Drinking Water, Washington, D.C.

Developed for Use by

EPA

Purpose

"Rate the contamination potential of groundwater from surface impoundments and to develop practices for the evaluation of different surface impoundments "(pits, ponds, lagoons)

It is considered a first-round evaluation

Chemicals Addressed

Not for chemical ranking/scoring

Summary of Method or Algorithm

The system includes two distinct evaluation phases which involve 1) rating groundwater contamination potential and 2) rating the relative magnitude of the hazard potential to users of the groundwater as a source of drinking water. This involves a six-step process as follows:

Step 1	Step 2	Step 3	Step 4	Step 5	Step 6
rating unsaturated zone	rating groundwater availability	rating groundwater quality	rating waste hazard potential	overall groundwater contam. potential	rating potential endangerment to water supplies

Criteria, Subcriteria, and Endpoints

Rating unsaturated Zone
- Earth material category (see below)
- Thickness of unsaturated zone

Groundwater availability
- Earth material
  - • unconsolidated rock
  - • consolidated rock
  - • permeability
- Thickness of saturated zone

Groundwater quality
- • total dissolved solids (TDS)(mg/l)

Waste hazard potential
- • toxicity (endpoint not specified)
- • mobility
- • persistence
- • volume
- • concentration

Overall groundwater contamination potential
- steps 1 - 4 summed

Potential endangerment of waste supplies
- distance of impoundment to groundwater or surface water source of drinking water.
- anticipated flow direction of waste place

Investigators' degree of confidence

Miscellaneous identifiers
- site in groundwater recharge area
- site in groundwater discharge area
- site in flood plain
- + 6 others

Data Selection Approach

"Precise data are not necessary for the application of the SIA evaluation system...It must be remembered that this evaluation system is a first-round approximation and therefore estimates based on the best available information will be used with the expectation that they will provide satisfactory results for first-round evaluations".

System Summary 31

The EPS Enviro-Accounting Method

References

Steen, B. & S. Ryding (1992). *The EPS Enviro-Accounting Method, An Application of Environmental Accounting Principles for Evaluation and Valuation of Environmental Impact in Product Design.* Swedish Environmental Research Institute (IVL), Göteborg, Sweden.

Developed for Use by: General use

Purpose

It is designed to be a tool for life cycle impact assessment, to assess environmental impacts in terms of ecological and health consequences. This includes basic assessment of the values of environmental qualities and changes in these values due to human activities.

Chemicals Addressed

(Not for chemical ranking/scoring)

Summary of Method or Algorithm

Values are assigned to impacts on the environment in terms of five "safe-guard subjects" (human health, biodiversity, production, resources & aesthetic values) according to willingness to pay to restore them to normal status. Emissions, use of resources, and other human activities are then valued according to their estimated contribution to the changes in these safeguarded subjects. The information on environmental impacts originates from LCA-based inventory of the materials/process under study.

Impacts are valued on a relative scale in environmental load units (ELU) which correspond to a standard monetary amount (one ELU equals one ECU in OECD countries).

Criteria, Subcriteria, and Endpoints

- Biological diversity
- Production
- Human health
- Resources
- Aesthetic values

Data Selection Approach

Empirical data are gathered from the most appropriate available sources. Error estimates should accompany results.

System Summary 32

Defense Priority Model

References

U.S. Department of Defense (1992). *User's Manual for the Defense Priority Model* (FY 93 version, Interim Draft). Prepared by Earth Technology Corporation and ERM Program Management Company, for U.S. Department of Defense, Office of Deputy Assistant Secretary of Defense. (Environment), Washington, D.C.

Developed for Use by: Department of Defense

Purpose

Following a remedial investigation feasibility study, site specific data are used to score sites for establishing remedial action priorities on DOD installations. "The DPM provides a numerical score which represents the relative potential threat to human health and the environment."

Chemicals Addressed: Not for chemical ranking or scoring

Summary of Method or Algorithm

Separate subscores are obtained for each of 8 combinations of potential transport pathways and potential receptors as shown below:

	Surface water	Groundwater	Air and Soil	
			(VOCs)	(dust)
human receptors	1	3	5	7
ecological receptors	2	4	6	8

Health and ecological hazards are assessed through monitoring, using toxicological benchmarks that 1) rank toxic chemicals according to relative toxicity; and 2) relate concentrations measured at a site to concentration or doses that may be toxic. Scores for confidence level in data quality are included and an overall site score is obtained.

Score aggregation:
"The pathway, hazard and receptor subscores for each pathway-receptor combination are multiplied together and the products of the subscores are normalized." The larger of the two air/soil pathway scores is used. The final score is obtained by the following algorithm:

$S_f = [5(S_{s,h})^2 + (S_{s,e})^2 + 5(S_{g,h})^2 + (S_{g,e}) + 5(S_{a,h})^2 + (S_{a,e})^2]^{½} / 4.24$
S_f = overall site score, $S_{s,h}$, $S_{s,e}$ etc. = scores for surface water - human health, surface water - ecological etc.

Criteria, Subcriteria, and Endpoints

Pathway Scoring

Surface water pathway
- detected releases
- distance to nearest surface water
- net precipitation
- surface erosion potential
- rainfall intensity
- hydraulic conductibility
- flooding potential
- waste containment effectiveness factor
- waste quantity factor

Groundwater pathway
- detected releases
- distance waste to water site
- permeability of unsaturated zone
- infiltration potential
- geochemical properties of vadose zone
- waste contamination effectiveness factor
- waste quantity factor

Air/Soil volatiles pathway
- detected releases
- average summer soil temperature
- net precipitation
- wind velocity
- soil porosity
- waste containment effectiveness factor
- waste quantity factor

Air/Soil dust pathway
- detected releases
- net precipitation
- wind velocity
- days/yr > 25 mm precipitation
- site activity
- waste containment effectiveness factor
- waste quantity factor

Contaminant hazard scoring (Get a score for each pathway)

Human health hazard
- measured concentrations
- daily intake (water + fish)
- acceptable daily intake (ADI)

Ecological hazard
- measured concentrations
- ecological effects benchmarks
  - aquatic (kg/l)
  - terrestrial (mg/l)

Receptors Scoring
- surface water receptors
  - human health
    - • population obtaining drinking water
    - • water use to nearest surface water
    - • population within 1/2 mile of site
    - • distance to nearest installation boundary
    - • land use (zoning within 2 miles of site)
  - ecological
    - • important biota and habitats near site
    - • "critical" environments near site
- groundwater receptors
  - human health
    - • groundwater travel time to water wells
    - • groundwater travel time to surface water as domestic water source
    - • groundwater use of uppermost aquifer
    - • population potentially at risk
    - • population within 1/2 mile of site
    - • distance to nearest installation boundary
  - ecological
    - • groundwater travel time to habitat or natural area
    - • important biota and habitats near site "critical" environments near site
- air/soil receptors
  - human health
    - • population within 4 miles radius
    - • land use
    - • distance to nearest installation boundary
  - ecological
    - • distance to important biota and habitat
    - • "critical" environments near site

Data Selection Approach

A summary of the data requirements is provided in Appendix A with a list of general data sources that may be used. Methods of estimation for missing data are provided throughout the document.

System Summary 33

Hazardous Air Pollutants: Proposed Regulations Governing Constructed, Reconstructed and Modified Major Sources

References

U.S. Environmental Protection Agency. *Hazardous Air Pollutants: Proposed Regulations Governing Constructed, Reconstructed and Modified Major Sources* (40 CFR Part 63). February 12, 1993 Draft.

Developed for Use by: EPA

Purpose

Guidance for identification of the relative hazard to human health from emissions of air pollutants (listed as HAPS). One important requirement of section 112(5)(1)(A) of the Clean Air Act (as amended in 1990) is that off setting emissions decreases must be considered "more hazardous" than emission increases. This system may be used to characterize pollutant emissions as more or less hazardous.

Chemicals Addressed

Hazardous air pollutants

Summary of Method or Algorithm

The first step involves assigning pollutants to one of four categories listed below and to determine the relative hazard of the categories.

4 categories of HAPs

- Threshold
- Non-threshold (no safety threshold for exposure can be determined)
- "High-concern" from acute or toxic exposure
- "Unrankable" pollutants

Non-threshold and high concern pollutants are considered "more hazardous" than threshold pollutants. The relative ranking of individual pollutants is done within (not between) these 4 categories. This ranking is based primarily on cancer potency and weight of evidence classification for non-threshold pollutants and composite score differences for threshold and high-concern pollutants.

Criteria, Subcriteria, and Endpoints

Non-threshold pollutants (carcinogens within EPA weight-of-evidence class A, B or C or IARC group 1, 2A or 2B)

Rank within category:

- weight-of-evidence (EPA, IARC)
- Dose-response (ED_{10})

Threshold pollutants

Rank within category:

- Reportable quantities (RQ) composite scores
  dose (RV_d)
  severity of effect (RV_c)
- oral RfD/inhalation RfCs (alternative option)

High concern pollutants

Criteria to be placed in category:

Ranking within category:

- composite (RQ) scores (for chronic toxicity)

potent acute toxicants (level-of-concern, LOC, < 8 mg/m^3)

Data Selection Approach

The guidance includes a data hierarchy for "non-threshold" pollutants where EPA assessments are preferred over IARC, and for "threshold" pollutants where RQs are preferred over RfDs. "Unrankable" pollutants include those which do not meet the criteria for non-threshold pollutants or "high concern" pollutants and have insufficient chronic toxicity data to be ranked as "threshold pollutants".

System Summary 34

Ranking System for 307 (a) List of Priority Pollutants

References

Poston, T.M. & L.A. Prohammer (1985). *A Ranking System for Clean Water Act Section 307 (a) List of Priority Pollutants*. Prepared by Battelle, for U.S. Environmental Protection Agency.

Cornaby, B.W. et. al. (1986). *Results of Implementation of a Chemical Ranking System.* Prepared by Battelle, for U.S. Environmental Protection Agency Criteria and Standards Division, Washington, D.C.

Developed for Use by: EPA

Purpose

An objective, scientifically-based quantitative ranking system for placement of chemicals on the Clean Water Act Section 307 (a) list of priority pollutants.

Chemicals Addressed

157 chemicals from various agency lists. Includes inorganics, organics and pesticides.

Summary of Method or Algorithm

The system is based on a two-tiered approach. Tier I is based on five effect-based scoring factors: aquatic toxicity, mammalian toxicity, human health effects, bioaccumulation and persistence. A total score of 10 or more points would indicate listing after consideration of Tier II for exposure. Chemicals receiving scores between 8 and 12 points should be reviewed further in Tier II. Tier II scores are not added to Tier I scores.

Criteria, Subcriteria, and Endpoints

Tier I:
Aquatic Toxicity
- acute LC_{50} (96 -h fish, 48 -h macroinvertebrates)
- chronic MATC (fish, *Daphnia*, midge)
- EC_{50} (algae)

Mammalian Toxicity
- acute oral LD_{50}
- acute dermal LD_{50}
- chronic/sub-chronic LD_{LO}, TD_{LO}

Human Health:
- carcinogenicity (qualitative evidence)
- mutagenicity (qualitative evidence)
- teratogenicity (qualitative evidence)

Bioaccumulation
- BAF (Bioaccumulation Factor)
- BCF
- log P (octanol-water partition coefficient)

Environmental Persistence (in aquatic environment)

1985 1986

- environmental half-life
- hydrolysis
- hydrolysis rate
- volatilization
- vaporization (Henry's constant)
- adsorption (K_{oc})
- K_d value
- oxidation

Tier II (examines potential for exposure on a national basis)
Exposure
- amount discharged per year
- number of sites of discharge having detectable concentrations
- frequency of detection in ambient waters
- frequency of detection in aquatic sediments
- frequency of detection in industrial or municipal effluents

Data Selection Approach

A data hierarchy exists for some criteria. The resulting score indicates the completeness of the data. Chemicals with sufficient documented hazards may be listed without a complete data set, but a problem exists for chemicals with potentially wide-spread use for which there is little or no toxicity data. Estimation methods such as QSARs are used.

System Summary 35

CERCLA Section 102 Reportable Quantity Ranking Process

References

U.S. Environmental Protection Agency (1989). *Technical Background Document to Support Rule Making Pursuant to CERCLA Section 102* (Volume 3) EPA Office of Solid Waste and Emergency Response.

Environmental Monitoring and Services, Inc. (1985). *Technical Background Document to Support Rule Making Pursuant to CERCLA Section 102* (Volumes 1-2). Prepared for U.S. Environmental Protection Agency.

Developed for Use by: EPA

Purpose

To adjust reportable quantities established under CERCLA and the Clean Water Act, in order to:

- reduce the burdens of reporting
- allow EPA to focus on the most serious released
- more effectively protect the public & environment and to make RQs under CWA and CERCLA consistent

Chemicals Addressed

Hazardous substances as defined in CERCLA

Summary of Method or Algorithm

Each hazardous substance is assigned an RQ level of 1, 10, 100, 1000, or 5000 pounds in several categories (aquatic toxicity, mammalian toxicity, ignitibility/reactivity and chronic toxicity/carcinogenicity). The lowest RQ is selected from 6 primary criteria. An increase of 1 RQ level is possible if indicated by secondary criteria (biodegradability, hydrolysis or photolysis).

Criteria, Subcriteria, and Endpoints

Primary criteria

Aquatic Toxicity
- 96-hr LC_{50}

Mammalian Toxicity
- oral LD_{50}
- dermal LD_{50}

Ignitability
- flash point
- boiling point
- pyrophoric (y/n)

Reactivity
- self-reacting
- reacts with water
- inflames with water

Chronic toxicity ("toxicity due to single, repeated, or continuous exposure from a single release or multiple releases")
- MED (minimum effective dose) for repeated exposures (mg/day, 70 kg man)
- type of effect (qualitative scale) (composite score = MED x effects)

Carcinogenicity
- potency factor ($1/ED_{10}$)
- EPA WOE

  A matrix including both results in assignment of high, medium or low

Secondary criteria

Biodegradability
- standard BOD tests

Hydrolysis
- identified as "subject to hydrolysis" in EPA-440/4-79-029

Photolysis
- identified as "subject to photolysis"

Data Selection Approach

An RQ is assigned for each of 4 categories (aquatic toxicity, mammalian toxicity, chronic toxicity/carcinogenicity and ignitability/reactivity) for which appropriate data are available. SARs may be used to assign an RQ when little data are available. The final RQ is the lowest RQ in all four categories.

System Summary 36

The Source Category Ranking System: (SCRS)

References

Radian Corporation. (1990). *The Source Category Ranking System: Development and Methodology*. Prepared for U.S. Environmental Protection Agency Office of Air Quality Planning Standards, Chemicals and Petroleum Branch.

Developed for Use by: EPA, Office of Air Quality Planning Standards

Purpose

To evaluate and prioritize air pollutant source categories for consideration within the regulatory process. It allows users to analyze pollutant hazards on a process of source category basis rather than on a single compound basis.

Chemicals Addressed

Potential air pollutants

Summary of Method or Algorithm

Long-term and short-term health effects and potential exposure are evaluated and scored separately for individual chemicals. First, long-term health effects data are combined with source and exposure data to obtain a long-term score for each chemical. A parallel evaluation is performed for short-term health effects data, combined with source and exposure data, to obtain a short-term score for each chemical. The long-term and short-term scores are then combined for each chemical to calculate a "net score". Net scores for all chemicals within a given source category are combined to yield a "total score". Source categories are then ranked according to their total scores.

Criteria, Subcriteria, and Endpoints

Health effects
- carcinogenicity
- reproductive and developmental toxicity
- acute toxicity
- non-lethal health effects

Exposure
- Pollutant concentration
  - Emissions estimates
    - emission rate
    - emission type (point, area, fugitive)
  - Atmospheric dispersion parameters
    - pollutant release height
    - pollutant release temperature
    - pollutant release flow rate
    - pollutant release vent diameter
  - Emission source data
    - pollutant identification
    - source category
    - state/county code
- Population exposed
  - county code
  - county population
  - county population density
- Estimates of pollutant concentration

Data Selection Approach

Data are needed for each endpoint, but may be estimated, as described. Endpoints for the health effects criteria were not specified.

System Summary 37

Sax Toxicity Rating System

References

Sax, N.I. & R.J. Lewis (1989). *Dangerous Properties of Industrial Materials*, volume 1, seventh edition. Van Nostrand Reinhold, New York.

Developed for Use by

Developed for inclusion in the reference cited to be used by the general public. It has subsequently been widely used by site ranking systems such as the original HRS.

Purpose

To rank chemical substances into three categories - low, medium or high based on toxicity and fire, reactive and explosive hazard.

Chemicals Addressed

A large number of industrial chemicals

Summary of Method or Algorithm

Substances are rated according to qualitative and quantitative criteria as follows:

Slight or mild toxicity (1)

- substances which produce changes in the human body which are readily reversible and disappear when exposure ceases
- LD_{50} between 4,000 and 40,000 mg/kg/day
- LC_{50} between 500 and 2500 ppm
- combustible

Moderate toxicity (2)

- substances which produce reversible changes in the human body, without causing serious physical or health impairment or threatening life
- LD_{50} between 400 and 4,000 mg/kg/day
- LC_{50} between 100-500 ppm
- highly flammable or reactive

High toxicity (3)

- substances which cause irreversible changes in the human body, producing serious physical or health impairment or threatening life
- LD_{50} < 400 mg/kg/day
- LC_{50} between 100 and 500 ppm
- explosive, spontaneously flammable or highly reactive

Criteria, Subcriteria, and Endpoints

Toxicity
- acute local
  - qualitative assessment
- acute systemic
  - qualitative assessment
  - LD_{50}
  - LC_{50}
- chronic local
  - qualitative assessment
- chronic systemic
  - qualitative assessment

Flammability
- qualitative assessment

Reactivity
- qualitative assessment

Explosivity
- qualitative assessment

Data Selection Approach

Quantitative scoring criteria are provided only for acute toxicity. Therefore, it is not clear exactly how the criteria are combined for an overall assessment. It appears as though all available data are used to assign chemicals to one of the three groups and it is not stated how substances with minimal data are characterized.

System Summary 38

Examination of the Severity of Toxic Effects and Recommendations of a Systematic Approach to Rank Adverse Effects

References

Environ Corporation (1986). *Examination of the Severity of Toxic Effects and Recommendation of a Systematic Approach to Rank Adverse Effects*. Prepared for U.S. Environmental Protection Agency, Office of Environmental Criteria and Assessment.

Developed for Use by: EPA

Purpose

To identify issues related to assessing severity, to review pertinent information for understanding how meausres of toxic effects reflect impairment of function and to utilize the resulting knowledge (resulting from this study) and understanding of severity (of toxic effects) to develop and analyze a numerical ranking or scoring scheme that might be used as a supplement to other information in evaluating the health significance of a substance in the environment.

Chemicals Addressed

Not specifically intended for chemical ranking/scoring. It may be applied to data for almost any chemical.

Summary of Method or Algorithm

Two algorithms are presented for determining a total severity score as indicated below:

Scheme 1:

> Total severity score = (histopathology severity score + histopathology score modifier) x organ system factor

Scheme 2:

> Total severity score = (toxicity test endpoint score + toxicity test endpoint modifier)
> (x organ system factor)

Criteria, Subcriteria, and Endpoints

2 Schemes Presented

Scheme 1:

Histopathology severity score (type of histopathologic lesion)
Histopathology severity score modifier
- organ weight change
- biochemical change
- organ system impairment

Organ system factor
based on ranking of organ importance and availability of replacement therapy
includes teratogenesis and fetotoxicity

Scheme 2:

Toxicity test endpoint severity score (based on type of effect)
Toxicity test endpoint severity score modifier
- organ weight change
- histopathological change

Organ system factor
- number or organs or organ systems affected

Data Selection Approach

The system is used to rank the severity of effects and relies on available experimental data only.

System Summary 39

Screening Procedures for Chemicals of Importance to the Office of Water

References

U.S. Environmental Protection Agency (1986). *Screening Procedure for Chemicals of Importance to the Office of Water*. EPA Office of Health and Environmental Assessment.

Developed for Use by: EPA Office of Water

Purpose

A simplified approach for screening and categorizing toxic chemicals

Chemicals Addressed

The approach is suggested for use on chemicals that are important to the Office of Water. It was initially tested on 30 chemicals, including inorganics, organics and pesticides.

Summary of Method or Algorithm

The screening procedure first assigns chemicals to one of a number of ranked categories. Criteria are set for "high" exposure and toxicity based on population and route of concern. Categories, not chemicals, are numerically scored, but chemicals may be ranked within a category. There are some suggested approaches for ranking within these categories. The ranked categories are listed below:

Rank Category

1. Chemicals legislatively mandated
2. Chemicals with high exposure and high toxicity
3. Chemicals with high exposure and low/unknown toxicity
4. Chemicals with high toxicity and low/unknown exposure
5. Chemicals with low/unknown exposure and toxicity
6. Chemicals screened out because of fate properties, etc. (includes chemicals with a very short environmental life time, those known to be "non-toxic", or those outside the EPA's jurisdiction, e.g. drugs)

Chemicals are first examined for inclusion in group 1 and group 6. Those not included in either of these groups are reviewed and compared against criteria established for inclusion into the other groups. The criteria differ for each combination of route and population.

Criteria, Subcriteria, and Endpoints

Toxicity
- Human
  - • human carcinogen (definite /probable/possible)
  - • developmental toxicity
- Aquatic
  - • acute (LC_{50})
  - • chronic

Exposure
- Human
  - drinking water exposure
    - • detection in drinking water
    - • defection in ambient water
    - • detection in wastewater effluent
    - • ENDPART prediction
  - fish ingestion exposure
    - • detected in fish
    - • detected in Ambient waters or sediment and BCF > 1000
    - • detected in wastewater effluents and BCF >1000
    - • ENDPART prediction
- Aquatic
  - • detection in ambient water (sediment /biota)
  - • detection in wastewater effluents
  - • ENDPART prediction
  - • BCF

Data Selection Approach

A score of "high" may be given for human or aquatic toxicity or exposure if one or two of several conditions are met. Therefore, data are not required for every endpoint. QSARs and other prediction models may be used to estimate missing data.

System Summary 40

Measuring Air Quality: The New Pollutant Standards Index (PSI)

References

U.S. Environmental Protection Agency (1978). *Measuring Air Quality: The New Pollutants Standards Index*. EPA Office of Policy Analysis.

Developed for Use by

Local and state air pollution control agencies

Purpose

"PSI provides a simple, uniform way to report daily air pollution concentrations, to tell the public about the general health effects associated with these concentrations..."

Chemicals Addressed

Not intended for chemical ranking or scoring

Summary of Method or Algorithm

A subindex is calculated for each of five air pollutants, as described below:

observed concentration / NAAQS = subindex

where NAAQS is the National Ambient Air Quality Standard.

The Pollutant Standards Index (PSI) is equal to the maximum subindex. This may be used for reporting conditions to the public according to the following scale:

PSI	Conditions
0 - 5	"good"
Above 50	"moderate"
Above 100	"unhealthful"
200 - 299	"very unhealthful"
300 +	"hazardous"
500	"significant harm level"

Criteria, Subcriteria, and Endpoints

Observed concentration of the pollutant
NAAQS

Data Selection Approach

The system can be used whenever the concentration of an air pollutant as well as its NAAQS are known.

Ranking the Relative Hazards of Industrial Discharges to POTWs and Surface Waters

References

Abt. Associates, Inc. (1991). *Ranking the Relative Hazards of Industrial Discharges to POTWs and Surface Waters*. Prepared for U.S. Environmental Protection Agency, Office of Policy Analysis.

Developed for Use by: EPA

Purpose: "To characterize and provide a hazard ranking of TRI releases to Publicly Owned Treatment Works (POTWs) and surface waters"

Chemicals Addressed: TRI Chemicals

Summary of Method or Algorithm

A hazard index is calculated and rankings for facilities, industries, etc. are provided for cancer, chronic and aquatic risk. This is based on the appropriate Reportable Quantity (RQ) for each category and is calculated as follows:

hazard index:

$$H = \text{Ó}\, R_x / RQ_x$$

where

H= Hazard index for set i
R_x= Pounds released of chemical x
RQ_x= Reportable quantity for chemical x

The three hazard values (cancer, chronic and aquatic) are not combined for a composite rank. The ranks for each category are provided separately. Additionally, using rates to reflect partitioning between sludge, air, water and degradation, rankings are provided for the individual pathway within each category (e.g. cancer, chronic, aquatic).

partitioning:

$$p_w = 1 - P_r$$
$$P_r = P_a + P_s + P_d$$

where

P_r= pollutant specific removal percentage
P_w= pollutant specific water partitioning percentage
P_a= pollutant specific air partitioning percentage
P_s= pollutant specific sludge partitioning percentage
P_d= pollutant specific degradation partitioning percentage

Indices may also be adjusted by a population density factor to account for varying human exposure potential around each POTW.

Criteria, Subcriteria, and Endpoints

Toxicity
- Cancer potency
  - RQ
- Chronic toxicity
  - RQ
- Aquatic toxicity
  - RQ

Exposure
- pounds released
- partitioning percentages

Data Selection Approach

RQs are required for ranking. When these are not available, a chemical may still be listed, but not ranked. The method is used for many types of assessments (i.e. to rank facilities, countries, chemicals, etc.). Rankings are separate for cancer vs. chronic vs. aquatic hazard indices.

System Summary 42

Targeting Pollution Prevention Opportunities
Using the 1988 Toxics Release Inventory

References

ICF Incorporated (1990). *Targeting Pollution Prevention Opportunities Using the 1988 Toxics Release Inventory*. Prepared for U.S. Environmental Protection Agency Pollution Prevention Office.

Developed for Use by

EPA Pollution Prevention Office

Purpose

To identify "high priority" TRI chemicals on the basis of toxicity and exposure potential for use in targeting pollution prevention opportunities. Once the "high priority" chemicals were identified the top 50 chemicals, facilities, and SIC codes for releases and transfers were identified.

Chemicals Addressed

1988 TRI chemicals

Summary of Method or Algorithm

1. High priority TRI chemicals were identified based on toxicity and exposure potential, selected for specific release or transfer types as well as for total releases. Chemicals were selected based on type of release/transfer:

- Point source and fugitive air emissions: based on CPF, potential carcinogen RQ, inhalation RfD, TPQ or presence on CAA Amendments List
- On-site land releases and underground injection: based on oral RfD, potential carcinogen RQ, CPF; chemicals with low leaching or soil mobility excluded
- Surface water and POTW releases: based on aquatic toxicity RQ, chronic or acute toxicity AWQC; all chemicals selected from on-site land or underground injection also included
- Off-site transfers to TSDFs: included if selected based on any other release/transfer type

2. An outline of a proposed method for estimating exposure to TRI chemical releases and transfers is also presented.

Criteria, Subcriteria, and Endpoints

Toxicological Potency
- Threshold Planning Quantities (TPQs)
- Reportable Quantities (RQs)
  - acute toxicity
  - chronic toxicity
  - carcinogenic potential
  - aquatic toxicity
- Reference Doses (RfDs)
  - inhalation
  - oral
- Cancer potency factors (CPFs)
- Aquatic Water Quality Criteria (AWQC)
  - acute
  - chronic
- Presence on CAA Amendments List

Ecological Risk[a]
- Phytotoxicity
- Chemicals toxic to soil invertebrates (y/n)
- RQs -aquatic toxicity RQ; chronic toxicity AWQC; acute AWQC

Exposure Potential[a]
- Potentially exposed population size
  - via air
  - via groundwater
  - via surface water
- TRI release and transfer data
- Environmental fate (based on TRI risk screening guide, reference #45)
  - volatilization
  - leaching/soil mobility
  - bioconcentration
  - biological treatment
- degradation
  - abiotic degradation in air
  - abiotic degradation in water
  - biotic degradation in water
  - biotic degradation in soil

It appears as though only those criteria for "toxicological potency" were used in selecting the high priority pollutants. The criteria for "ecological risk" and "exposure potential" were merely suggested, but not utilized.

Data Selection Approach

Each type of release/transfer (e.g. fugitive air, off-site transfers, etc.) has its own algorithm for selecting the "high priority" pollutants. Each algorithm contains several criteria. Chemicals meeting any of the criteria are selected as "high priority" chemicals.

System Summary 43

Chemical Use Clusters Scoring Methodology

References

U.S. Environmental Protection Agency (1993). *Chemical Use Clusters Scoring Methodology*. EPA Office of Pollution Prevention and Toxics, Chemical Engineering Branch, Washington, D.C.

Developed for Use by

EPA, Office of Pollution Prevention and Toxics Design for the Environment Program

Purpose

To systematically identify and screen chemical concerns, emphasizing pollution prevention and the use of safer substances.

Chemicals Addressed

Over 700 chemicals, based on chemical functional use categories

Summary of Method or Algorithm

The method involves four major steps. First, chemicals are assigned to use clusters. Next, data are gathered on: potential human and ecological exposure; potential human and ecological hazard; pollution prevention potential; and past EPA regulatory interest. Then, individual chemicals are ranked within clusters. Finally, clusters are ranked as a whole into high, medium, or low concern categories. The overall chemical and cluster scores are obtained as follows:

Overall chemical score = Human risk reduction potential
+
Ecological risk reduction potential
+
EPA interest score

Overall cluster score = Pollution prevention potential cluster score
+
average chemical score for cluster

Overall pollution prevention cluster score = the mean of the release reduction potential scores and the higher of either human health risk reduction potential or ecological health risk reduction potential cluster score.

Criteria, Subcriteria, and Endpoints

- Potential Exposure
  - Human exposure
    - use volume
    - total releases to the environment
    - consumer use
    - number of potentially exposed workers
    - number of use sites (in SIC codes)
    - bioaccumulation (log Kow)
    - persistence (expert judgement or log Kow)
  - Ecological exposure
    - use volume
    - total releases to the environment
    - number of sites
    - bioaccumulation (log Kow)
    - bioconcentration (BCF)
    - persistence
- Potential hazard
  - Human hazard
    - noncarcinogenic effects
      - reference dose (RfD) [a]
      - reference concentration (RfC) [a]
      - reportable quantity (RQ) [a]
      - threshold planning quantity (TPQ) [a]
      - human health water quality criteria (HHWQC) [a]
      - chronic NOAEL [b]
      - chronic LOAEL [b]
      - subchronic NOAEL [b]
      - subchronic LOAEL [b]
      - human health structure activity team rank (HHSATR)[c]
      - chemical category human toxicity estimate (CCHTE)[c]
      - TSCA §8(e) submission [c]
    - carcinogenic effects
      - weight-of-evidence class
      - q_1^* potency factor [a]
      - RQ potency factor [a]
      - structure activity team rank (SATR) [c]
      - CCHTE [c]
      - TSCA s8(e) submission [c]

Criteria, Subcriteria, and Endpoints, continued:

- Ecological hazard
  - aquatic water quality criteria [a]
  - aquatic toxicity reportable quantities [a]
  - QSARs [b]
  - ecotoxicity structure activity relationships (SARs) [c]
  - chemical category ecotoxicity estimate [c]
- Pollution Prevention Potential
  - human risk reduction potential (HRRP)
  - ecological risk reduction potential (ERRP)
  - release reduction potential
- Past EPA regulatory Interest
  - EPA interest lists (9 lists)

(a) high quality data; (b) medium quality data; (c) low quality data.

Data Selection Approach

Within each category, any one of several endpoints may be used for assessment. Preference is given to data considered to be of high quality, as specified. For the human health hazard potential score, both the carcinogenic and non-carcinogenic effects are scored and the higher of the two is used for chemical scoring. Likewise, when a pool of endpoints are available for other criteria, the highest rank of the highest quality data are assigned.

System Summary 44

Screening Methodology for Pollution Prevention Targeting

References

U.S. Environmental Protection Agency Office of Toxic Substances. (Date unknown). *Screening Methodology for Pollution Prevention Targeting.*

Developed for Use by: EPA

Purpose

"To isolate TRI chemicals which have high production, high releases, and high toxicity concerns"

Chemicals Addressed

The top 100 produced TRI chemicals (based on 1988 TRI)

Summary of Method or Algorithm

A relative hazard score may be obtained for each chemical according to the following equation:
Hazard score = (Onc x 3)+(RDN x 1)+(Chr x 2)+(Eco x 2)
where:
Onc = toxicity score for cancer or oncogenicity
RDN = toxicity score for reproductive, developmental or neurotoxic effects
Chr = toxicity score for chronic toxicity
Eco = toxicity score for ecotoxic effects

Toxicity scores are based on the HERD Structure Activity Team (SAT) matrix indicating relative concern as follows: high=3, mid-high=2, mid = 1

A composite score combines a measure of exposure with the hazard score:

$$\text{Composite score} = \frac{\text{Releases}}{\text{Production}} \times \text{Hazard score}$$

Criteria, Subcriteria, and Endpoints

Toxicity
- cancer weight-of-evidence
- reproductive, developmental, neuro-toxicity
- chronic toxicity
- ecotoxicity

Exposure
- release volume
- production volume

Data Selection Approach

It appears as though missing data become zeros in the calculation of the hazard score. The use of estimation methods is not discussed.

System Summary 45

TRI Risk Screening Guide

References

U.S. Environmental Protection Agency (1989). *Toxic Chemical Release Inventory Risk Screening Guide* (Vol. 1). EPA Office of Toxic Substances. EPA 560/2-89-002.

Developed for Use by

"Those individuals who are involved in interpreting and explaining environmental pollution, exposures, and health risks to the general public, especially at the local or sub-state level."

Purpose

To provide a risk screening procedure that:

- is quick and easy to use
- is scientifically supportable
- is consistent with other EPA risk screening procedures
- can be used with readily available input data
- produces an expression of risk compatible with the type and quality of input data

The framework is intended to aid in priority setting for followup on TRI facilities and chemicals within particular geographic areas.

Chemicals Addressed

TRI chemicals

Summary of Method or Algorithm

"The risk screening system is a simplified version of EPA's Hazard Ranking System." Evaluations are performed on a facility- specific basis by filling out 3 work sheets for each environmental medium of concern:

1. site-specific data
2. chemical-specific data,
3. relative risk work sheet

There are up to 3 media of concern: air, surface water or POTW, and land.
After the facility evaluations, risk-based priorities can be set for follow up investigations of facilities, chemicals, and populations of interest.

This provides guidelines, but it leaves many decisions up to the user.

Criteria, Subcriteria, and Endpoints

Toxicological Potency:

- Reportable Quantities (RQs)
- Threshold Planning Qualities (TPQs)
- Cancer potency (unit risk factors)
- Reference Doses (RfDs)
- Aquatic Water Quality Criteria (AWQC) - acute and chronic

Exposure Evaluation:

- Plausible exposure pathway
  - site-specific data
    - location of chemical release
    - characterization of populations of interest
    - media uses
    - geographic distance to populations of interest
    - physical transport characteristics of area
  - chemical-specific data
    - physical transport characteristics: adsorption, bioconcentration, volatilization (all y/n)
    - environmental transformation characteristics (+ET or -ET)
- Potential environmental levels
  - site-specific data
    - geographic distance to populations of interest
    - physical transport characteistics of area
  - chemical-specific data
    - quantity of release
    - physical transport characteristics
    - environmental transformation characteristics
    - rates of release

Data Selection Approach

This document provides guidelines for setting priorities regarding facilities, but many decisions are left to the user. Therefore, the method of handling data are somewhat flexible.

System Summary 46

TRI Screening in OTS

References

U.S. Environmental Protection Agency (Date unknown). *TSCA's TRI Chemical Risk Assessment Pre-Screening Methodology*. EPA Office of Toxic Substances

Developed for Use by: EPA

Purpose

"Select chemicals for risk assessment and possible regulation under TSCA"

Chemicals Addressed

TRI chemicals

Summary of Method or Algorithm

The evaluation method includes five major steps as listed below:

1. prescreening: deferral of chemicals from first round of screening
2. hazard ranking: "high, medium, low" toxicity concerns
3. exposure ranking: "high, medium, low" exposure rank in each environmental medium
4. exposure evaluation: rough quantitative estimates of site-specific exposures
5. preliminary risk assessment: integration of hazard and exposure information

In the screening process, hazard and exposure rankings are combined and selected chemicals undergo further review. A few chemicals are selected for a more detailed exposure evaluation and preliminary risk assessment.

Criteria, Subcriteria, and Endpoints

Prescreening

- reviewed by the Existing Chemicals Assessment Division (ECAD) to screen out chemicals that are already in a more detailed assessment stage under TSCA and chemicals that are not good TSCA candidates.

Hazard Ranking

e.g. CERCLA RQs, RfDs, carcinogenic slope factors (not specified)

Exposure Ranking:

- TRI data
- fate and transport modeling to air and water
- physical/chemical properties

Data Selection Approach

"This system allows the user to create algorithms to sort and rank chemicals using readily available data." The criteria are not specified and the chemical selection process is ambiguous.

System Summary 47

Priority Setting of Existing Chemicals

References

Weiss, M., W. Kördel, D. Kuhnen-Clausen, A.W. Lange, & W. Klein (1988). Priority Setting of Existing Chemicals. *Chemosphere, 17,* 1419-1443.

Developed for Use by: European Community (EC)

Purpose

A system "allowing the selection of those chemicals on the European market which require priority assessment." Substances are to be assessed for hazard or risk.

Chemicals Addressed

European Inventory of Existing Commercial Chemical Substances

Summary of Method or Algorithm

Separate priority settings are made for air, soil and water. Weights are assigned to indicate the relative importance of a criterion for the three compartments. Ranks are determined for exposure and for biological effects for each chemical. The two ranks are plotted for each chemical in a 2-dimensional diagram (with exposure as the ordinant and effects as the abscissa). Different areas on the diagram could be defined. Four are suggested:

- high priority: substances with high toxicity and considerable exposure
- intermediate priority: substances in a mid-range
- lowest priority: substances with low toxicity and low quantities
- "Black Box": chemicals are of highest priority due to unacceptable biological properties whenever the release ratio is $\geq$ 1 ton/annum

Criteria, Subcriteria, and Endpoints

Exposure Criteria
- quantity in compartment (t/a)
- initial partitioning (t/a)
- biodegradation
- photolysis half life (d)
- accumulation (log P_{ow})

Effects Potential
- carcinogenesis/mutagenesis (y/n)
- prolonged toxicity
  - chronic toxicity (2 yrs)
    - oral / dermal or
    - inhalative
  - subchronic/subacute toxicity
    - oral/dermal
    - inhalative
  - prolonged aquatic toxicity (fish, daphnia; worst case)
  - plant growth
  - algae
  - bioaccumulation or log P_{ow} (<u>if</u> no long term toxicity data available)
- teratogenesis/fertility
  - teratogenesis (y/n)
  - fertility, terrestrial (y/n)
  - fertility, aquatic (y/n)
  - fertility, plants (y/n)
- acute toxicity
  - acute toxicity (not aquatic)
    - rat oral
    - rat dermal
    - rat inhalation
    - birds oral
    - earthworm
  - acute aquatic toxicity (fish, daphnia; worst case)
- skin effects
  - skin irritation (severity)
  - skin sensitization (y/n)

Data Selection Approach

All accessible data are taken into account. A minimal data set is required. QSARs may be used to complete data sets. The minimum data set includes production volume, use type (intermediate/processing/end use) and an acute toxicity test. Missing tests should be performed with high priority. Acute aquatic toxicity and mutagenesis data are also essential, but may be estimated by SARs in most cases. Scores are normalized on a percent scale based on the number of available data.

The Multimedia Environmental Pollutant System Assessment System (MEPAS)
(the follow-up to the Remedial Action Priority System)

References

Whelan, G. et al. (1987). *The Remedial Action Priority System (RAPS): Mathematical Formulations*. U.S. Department of Energy, Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, WA.

Droppo, J.G. et al. (1989). *Supplemental Mathematical Formulations: The Multi-Media Environmental Pollutant Assessment System (MEPAS).* Pacific Northwest Laboratory, Richland, WA.

Strenge, D.C., S.R. Peterson, & S. Sager (1989). *Chemical Data Base for the Multimedia Environmental Pollutant Assessment System (MEPAS): Version 1*. U.S. Department of Energy, Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, WA.

Droppo, J.G., Jr. et al. (1989). *Multimedia Environmental Pollutant Assessment System Application Guidance, Volume 2 - Guidelines for Evaluating MEPAS Input Parameters*. Battelle Memorial Institute, Pacific Northwest Laboratory, Richland, WA.

Whelan, G. et al. (1992). Overview of the Multimedia Environmental Pollutant Assessment System (MEPAS). *Hazardous Waste & Hazardous Materials*, 9 (2), 191-208.

Developed for Use by
Pacific Northwest Laboratories which is operated for the U. S. Department of Energy. MEPAS is used by the DOE in its Environmental Restoration Priority System (ERPS).

Purpose
A site-specific assessment for estimations of potential health impacts. It provides a risk-based ranking of priorities.

Chemicals Addressed
Not intended for chemical ranking or scoring. It includes elements for radioactive wastes, hazardous chemical wastes and mixtures of these.

Summary of Method or Algorithm
The process may be divided into six major steps including identifying the contaminant source, developing the data base, analyzing the transport pathways, performing an exposure analysis and hazard assessment, and assessing the results. The data base is developed with site-specific data. The exposure analysis relies on site-specific fate and transport modelling to estimate exposure via inhalation, ingestion, external dosing and dermal contact. The hazard assessment is for human health and includes assessment of carcinogens, non-carcinogens and radionuclides. The model is much more sophisticated and requires more data than this brief summary indicates.

Criteria, Subcriteria, and Endpoints

Exposure
Relies on site-specific fate and transport modelling and requires many data entries for estimating exposure via the following:

- inhalation
- ingestion
- external dose
- dermal contact

Health Effects (chemical toxicity)

carcinogens

- inhalation cancer potency
- ingestion cancer potency

non-carcinogens

- inhalation RfD
- ingestion RfD

Data Selection Approach

Data are necessary to complete the chemical-specific data summaries. If the necessary data are unavailable, equations may be used to define physical-chemical properties where possible. A data hierarchy is specified for the toxicity parameters when preferred data are unavailable. Default values may be assigned for other parameters in the absence of data.

System Summary 49

Canadian ARET Scoring Protocol

References

ARET Criteria Sub-Committee (ARET)(1993). ARET Criteria Sub-Committee Report, revision date September 27, 1993.

ARET Committee (ARET) (1994), The ARET Substance Selection Process and Guidelines, January, 1994

Canadian Labor Congress (CLC) (1992). *A Critique of the Ontario Hazard Assessment System.* CLC Environment Bureau, Ottawa, Ontario.

Developed for Use by: The Canadian government

Purpose

"To select and develop criteria for identifying candidate substances which, due to their physicochemical and toxicological characteristics, warrant action via ARET".

Chemicals Addressed

The criteria will first be applied to substances in the Chemical Evaluation Search and Retrieval System (CESARS) database. Of approximately 2000 substances in the database, about 25% had sufficient data for screening.

Summary of Method or Algorithm

The sub-committee relied on the MOEE *Candidate Substances List for Bans or Phase-Outs* (Socha et al., 1992) during the development of the selection criteria. The proposed selection process involves the following steps:

1. Rank chemicals by toxicity
   - uses MOEE scoring criteria; and
   - data for at least 3 toxicity elements are required to obtain a normalized toxicity score (NTS). There can be as many as 6 toxicity elements included
2. Screen chemicals by toxicity
   - set an NTS cut-off above which the substances are further considered for action.
   - chemicals receiving a maximum score in any toxicity criterion are further considered for action.
3. Score for bioconcentration and persistence
4. Select substances for inclusion on one of four lists according to the following criteria:
   - The chemical passes the toxicity screen; and
   - Priority List 1: bioconcentration and persistence scores of 7 or 10 (with 10 being the maximum score);
   - List 2A: bioconcentration score of 7 or 10 , but a persistence score lower than 7;

• List 2B: bioconcentration score below 7, but a persistence score of 7 or 10;
• List 3: bioconcentration and persistence scores below 7.

Criteria, Subcriteria, and Endpoints

Persistence
- t ½

Bioaccumulation
- BCF
- log k_{ow}

Acute lethality
- oral LD_{50}
- dermal LD_{50}
- inhalation LC_{50}
- aquatic LC_{50}

Chronic/subchronic

non-mammals

aquatic
- EC_{50}
- MATC
- NOAEC

terrestrial
- subchronic NOEL
- chronic NOEL

plants
- % growth reduction (NOEL,EC_{50})

mammals
- oral NOEL
- inhalation NOEL

Teratogenicity
- effective dose (mg/kg/day)

Carcinogenicity
- combines mechanism of action with number of species
- EPA weight-of-evidence classification
- IARC strength-at-evidence classification

Genotoxicity/Mutagenicity (used only if reliable carcinogenicity data are lacking)
- type of effects (*in vitro* or *in vivo*)

Data Selection Approach

Data for at least 3 toxicity elements, bioconcentration and persistence are required. A data hierarchy is specified for most criteria with preference given to a particular endpoint, duration, etc. Substances for which there are insufficient data are set aside for further data search. Questionable and limited data are flagged. When there are multiple preferred data available for a particular criterion, the "worst case" is selected unless it is deemed to be inappropriate for the Canadian environment.

System Summary 50

Risk Assessment Guidance under CERCLA
- for screening chemicals of potential concern

References

U.S. Environmental Protection Agency (1989). *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual* (Part A). EPA Office of Emergency and Remedial Response, Washington, D.C. EPA/540/1-89/002.

Developed for Use by: EPA

Purpose

"To identify chemicals in a particular medium that - based on concentration and toxicity - are most likely to contribute significantly to risks calculated for exposure scenarios involving that medium, so that the risk assessment is focused on the "most significant" chemicals." This screening process reduces the number of chemicals that are carried through the risk assessment process.

Chemicals Addressed: Chemicals found at Superfund sites

Summary of Method or Algorithm

Each chemical is scored to obtain a risk factor based on its concentration and toxicity according to the following equation:

$R_{ij} = (C_{ij})(T_{ij})$
where:
R_{ij} = risk factor for chemical i in medium j;
C_{ij} = concentration of chemical i in medium j;
T_{ij} = toxicity value for chemical i in medium j (i.e. either the slope factor or 1/RfD)

A total chemical score (per medium) is calculated as follows:
$R_j = R_{1j} + R_{2j} + R_{3j} \ldots R_{ij}$
where:
R_j = total risk factor for medium j; and
$R_{1j} \ldots R_{ij}$ = risk factors for chemical 1 through i in medium j.
A separate R_j is calculated for carcinogenic and non-carcinogenic effects. The ratio of the risk factor for each chemical to the total risk factor (i.e. R_{ij}/R_j) is used to approximate each chemical's relative risk in medium j. Chemicals which do not contribute to a specified fraction of the total risk factor for each medium is not considered further in the risk assessment for that medium.

Criteria, Subcriteria, and Endpoints

Toxicity
- carcinogenicity
  - slope factor (q_1^*)
- non-carcinogenic effects
  - 1/RfD

Exposure
- maximum detected concentration

Data Selection Approach

When determining the risk factor for each medium, the absolute units must be the same among chemicals in a particular medium, although the actual units do not matter. The maximum detected concentration should be used for exposure assessment. For obtaining toxicity information, a data hierarchy is supplied. EPA's IRIS data base is the preferred source, and other data sources are used only if the necessary information is not contained in IRIS. Chemicals cannot be screened using this process if toxicity values cannot be obtained, and these chemicals should not be eliminated from the risk assessment. If both oral and inhalation toxicity values are available, the most conservative is selected. If only one exposure route is likely, the corresponding toxicity value should be used.

A Proposal for Priority Setting of Existing Chemical Substances (EC System)

References

van de Zandt, D.T.J. and C.J. van Leeuwen (1992). A Proposal for Priority Setting of Existing Chemical Substances. Netherlands Ministry of Housing, Physical Planning and the Environment, Risk Assessment and Environmental Quality Division.

Developed for Use by

The Directorate-General for Environment, Nuclear Safety and Civil Protection of the Commission of the European Communities

Purpose

It was designed to rank chemicals on the basis of exposure and effects potential. It is to be used to set priorities for further investigation and to identify chemical substances which could pose a real risk to humans and the environment.

Chemicals Addressed: 51 High Production Volume Chemicals (HPVCs)

Summary of Method or Algorithm

The system would generate four lists of values: human health exposure and effects and environmental (aquatic) exposure and effects. These would be combined into two lists which would include one list of priority substances based on the human health hazard potential and another for environmental hazard potential. Eventually, these two lists could be combined into one final priority list. Scores are obtained as follows:

Aquatic exposure

aquatic exposure score = [log (tonnage x use x distribution x biodegradation + 2.824] x 1.133

Aquatic effects

$EFS = (-\log EFVd \times 1.4) + EFS_i$

EFS = aquatic effects score

$EFVD_d$ = direct aquatic effects value

EFS_i = indirect aquatic effects value

Aquatic priority score

aquatic priority score = aquatic exposure x aquatic effects

Human exposure

human exposure score = [log tonnage x use x physico-chemical score) + 0.903] x 1.45

Human effects

The score is the highest assigned in all categories

Human health priority score

human health priority score = exposure score x effects score

System Summary 51, continued

Criteria, Subcriteria, and Endpoints

Aquatic Exposure
- quantity produced and/or imported (tonnage)
- use pattern
- environmental distribution
  - MacKay Level I modelling
- biodegradation

Aquatic Effects

Acute effects (fish, Daphnia, algae)
- LC_{50}
- EC_{50}

Chronic effects (fish, Daphnia, algae)
- NOEC

Bioconcentration
- BCF
- log K_{ow}
- molecular weight

Human Exposure
- quantity produced or imported
- use patterns
- physico-chemical properties
  - boiling point
  - vapor pressure
  - log K_{ow}

Human Health Effects

Carcinogenicity (were unable to obtain a copy of document where criteria were included)

Mutagenicity
- amount/type of evidence

Reproductive toxicity
- amount/type of evidence

Respiratory sensitization

Repeat dose toxicity

Acute toxicity

Irritation

Skin sensitization

Data Selection Approach

HEDSET data submitted by manufacturers and importers are utilized in the scoring. Sometimes, several data may be available in the data set for the same parameter (e.g. acute fish toxicity). For direct aquatic effects the most sensitive species and/or biological endpoint is selected as the decisive test. For human health effects, all high quality available data are considered, but only one of the applicable criteria is needed for scoring. The highest score assigned becomes the overall human health effects score. Default values are assigned for some parameters in the absence of data.

APPENDIX B
RANKING AND SCORING SYSTEMS IDENTIFIED

Table B-1. Overview of Developers/Users, Purpose, and Approach for Evaluated Systems

System No.	System Name (in the absence of a system name, the title of the document is cited)	Developers/users (reference)	Purpose	Overall approach[b]
1	TRI Environmental Indicators Methodology (2)	By Abt Associates Inc. for U.S. EPA, OPPT (Abt Assoc.,1992)	impact evaluation: "to devise a measure that reflects the impacts of chemical releases and transfers"	chemical-specific
2	ATSDR, "CERCLA Section 104 Third Priority List" (1,2,4)	By and for U.S. EPA OTS and ATSDR (ATSDR, 1992)	priority setting: "to prepare a prioritized list of at least 100 hazardous substances commonly found at NPL sites..." (4)	chemical-specific
3	Existing Chemicals of Environmental Relevance (6)	By and for Society of German Chemists, Beratergremium für Umveltrelevante Altstoffe (BUA) (Behret, 1989a Vol 1)	regulatory action: to select chemicals which should be considered in greater detail from an environmental standpoint	chemical-specific
4	Existing Chemicals of Environmental Relevance II, Selection Criteria and Second Priority List	By and for Society of German Chemists, Beratergremium für Umveltrelevante Altstoffe (BUA) (Behret, 1989b Vol 2)	regulatory action: to set priorities for additional substances and in an advisory function to the German Federal Govt in assessing existing chemicals	chemical-specific
5	Review of Region VII TRI Strategy (1)	By and for U.S. EPA Region VII (Bouchard, 1991)	priority setting: "to determine areas most in need of investigation for further enforcement, remediation, technical assistance or other purposes" (1)	chemical-specific

Table B-1, continued

System No.	System Name (in the absence of a system name, the title of the document is cited)	Developers/users (reference)	Purpose	Overall approach[b]
6	Candidate Substance List for Bans or Phase-outs (6)	By and for Ontario Ministry of the Environment (Socha et al, 1992)	regulatory action: to establish an integrated approach for development and delivery of Ontario MOE's programs (6)	chemical-specific
7	Criteria Identifying High Risk Pollutants (4)	By and for U.S. EPA (BNA, 1991)	regulatory action: to identify high- risk chemicals to evaluate emission reductions under the CAA Amendments of 1990 (1)	chemical-specific
8	A Classification System for Hazardous Chemical Wastes (4)	By authors for general use by those who manage and dispose of hazardous waste (Crutcher & Parker, 1990)	"a relative ranking system for hazardous wastes". Also, "to assist managing and disposal of these substances" (4)	chemical-specific
9	CERCLA Hazard Ranking System (HRS) (1,2,4,9)	By and for U.S. EPA OSWER (EPA, 1990)	regulatory action: "as the means of selecting sites for the NPL" (4)	site ranking
10	Identifying Chemical Candidates for Sunsetting: George Washington University (2, 3)	By GWU and Pollution Probe of Toronto for IJC (Foran & Glenn, 1993)	regulatory action: to develop a mechanism for identifying, evaluating and classifying chemicals as candidates for Sunsetting in the Great Lakes Basin	chemical-specific

Table B-1, continued

System No.	System Name (in the absence of a system name, the title of the document is cited)	Developers/users (reference)	Purpose	Overall approach[b]
11	Existing Chemicals: Systematic Data Collection and Handling for Priority Setting	By a Nordic Working Group for Nordic countries (Gjos et al., 1989)	priority setting: "to develop a systematic method for the selection of chemicals of potential hazard to human health or the environment	chemical-specific
12	Substances and Preparations Dangerous for the Environment: A System for Classification, Labeling and Safety Data Sheets	By a Nordic Working Group for Nordic countries (Gustafsson & Ljung, 1990)	regulatory action: a proposed system for "classification, labelling, and safety data sheets for substances and preparations dangerous to the environment"	chemical-specific
13	Notes on Ranking Chemicals for Environmental Hazard (4)	By authors for general use (Halfon & Reggiani, 1986)	To rank hazardous chemicals (4)	chemical ranking
14	Application of the Hazard Ranking System to the Prioritization of Organic Compounds Identified at Hazardous Waste Remedial Action Sites (1)	By and for U.S.EPA OSWER (Hallstedt et al., 1986)	priority setting: "to target those chemicals that are of highest concern with respect to hazardous waste cleanup and the reduction of hazards to human health" (1)	chemical-specific
15	Modified Hazard Ranking System (mHRS); A Ranking System for Hazardous Waste Sites and with Mixed Radioactive and Hazardous Wastes (4)	By and for U.S. DOE (Hawley & Napier, 1985)	"to allow discrimination of the various radioisotopes that pollute the DOE facilities and to allow ranking of these sites with the HRS" (4)	site ranking (includes a method for scoring radionuclides)

Table B-1, continued

System No.	System Name (in the absence of a system name, the title of the document is cited)	Developers/users (reference)	Purpose	Overall approach[b]
16	A Groundwater Pollution Priority System (GWPPS) (4)	By and for the State of New Jersey (Hutchinson & Hoffman, 1983)	priority setting: to rank sites polluting groundwater (4)	site ranking
17	The Great Lakes Water Quality Agreement (GLWQA) Annex 1, Lists 1,2,3 (6)	By and for International Joint Commission of the US and Canada, Binational Objectives Committee (IJC, 1989)	regulatory action: to identify substances 1) present and toxic in the Great Lakes; 2) for additional study; 3) for additional monitoring in the Great Lakes system (6)	chemical-specific
18	Chemical Scoring by a Rapid Screen of Hazard (RASH) Method	By authors for general use (Jones et al., 1987)	"to present a rapid screening of hazard method (RASH) for estimating the composite relative toxicological potency of hazardous substances"	chemical-specific
19	Systematic Approach for Environmental Hazard Ranking of New Chemicals	By authors for general use in the European Community (Klein et al., 1988)	regulatory action: "to assess the environmental hazard of new chemicals"	chemical-specific
20	WMS Scoring System (2,5,6,8)	by and for Netherlands Directorate General for Environmental Protection (Könemann & Visser, 1988; Timmer et al., 1988)	priority setting: to select chemicals for further study and for development of environmental/health protection policy (6)	chemical-specific
21	Benchmark Comparisons (4)	By authors for general use (Laskowski et al., 1982)	impact evaluation: "to rank pesticides and herbicides" (4)	chemical-specific

Table B-1, continued

System No.	System Name (in the absence of a system name, the title of the document is cited)	Developers/users (reference)	Purpose	Overall approach[b]
22	Michigan Critical Materials Register (MCMR) (2,6,7)	by the State of Michigan for MI DNR (Michigan DNR, 1987)	regulatory action: to list chemicals of high environmental concern used, discharged or disposed of in Michigan (6)	chemical-specific
23	USEPA Unfinished Business Report: A Comparative Assessment of Environmental Problems (1)	By U.S. EPA for the EPA Administrator (Morgenstern et al., 1987)	priority setting: to rank prominent environmental problems by the risk each poses to society to prioritize the use of EPA resources (1)	issue ranking
24	Chemical Scoring System for Hazard and Exposure Identification (1,6) (based on #62)	By and for EPA OTS and ORNL (O'Bryan & Ross, 1988)	regulatory action: "to screen chemicals for further investigation for potential regulation under TSCA" (1)	chemical-specific
25	Effluent Monitoring Priority Pollutant List (EMPPL) (6)	By and for Environment Ontario (1987, 1988)	regulatory action: to develop chemical specific monitoring regulations under MISA (6)	chemical-specific
26	Coastal Hazardous Waste Site Review (4)	By and for NOAA (Beckvar & Harris, 1985)	priority setting: to rank uncontrolled hazardous waste sites that are a threat to the marine environment (4)	site ranking
27	Site Ranking System (SRS) for Chemical and Radioactive Waste (4)	By and for DOE/HAZWRAP (Rechard et al., 1988, 1991)	priority setting: ranking hazardous waste sites according to human health risks (4)	site ranking

Table B-1, continued

System No.	System Name (in the absence of a system name, the title of the document is cited)	Developers/users (reference)	Purpose	Overall approach[b]
28	A Practical Method for Priority Selections and Risk Assessment Among Existing Chemicals (5)	By authors for the Italian government and general use (Sampaolo & Binetti, 1986, 1989)	priority setting: to assess intrinsic chemical dangers, identify data needs, used for priority assessment or risk assessment	chemical-specific
29	UT Chemical Ranking System (2)	by University of Tennessee for EPA RREL (Davis et al., 1993)	priority setting: to prioritize chemicals for safer substitutes evaluation	chemical-specific
30	A Manual for Evaluating Contamination Potential of Surface Impoundments (4)	By and for U.S. EPA (Silka & Swearingen, 1978)	priority setting: "to estimate relative groundwater contamination potential of waste-holding surface impoundments" (4)	site ranking
31	The EPS Enviro-Accounting Method	By Swedish Environmental Research Institute and the Federation of Swedish Industries for general use (Steen & Ryding, 1992)	impact evaluation: a tool for life cycle impact assessment of products	the exact approach is unclear, it includes some chemical-specific properties
32	Defense Priority Model (FY 1993 Version)	By Earth Technology Corp. and ERM Program Management Co. for U.S. Department of Defense (DOD, 1991)	priority setting: "to establish priorities for remedial action" (4)	site ranking
33	Hazardous Air Pollutants: Proposed Regulations Governing Constructed, Reconstructed and Modified Major Sources	By and for U.S. EPA (EPA, 1993b) (40 CFR 63)	regulatory action: identification of the relative human health hazards from air pollutants	chemical-specific

Table B-1, continued

System No.	System Name (in the absence of a system name, the title of the document is cited)	Developers/users (reference)	Purpose	Overall approach[b]
34	Ranking System for Clean Water Act Section 307(a) List of Priority Pollutants (1)	By Battelle for U.S. EPA Criteria and Standards Division (Poston and Prohammer, 1985; Cornaby et al, 1986)	regulatory action: "to determine which chemicals should be added to or subtracted form the Priority Pollutant List" (1)	chemical-specific
35	CERCLA Section 102 Reportable Quantity Ranking Process (2,6,9)	By U.S. EPA and Environmental Monitoring and Services, Inc. for U.S. EPA (EMS, 1985; EPA, 1989c)	regulatory action: to adjust the RQs of hazardous substances designated in CERCLA sec 101(14) (6)	chemical-specific
36	The Source Category Ranking System (1)	By Radian Corporation for U.S. EPA Office of Air Quality Planning Standards, Chemicals & Petroleum Branch (Radian , 1990)	priority setting: "to rank sources of different emissions in order to prioritize air pollutant source categories" (1)	chemical-specific
37	Sax Toxicity Ratings (or Hazard Index)	(Sax & Lewis, 1989)	to briefly identify the level of toxicity or hazard of a material	chemical-specific
38	Examination of the Severity of Toxic Effects and Recommendations of a Systematic Approach to Rank Adverse Effects (1)	By Environ Corporation for U.S. EPA (Environ , 1986)	to differentiate and rank the noncancer effects of chemicals on humans (1)	severity ranking, specific for effects
39	Screening Procedure for Chemicals of Importance to the Office of Water (1)	By and for U.S. EPA Office of Water, Office of Health and Environmental Assessment (EPA, 1986)	priority setting: "to differentiate quickly and inexpensively between higher and lower risk chemicals... (1)	chemical-specific

Table B-1, continued

System No.	System Name (in the absence of a system name, the title of the document is cited)	Developers/users (reference)	Purpose	Overall approach[b]
40	Measuring Air Quality: The New Pollutants Standards Index (1)	By and for U.S. EPA Office of Policy Analysis (U.S EPA, 1978)	an index to measure air quality based on potential acute human health effects of 5 major pollutants (1)	chemical-specific, used only for 5 major pollutants
41	Ranking the Relative Hazards of Industrial Discharges to POTWs and Surface Waters (1)	By Abt. Associates, Inc. for EPA Office of Policy Analysis (Abt Assoc., 1991)	priority setting: "to rank water bodies and POTWs reported in the TRI" It is used to rank facilities, counties and states. (1)	site ranking, includes chemical-specific scoring
42	Targeting Pollution Prevention Opportunities Using the 1988 TRI (1)	By ICF for U.S. EPA Office of Policy, Planning and Evaluation, Pollution Prevention Division (ICF, 1990)	"to rank chemicals and facilities based on total volume of a subset of TRI chemicals" Also used to rank industries (1)	site ranking, includes chemical-specific scoring
43	EPA Design for the Environment Program Use Cluster Scoring System (also called: Chemical Use Clusters Scoring Methodology) (2,3)	By and for U.S. EPA OPPT, Design for the Environment (EPA, 1993a)	priority setting: to improve the chemical screening process and be used to set priorities for risk reduction and pollution prevention	chemical-specific
44	Screening Methodology for Pollution Prevention Targeting (1)	By and for U.S. EPA Office of Toxic Substances (EPA, date unknown)	priority setting: a tool for targeting chemicals for pollution prevention (1)	chemical-specific
45	Toxic Chemical Release Inventory Risk Screening Guide (1)	By and for U.S. EPA Office of Toxic Substances (EPA, 1989a)	priority setting: "to explain both the meaning of TRI data and ways of interpreting the data" (1)	chemical-specific

Table B-1, continued

System No.	System Name (in the absence of a system name, the title of the document is cited)	Developers/users (reference)	Purpose	Overall approach[b]
46	TSCA's TRI Chemical Risk Assessment Pre-Screening Methodology (1)	By and for U.S. EPA Office of Toxic Substances (EPA, date unknown)	regulatory action: "to select the most likely candidates among TRI chemicals for possible regulation under TSCA" (1)	chemical-specific
47	Priority Setting of Existing Chemicals (5)	By authors for the European Community (Weiss et al., 1988)	priority setting: "for priority ranking of existing chemicals with regard to their possible effects on the environment" (5)	chemical-specific
48	Multi-Media Environmental Pollutants Assessment System (MEPAS), formerly the Remedial Action Priority System (RAPS) (4)	By and for U.S. DOE (Whelan et al., 1987; Droppo et al., 1989; Strenge et al., 1989; Whelan et al., 1992)	"as a means of ranking their hazardous, radionuclide, and mixed waste sites" (4)	site ranking
49	Canadian Accelerated Reduction/Elimination of Toxics (ARET) Scoring Protocol (3)	By Canadian Labor Congress for the Canadian government (CLC, 1992; ARET, 1993)	priority setting regulatory action: may be used in various ways for pollution prevention programs in Canada	chemical-specific
50	RA Guidance under CERCLA, screening chemicals of potential concern	US EPA, 1989d	impact evaluation: to select chemicals of potential concern for a baseline risk assessment under CERCLA	chemical-specific
51	EC Proposal for Priority Setting of Existing Chemical Substances (3)	(van der Zandt and van Leeuwen, 1992) (Draft)	priority setting: To identify substances which might pose a "real and significant risk to man and the environment"	chemical-specific

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NOTES:

Table B-1, continued

(a) System numbers are used only as a shorthand method of tracking the systems. They were based on a preliminary alphabetical list of references, but at this time are essentially an arbitrarily assigned number.
(b) A chemical-specific approach is one that includes ranking, scoring or categorizing a list of chemicals based on chemical-specific properties
(1) described in Appendix A of Abt Assoc., 1992
(1')mentioned briefly in Abt Assoc., 1992
(2) discussed by Davis & Jones, 1993
(3) discussed in ICF, 1993
(4) discussed in Waters et al., 1993
(5) discussed in Annex II "Scoring Systems, Description and Evaluation" (author unknown)
(6) discussed in Foran and Glenn, 1993
(7) Hushon and Kornreich, 1984
(8) OECD 1986
(9) discussed in Environ, 1986
(a prime indicates a system was listed or mentioned briefly, but not discussed in that reference)
DNR: Department of Natural Resources
IJC: U.S./Canadian International Joint Commission
GWU: George Washington University
OPPT: Office of Pollution Prevention and Toxics

Table B-2. Overview of Developers/Users, Purpose, and Approach for Systems Identified but not Evaluated

System Name (in the absence of a system name, the title of the document is cited) System No.		Developers/users (reference)	Purpose	Overall approach[b]
53	NY State Dept of health System (4)	(Hawley, 1985)	"to evaluate the potential human health risks due to hazardous waste disposal sites" (4)	
54	RCRA hazardous waste 40 CFR 261 (4)	(U.S. EPA, 1980)		
55	Multistage Scoring (ITC) Scoring System (3,7,8',9)	by Clement Assoc. for ITC/U.S. EPA (ITC, 1977; U.S. EPA, 1977; Nisbet, 1979; Walker, 1993)	"to identify chemicals for further testing" (8)	chemical-specific
56		Roy et al., 1989 (4)		
57		(NFPA, 1980) (4)		
58	Environmental Hazard Assessment of New Chemicals Using Level Zero Data (5,8)	by and for UK DoE (Hinchcliffe, 1982)	to screen new chemicals to determine need for further testing (8)	
59	TRI chemical ranking system (1')	US EPA Office of Water __		
60	EPA Compound Evaluation System (1')	EPA __		
61	National Air Toxics Information Clearinghouse Pollutant Selection and Prioritization Method (1')			
62	OTS Chemical Scoring System (1',7,8',9)	by ORNL, for EPA OPTS (Ross and Lu, 1981)	"to select chemicals for more indepth evaluation by OPTS" (7)	

Table B-2, continued

System No.	System Name (in the absence of a system name, the title of the document is cited)	Developers/users (reference)	Purpose	Overall approach[b]
63	Union Carbide Corp. Industrial Hygiene Sampling and Monitoring Program List (1)	Union Carbide Institute Plant, 1984	to develop a list of priority chemicals for plant monitoring program (1)	
64	Philadelphia Air Pollution Control Board Toxic Air Contaminants List (1)	Air Pollution Control Board of the Phil. Dept of Public Health, 1981	develop chemical lists to require industry emissions reports (1)	
65	DOT Poisonous Substances List (1)	DOT Hazardous Materials Regulations, 49 CFR 172.101		
66	NJ Dept of Environmental Protection Highly Toxic Substances List (1)	State of NJ Dept of Environmental Protection, Division of Environmental Quality		
67	California Air Resource Board Toxic Chemical List (1)	Air Resource Board of the State of California	(any chemical listed in the NIOSH/OSHA Pocket Guide w/ IDLH <2000ppm and VP >20 torr) (1)	
68	Rapid Screening and Identification of Airborne Carcinogens of Greatest Interest (7,8')	by SAI, for California Air Resources Board (Margler et al., 1979)		
69	Louisiana's Environmental Action Plan "Leap to 2000" (1)	Public Advisory and Steering Committee Risk Ranking Retreat Briefing Material, March, 1991		issue ranking
70	Air Toxic "Hot Spots" Program Risk Assessment Guidelines (1)	California Air Pollution Control Officers Association, March, 1990		

Table B-2, continued

System Name (in the absence of a system name, the title of the document is cited) System No.		Developers/users (reference)	Purpose	Overall approach[b]
71	Chemical on Which Data are Currently Inadequate: Selection Criteria for Health and Environmental Purposes (1)	Organization for Economic Co-operation and Development, Berlin, March, 1985	[NOTE: WMS system "follows the lines of the OECD report"] general methodology for a step-wise selection process for chemicals using readily available data sources and expert judgement	
72	Rhone-Poulenc Environmental Index (1)	Rhone-Poulenc memo, July 25, 1991		
73	Select Organic Compounds Hazardous to the Environment and Human Health (7,8,9)	by SRI for NSF (Brown et al., 1975; Nelson et al., 1975; Stephenson, 1977)	"to identify high-exposure compounds for review by NSF panel" (7) "to establish priorities for environmental and human health research" (8)	
74	System for Rapid Ranking of Environmental Pollutants (7,8',9)	by SRI for EPA/ORD (Brown et al., 1976; 1978)	"to choose chemicals on which to prepare scientific and technical reports (STARs)" (7)	
75	TSCA-ITC Scoring System Workshop (7,8')	by Enviro Control Inc for EPA/ITC (Enviro Control Inc., 1979)	"to develop and improved, integrated health and environmental effects scoring system to identify chemicals for which testing is required for ITC" (7)	
76	Hazard Evaluation Procedure for Potentially Toxic Chemicals (7,8')	by Monitoring and Assessment Research Centre (MARC), for UNEP (Harriss, 1976)	"screening procedure to identify high-risk chemicals" (7)	

Table B-2, continued

System Name (in the absence of a system name, the title of the document is cited) System No.		Developers/users (reference)	Purpose	Overall approach[b]
77	Hazard Assessment by a Qualitative System (7,8)	by Assn. Chimie et Ecologie for the French Ministere de l'Environment (Jouany et al., 1982; 1983)	"to determine whether a new chemical represents a hazard based on MPD data" (7) and to determine further information needs (8)	chemical ranking
78	Integrated Environment Management Program (1,9)	(IEMP, 1983): Integrated Env Mgmt Program, briefing notes from Alan M. Ehrlich	"to incorporate the severity of the toxic effect into a chemical release ranking system (1)	
79	Pesticide Manufacturing Air Prioritization (7,8')	by Monsanto, for EPA/IERL (Archer, et al., 1978)	"to characterize airborne exposures to synthetic organic pesticides" (7)	
80	Sequential Testing for Chemical Risk Assessment (7,8',9)	by and for Eastman Kodak Co. (Astill et al., 1980)	"to rank the toxicity of a new chemical by a variety of routes and test systems"(7)	
81	Index of Exposure (7,8')	By Auerbach Assoc., for EPA (Auerbach Assoc., Inc., 1977)	"to indicate the relative potential for exposure associated with a given use of each chemical"(7)	
82	Chemical Hazard Ranking System (7,8')	by IIT Research Institute, for CPSC (Becker, 1978)	"to rank chemical components of consumer products by probable health impact"(7)	
83	System for Evaluation of the Hazards of Bulk Water Transportation of Industrial Chemicals (7,8',9)	by NAS, for U.S. Coast Guard (Beckman et al., 1974)	"to identify hazards of chemicals being transported by water"(7)	

Table B-2, continued

System Name (in the absence of a system name, the title of the document is cited) System No.		Developers/users (reference)	Purpose	Overall approach[b]
84	BAAR Inc. Model (7,8',9)	by Booz-Allen Appleid Research Inc. (1973; 1975), for EPA/SWRL	"to develop a system to rank dumpsite chemicals as to whether they present a hazard" (7)	
85	Ranking Algorithm for EEC Water Pollutants (7,8',9)	by SRI, for the European Economic Community (EEC) (Brown et al., 1980)	"to select a subset of chemicals present in the aquatic environment for further study" (7)	
86	Setting Priorities for Research and Development on Army Chemicals (7,8',9)	by SRI, for USAMRDC, (Brown et al., 1977; 1978)	"to select research priorities"(7)	
87	Estimating the Hazard of Chemical Substance to Aquatic Life (7,8')	by ASTM Committee D-9 (Cairns et al., 1979)	"to determine what impact chemicals will have on aquatic life"(7)	
88	Estimation of Toxic Hazard - a Decision Tree Approach (7,8')	by Flavor and Extract Manufacturer's Assoc. (FEMA) (Cramer et al., 1978)	"to identify potentially dangerous food constituents for additional testing" (7)	
89	An Approach to Prioritization of Environmental Pollutants: the Action Alert System (7,8')	by A.D. Little, for EPA/OWRS (Fiksel and Segal, 1982)	"to help the OWRS to set priorities regarding chemicals identified in water"(7)	
90	Scoring of Organic Air Pollutants (7,8',9)	by MITRE corp, for EPA/OAQPS (Fuller et al., 1976)	"to select organic air pollutants for more indepth study"(7)	
91	Ranking of Environmental Contaminants for Bioassay Priority (7,8')	by SRI, for NCI (Gori, 1977)	"to select chemicals for NCI bioassay" (7)	

Table B-2, continued

System Name (in the absence of a system name, the title of the document is cited) System No.		Developers/users (reference)	Purpose	Overall approach[b]
92	PHL Model (7,8')	(Hagerty et al., 1973)	"to identify landfill components likely to represent human health hazards" (7)	
93	Selection of Chemicals for Inclusion in a Trend Monitoring (7)	by MITRE, for Federal Republic of Germany (Hushon et al., 1978)	"to select chemicals and chemical classes to include in a monitoring program to follow trends" (7)	
94	RCRA Risk/Cost Policy Model (1',7,8',9)	by ICF Inc., for EPA/OSW (ICF Inc., 1982; 1984)	"to identify relative risks from exposure to chemicals in wastes" (7)	
95	Ranking of Food Contaminants (7,9) or Priority Setting of Toxic Substances for Guiding Monitoring Programs (8')	by Clement Assoc., for OTA (Kornreich et al., 1979; 1980)	"to identify for OTA organics, inorganics, and radionuclides that are possible food contaminants" (7)	
96	National Occupational Hazard Survey (7,8')	by and for NIOSH (NIOSH, 1977)	"to rank hazards according to the amount of occupational exposure" (7)	
97	Assessment of Oncogenic Potential (7,8')	by Hooker Chemical (Nees, 1979)	"to identify carcinogens and to rank them relative to the evidence" (7)	
98	ITC Scoring for Exposure (7)	by Clement Assoc., for EPA/ITC (OTS/EPA, 1977)	"to rank chemicals on the basis of potential for human exposure and environmental release" (7)	
99	Ordering of Commercial Chemicals on NIOSH's Suspected Carcinogens List (7,8')	by EPA/OTS (OTS/EPA, 1977)	"to determine which suspected carcinogens are of concern to OPTS" (7)	

Table B-2, continued

System Name (in the absence of a system name, the title of the document is cited) System No.		Developers/users (reference)	Purpose	Overall approach[b]
100	Identification of High-Risk Occupational Groups and Industrial Processes Using RTECS/NOHS Data (7,8',9)	by Tracor Jitco, for NIOSH DCCP/NCI (Pielmeier, 1981; NIOSH, 1983)	"tool to objectively assess potential health risk from workplace exposures" (7)	
101	OECD Ecotoxicology Testing Scheme (7)	by Battelle, for EPA/OPTS (Pommeroy et al., 1980)	"to test how well aquatic tests predict hazard potential" (7)	
102	Ranking Animal Carcinogens (7,8',9)	Squire (1981)	"to classify animal carcinogens to permit the use of different regulatory options" (7)	
103	Environmental Scoring of Chemicals (7)	by ORNL, for EPA/OTS (Ross and Welch, 1980)	"to select chemicals presenting an environmental risk under TSCA and for use by ITC to identify chemicals for additional environmental testing" (7)	
104	Catalogue of Water Pollutants (8)	Germany: (Unweltbundesamt, Berlin, 1979; 1983)	"to place substances into categories according to their potential for water pollution" (8)	
105	UBA Environmental Hazard Ranking System (8)	for German Unweltbundesamt (SRI Intl, 1982; Klein and Haberland, 1982)	"multi-stage scoring system to screen new chemicals for further decisions, including testing needs" (8)	
106	Defining Priorities for the Italian Inventory of Substances (8)	(Costatini et al., 1982)	to develop a national inventory of chemical substances relevant to human health and environmental risk (8)	

Table B-2, continued

System Name (in the absence of a system name, the title of the document is cited) System No.		Developers/users (reference)	Purpose	Overall approach[b]
107	MITI and Ministry of Health and Welfare System (8)	Japan: MITI and Ministry of Health and Welfare (Kobayski, 1981)	"sequential testing system for selection of chemicals for regulation" (human health and environment) (8)	
108	NEDF Technical Department System (8)	Sweden: National Environmental Protection Board (Firm, 1982)	"to identify and classify industrial chemicals by industry segment with environmental concern" (8)	
109	Dangerous Substances Which Might be Included in List 1 (8)	for the EEC (Official Journal of the European Communities, 1982)	to determine dangerous substances (aquatic environment) which might be included in List 1 of Council Directive 76/464/EEC (8)	
110	FDA Levels of Concern (8,9)	U.S. FDA (1982)	"specific criteria for establishing the safety of new additives and to assure their continued safety" (8)	
111	Priorities for the Evaluation of Flavoring Substances (8)	Joint FAO-WHO Expert Committee on Food Additives (Stofberg, 1981)	"to establish, in decreasing order of potential health hazard, the order which flavoring materials should be evaluated" (8)	
112	Selection for Environmental Survey Programme (8)	Japanese Environment Agency (1983)	"for selection of environmentally persistent chemicals for long-term monitoring" (8)	
113	Review of Strategies for Identifying Hazardous Chemicals (8')	Canada, Dept. of Health and Welfare (Van Netten)		

Table B-2, continued

System Name (in the absence of a system name, the title of the document is cited) System No.		Developers/users (reference)	Purpose	Overall approach[b]
114	Environmental Hazard Ranking System (8')	by SRI, for German UBA (Klein and Haberland)		
115	OTS Pre-screening System (8')	by A.D. Little, for EPA		
116	Cosmetics Ingredients Review (8')	by CIFA, for CIPA [sic]		
117	Food Animal Additives (8')	by and for FDA		
118	Automatic Procedure for Carcinogen Assessment (8')	by Dehn et al, for NCI		
119	Investigation of Industrial Chemicals as Potential Food Contaminants (8',9)	by and for FDA (Oiler et al., 1980)	"to evaluate toxic materials that may be residues in food supplies" (9)	
120	System for Food Safety Assessment (8')	by the Food Safety Council		
121	Hazard Assessment of Chemicals in the Aquatic Environment (8')	by Branson		
122	Multimedia Environmental Goals for Environmental Assessment (8')	by Cleland et al., for EPA		
123	Environmental Assessment Sampling and Analysis	by Dorsey et al., for EPA		

Table B-2, continued

System No.	System Name (in the absence of a system name, the title of the document is cited)	Developers/users (reference)	Purpose	Overall approach[b]
124	Identification Systems for Selecting Chemicals as Candidates for Evaluation (8')	by Battelle, for EPA (Flinn et al.)		
125	Ranking of Hazardous Materials by Means of Hazard Indices (8')	by Jones		
126	Priority Pollutants (8')	by Keith and Telliard		
127	Environmental Safety of New Materials (8')	by Monsanto, for ASTM (Kimerle et al.)		
128	Economics-Based Methodology for Projecting Future Pollution Problems (8')	by Battelle, for EPA (Stacey and Flinn)		
129	Criteria and Procedures for Chemical Selection (8')	by SRI, for NCI		
130	Toxicity Testing - Strategies to Determine Needs and Priorities (8',9)	by Nat'l Research Council of NAS, for the Nat'l Toxicology Program/Nat'l Institute of Environmental Health Sciences (NRC, 1982)	"to develop criteria for selecting substances and determining toxicity-testing needs" (9)	
131	International Report: Priority Pollutants Project (8',9)	by UNEP (UNEP, 1978)	"to identify and control hazardous environmental chemicals" (9)	
132	Criteria to Select Chemicals for Carcinogenicity Testing (8')	for IARC		

Table B-2, continued

System No.	System Name (in the absence of a system name, the title of the document is cited)	Developers/users (reference)	Purpose	Overall approach[b]
133	Assessment of Air Emissions from Hazardous Waste, Treatment Storage and Disposal Facilities (9)	by Land Disposal Branch of the OSW (CGA, 1983)	"to prioritize chemicals which are potential air pollutants at hazardous waste treatment, disposal and storage facilities" (9)	chemical ranking
134	Toxicity Scoring System Using RTECS Database (9)	by Clement Assoc., for the Hazardous and Industrial Waste Division of OSW (Clement, 1982)	"to classify substances according to their inherent hazard" (9)	chemical ranking
135	Washington State, Degree of Hazard Scheme (9)	Washington Department of Ecology (1978)	to "classify wastes for purposes of characterization and management" (9)	
136	Rhode Island, Degree of Hazard Scheme (9)	State of Rhode Island (1981)	"for the classification and management of hazardous wastes" (9)	
137	California Degree of Hazard Scheme (9)	State of California Department of Health Services (1982)	to "classify wastes for purposes of waste management" (9)	
138	Management of Hazardous Wastes by Degree of Hazard (9)	Chemical Manufacturers Association (CMA, 1979)	"for use in the management of hazardous wastes" (9)	
139	Classification by Degree of Hazard (9)	by Dow Chemical USA (Dow Chemical, 1979)	to place substances in hazard categories (9)	
140	Steps Towards Environmental Hazard Assessment of New Chemicals (9)	(Schmidt-Bleek et al., 1982)	"to select from many new chemicals, a few which are potentially Hazardous" (9)	
141	Environmental Impact Evaluation of Hazardous Waste Disposal in Land (9)	(Pavoni et al., 1972)	"a priority-rating system which evaluated quantitatively the environmental impact resulting from the landfilling of hazardous wastes" (9)	

Table B-2, continued

System Name (in the absence of a system name, the title of the document is cited) System No.		Developers/users (reference)	Purpose	Overall approach[b]
142	IARC Carcinogen Ranking Scheme (9)	(IARC, 1982)	"to be used in the assessment of the carcinogenicity of a chemical" (9)	
143	EPA-CAG Carcinogen Ranking Scheme (9)	(EPA, 1984)	"to assess the weight of evidence that a chemical is a carcinogen" (9)	
144	National Toxicology Program Carcinogen Ranking Scheme (9)	(NTP, 1984)	a series of categories relating to the strength of experimental evidence that a chemical is a carcinogen (9)	
145	RCRA Risk-Cost Analysis Model (1)			
146	Polaroid Five-Category Ranking Scheme (1)	Polaroid Corporation, 1991	to categorize chemicals in order to set goals for chemical use reduction based on the Mass. Toxics Use Reduction Act	
147	The Boston Herald Algorithm (1)	The Boston Herald, May 13, 1991	considers volume and toxicity to rank chemical releases	chemical ranking
148	The European Communities Council Directive Chemical Hazard List (1)	EEC, 1982	An industry must list its uses of any of the chemicals on the list as mandated by the EC	

NOTES:
(a) System numbers are used only as a shorthand method of tracking the systems. They were based on a preliminary alphabetical list of references, but at this time are essentially an arbitrarily assigned number.
(b) A chemical-specific approach is one that includes ranking, scoring or categorizing a list of chemicals based on chemical-specific properties
(1) described in Appendix A of Abt Assoc., 1992
(1')mentioned briefly in Abt Assoc., 1992
(2) discussed by Davis & Jones, 1993
(3) discussed in ICF, 1993
(4) discussed in Waters et al., 1993
(5) discussed in Annex II "Scoring Systems, Description and Evaluation" (author unknown)
(6) discussed in Foran and Glenn, 1993
(7) Hushon and Kornreich, 1984
(8) OECD 1986
(9) discussed in Environ, 1986
(a prime indicates a system was listed or mentioned briefly, but not discussed in that reference)
DNR: Department of Natural Resources
IJC: U.S./Canadian International Joint Commission
GWU: George Washington University
OPPT: Office of Pollution Prevention and Toxics