Suggestions for the Development of a Hazard Evaluation Procedure for Potentially Toxic Chemicals

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PREFACE

When a chemical substance, however beneficial, is used by man there is nearly always some element of risk of inconvenient side-effects, potentially harmful to man himself, to his crops and livestock, or to wildlife. Although it may be difficult enough to assess the risk with chemical substances which already exist in the environment but which are being manufactured in increasing amounts by man, the real difficulty arises with newly synthesized chemicals. Appearing for the first time on earth, neither man nor any other living thing has been exposed to them. As such, no biochemical mechanisms may be available to render them harmless.

This basic problem is aggravated by lack of background information about their behaviour and by their sheer numbers; many thousands are already in use with several more being introduced daily. Gathering experimental information on their potential hazards is so expensive and time consuming that it is quite impossible to test all of them carefully.

Either we do nothing and wait for side-effects to appear before restricting the worst offenders or we try to predict as best we can the ones likely to pose the greatest risk. This latter alternative, although admittedly inadequate, can possibly be developed from the systematic collection of all the available information on physico-chemical and other salient properties relevant to potential harm. Hopefully, in this way, some crude first-screening procedure can be evolved to characterize the most likely high-risk chemicals. The limited resources that are available could then be concentrated on further study of these — future monitoring and other more careful checking procedures.

Many governments and industrial companies have been attracted to the idea. The drug industry has developed hazard schemes for risks to human health and this gives some hope that parallel schemes could in future be evolved for potential risk to the environment. However, systematic guidelines for carrying this out are so difficult to construct that many believe the task to be hopeless.

The author of this paper is well aware of the difficulties but feels that a good deal more detailed work is needed before conceding defeat. It is hoped that the initial thinking set down here will act as a stimulus for the international discussion needed to build a more secure framework for the chemical screening process. Practical experience with screening familiar chemicals should eventually indicate how

usable the concept really is.

In the meantime, readers are invited to assist by sending to MARC ideas and suggestions for improvement. One of the basic questions is whether separate hazard estimates should be developed for man as distinct from agricultural resources and from wildlife.

It is to be hoped that this frankly tentative and preliminary Research Memorandum will provide the basis for a future Technical Report on a screening procedure for new chemicals.

Gordon T. Goodman
Director

1.0 Introduction

This document presents initial thinking on the development of a methodology designed to identify those chemicals being released into the environment which are likely to cause undue perturbations in essential biological processes.

At present it is difficult, time-consuming and costly to assess the relative advantages and disadvantages resulting from the use of a particular chemical. An assessment of environmental costs related to the use of a particular substance requires information on the magnitude of its impact in relation to environmental exposure, and the value attached by society to the environmental resources which suffer negative effects.

The world's industrialized nations are currently producing annually over 10,000 chemicals in amounts exceeding 500 kilograms. Many of these chemicals become widely dispersed in the environment during their production, transport, use, and disposal. Only in a few cases (*e.g.* DDT, mercury, and the radioactive elements) have extensive studies on environmental costs versus social benefits been attempted. The results of these few assessments demonstrate clearly that the complexity, costs and time taken in trying to measure the innumerable potential effects of changes in the environment related to the release of each new chemical will be beyond the capability of even the rich nations.

Different nations have evolved a wide range of strategies for environmental protection in general and for the regulation of chemicals in particular. However, none of the existing strategies for environmental protection has proved entirely successful. Although environmental quality is being improved at the local scale in some cases, the overall number and complexity of trace substances in the regional and global environment continues to increase.

The primary objective in developing the methodology in this document is to design a low cost, rapid process for organizing and evaluating available data and expert judgement in a manner which will provide the best possible early warning indications of potential environmental hazard related to the production and use of a particular chemical. The questions used in the assessment seek answers based, as much as possible, on hard factual information. However, because the assessment is focused on an early warning of the entire range of possible consequences to the biosphere related to the release of a chemical, and should therefore ideally be used at the pre-market

phase of production, certain aspects of the methodology must necessarily be based on expert judgement and preliminary information. The assessment must be continually revised as improved information becomes available. The output from this procedure is an aid to, not a substitute for, the final determination of acceptable risk which must be reached by decision-makers accountable to society.

2.0 Hazard evaluation as a link between the IRPTC and GEMS in Earthwatch

Two current UNEP activities under the Earthwatch Program are the establishment of an International Referral System (IRS) and the implementation of a Global Environmental Monitoring System (GEMS). An important component of IRS is the International Registry for Potentially Toxic Chemicals (IRPTC) which is a data bank of information including the physico-chemical characteristics, production rates, and uses of commercially produced chemicals which may pose environmental hazards. Among other things, GEMS is being set up to assess the magnitude and distribution of chemical contaminants in the biosphere (1). However, there is a fundamental problem which now must be addressed if GEMS is to accomplish its goal in this area of concern. Since the number of potentially hazardous chemicals produced each year far exceeds the number which can be exhaustively monitored given certain budgetary and scientific limitations, how can priorities best be established?

The assessment methodology described in the present document is intended as a preliminary step towards designing a process to link the chemical data in the IRPTC to the GEMS effort by translating the available data into a ranking of chemicals in relation to the relative hazard they may pose to components of the biosphere. The data in the IRPTC (or any other chemically related data bank) can serve as primary input to the assessment process proposed here. The output of the assessment is a priority listing of chemicals ranked according to the relative hazard they pose to the biosphere and, as such, is one component of the total contribution needed to establish priorities for GEMS.

There is a growing body of opinion both nationally and internationally that it is becoming increasingly necessary to have some mechanism for evaluating at an early stage, the safety of chemicals which are likely to be dispersed in the environment in significant amounts. This author is aware of two national programs on com-

prehensive environmental hazard evaluation procedures for chemicals *viz.*, that by the Stanford Research Institute for the National Cancer Institute of the United States, and draft legislation by the French government. Most of the other existing national research and legislative efforts are focused on specific media (air, water, food, etc.) or pollutants. The legislative action most compatible with the type of assessment proposed in this document is the Toxic Substances Control Act now pending in the United States Congress.

The testing of chemicals is expensive and the results are often highly controversial. In the case of chemicals likely to be dispersed in the regional or global environment, and where the cost/benefit situation will clearly vary from one country to another, it would seem reasonable that internationally agreed basic criteria for evaluation should be available. This could best be done by an international organization such as the United Nations rather than separately by individual nations. Thus, the development of hazard assessment techniques would seem desirable for Earthwatch.

3.0 Rationale for the proposed hazard evaluation methodology

The ensuing section is a general discussion of the rationale for the proposed hazard evaluation scheme in terms of the assumptions made, criteria used to identify potential chemical hazards in the environment, and some of the problems in quantification of relative hazard.

A preliminary checklist for evaluating hazards is presented in Annex 1. The further step of synthesizing checklist entries into a single rating is the subject of further investigation, but some possible alternative methods are mentioned in Section 3.3.

3.1 Assumptions

The following four assumptions underlie the design of the hazard evaluation checklist presented in Annex 1:

(1) The checklist is designed as a working tool for the immediate problem of screening a large number of unevaluated chemicals and will be continually improved in the light of experience gained from application.

(2) The checklist, at present, is likely to identify clearly only the most serious possible situations where immediate regulation of a chemical is required and cases where the maximum projected scale of intended production and use should result in little or no risk to the environ-

ment. Any finer resolution of potential hazards will require a more detailed and expensive assessment. **However, it should be emphasized again that this checklist is intended only as a first screening device for the early warning of potential hazard**. In cases where information is inadequate or the assessment is inconclusive, the hazard evaluation process may spotlight important research and monitoring needs for a particular chemical.
(3) Any hazard assessment of a particular chemical is dependent on the status of available information and must be regularly updated as new information becomes available.
(4) It is unlikely that any chemical can ever be proven to be environmentally safe. The best approach to the assessment of potential hazards is to reduce uncertainty in the range of potential impacts and to stimulate planning to minimize the effects of low probability, high risk failure situations.

3.2 Criteria for evaluating potential chemical hazards
The criteria used in the proposed checklist (Annex 1) to evaluate the relative hazard posed by chemicals anthropogenically introduced into the environment can be generally grouped into five categories including:
(1) Scale of production, use patterns, and expected magnitude of environmental exposure under normal operating conditions.
(2) Projected environmental biogeochemistry with emphasis on transport pathways, concentration mechanisms, and ultimate environmental stability of the chemical.
(3) Identification of potential receptor organisms.
(4) Acute and chronic toxicity of the chemical to potential receptor organisms at maximum projected exposure conditions. Where possible this factor should also include consideration of system impacts with indirect toxicity (*e.g.* climate change, chemical transformation of a relatively harmless chemical to a more toxic byproduct in the environment, etc.).
(5) Likelihood and possible consequences of accidental exposure during production, distribution, use and disposal and/or recycling.

The development of these criteria is based on previous literature (2-5) which was available to this author, and on discussions with the MARC scientific staff. Unfortunately, much of the research on hazard assessment being conducted for governmental organizations is not published in the open literature and is therefore not readily available

for study and comparison.

3.3 Problems in quantifying relative risk

Once a set of criteria relating to the potentially hazardous characteristics of chemicals are established, a mechanism is required to quantify the relative risk of the many different chemicals being introduced to the environment. The criteria alone are only a qualitative statement of the potential hazards which should be considered in an assessment. In order to aid the decision-making process, techniques are required to determine priorities for different actions such as immediate regulation, continued research and development, monitoring, and/or approval for unrestricted use. Governmental and international organizations such as the World Health Organization, National Cancer Institute (U.S.), and Environmental Protection Agency (U.S.) are continually faced with the problem of establishing a priority ranking for potentially hazardous chemicals. Once established, the relative risk of using a particular chemical can then be compared to the relative social benefits expected from the chemical (an entirely separate assessment is required to determine relative social benefit) and these factors plus any other considerations must be subjectively evaluated by a decision-maker responsible to the public.

The design of a mechanism for quantifying relative risk from different chemicals using the criteria presented in the proposed assessment methodology is very incomplete. In this document the evaluation of a chemical involves an assessment of each of the five basic criteria for evaluating potential hazards. The criteria involve several factors which are presented in the form of questions or statements requiring specific information which can be related to hazard potential. Each factor, which is in the form of descriptive statements, is accompanied by a preliminary hazard rating scheme which simply ranks responses into high, medium, and low hazard potential.

The development of a more quantitative procedure for ranking responses to the assessment presented in Annex 1 is still under active investigation. Ideally the ranking procedure should be set up such that information on each chemical can be translated into a relative hazard ranking using a format compatible with computer analysis.

Several alternative approaches to ranking include:

(1) A numerical hazard rating can be specified for each response to any factor in the assessment. A comparative hazard ranking can then be obtained by simple numerical analysis if the factors are treated as independent variables.

(2) A pattern analysis scheme* might be used to identify particular combinations of potential hazards which require different types of response. For example, chemicals could be ranked according to priorities for regulation, monitoring, and research. This type of analysis would require a differential weighting scheme for each ranking objective.
(3) The hazard rating scheme for objective factors might be quantified on a numerical basis, with subjective factors being rated on a probability scale.
(4) Techniques such as Delphi Analysis* and Cross Impact Analysis* should also be considered both as means for establishing individual ratings for specific factors and as possible summary ranking methodologies.

The hazard assessment checklist presented in Annex 1 can at the very least be used in its present format as a qualitative list of factors which should be considered in evaluating the potential hazards a chemical may pose to the environment. If the preliminary rating scale presented in this document is applied with caution it may be possible to identify the extreme high and low risk groups of chemicals in a semi-quantitative manner, even at this stage. However, during further development, special attention will have to be paid to certain interactive combinations of factors. Thus high and accelerating production of a chemical will only denote a high hazard rating if hazards are high from other factors, *e.g.* acute and chronic toxicity.

4.0 References

(1) Martin, B., and Sella, F., (1976), Earthwatching on a macroscale. *Environ. Sci. Tech.* **10**: 230-233.
(2) Goodman, G. T., (1974), How do chemical substances affect the environment? *Proc. R. Soc. Lond.* B. **185**: 127-148.
(3) National Academy of Sciences, (1975), *"Principles for evaluating chemicals in the environment."* Printing and Publishing Office, NAS, Washington, D.C., 454 pp.
(4) Flinn, J. E. and R. Reimers, (1974), *"Development of predictions of future pollution problems."* Environmental Protection Agency Report EPA-600/5/74-005, 132 pp.
(5) Environmental Protection Agency (1975) Papers of a seminar on early warning systems for toxic substances. Report No. EPA-560/1-75-003, 201 pp.

* These are well-established statistical techniques described in medium level textbooks.

ANNEX 1 — CHECK LIST

I **Scale of production, use patterns, and expected magnitude of environmental exposure under normal operating conditions.**

1. What trends are forecast for production over the next five years?

Hazard Rating	Description
low	Decrease in production associated with phase-out of all use.
medium	Production likely to be below 10 000 kilograms annually.
high	Significant (>25 per cent) production increases expected.

2. Estimate total production of the chemical to date.

Hazard Rating	Description
low	Total production to date less than 1000 kilograms.
medium	Total production to date between 1000 and 100 000 kilograms.
high	Total production to date exceeds 100 000 kilograms.

3. What is the projected primary use pattern for the chemical?

Hazard Rating	Description
low	Highly restricted use at easily identified sites *(e.g.* hospitals, research, etc.).
medium	Unrestricted use at easily identified sites *(e.g.* industries).

high	Unrestricted use at non-point sources (*e.g.* agriculture, general household use).

4. Estimate the relative social and political complexity of projected use patterns.

Hazard Rating	Description
low	No international trade in this chemical.
medium	International trade restricted to a single continent.
high	International market with potential for global consumption.

5. If the chemical under investigation is similar to a naturally occurring substance how does the quantity used by human activities compare to the natural geochemical fluxes?

Hazard Rating	Description
low	Chemical production less than 10 per cent of natural geochemical fluxes.
high	Chemical production is greater than 10 per cent of natural geochemical fluxes.
high	The chemical is a synthetic compound with no natural analogue.

6. Does a satisfactory substitute exist which can be used in place of the chemical?

Hazard Rating	Description
low	Chemical substitutes exist which are within 10 per cent of the cost of the chemical under investigation.

medium	Chemical substitutes exist but will increase costs by more than 10 per cent.
high	No known substitutes are available.

II Environmental biogeochemistry: Transport, pathways, concentration, and stability.

1. What is the physical nature of the chemical when released to the environment?

Hazard Rating	Description
low	Chemical always occurs in solid state.
medium	Chemical occurs primarily in liquid state.
high	Chemical can occur in all natural media including gaseous phase.

2. Estimate the order of magnitude of the expected dispersion rate in the environment.

Hazard Rating	Description
low	Ultimate dispersion from any release will be restricted to the immediate area (radius of 10km. from point of release).
medium	Limited mobility with primary dispersion pathway restricted to sediment and/or water transport. Long term release likely to result in regional contamination.
high	Dispersion in gaseous phase with global distribution within one year.
high	No estimate of chemical mobility in the environment.

3. Does the chemical exhibit physico-chemical properties which indicate a potential for persistence in any environmental medium?

Hazard Rating	Description
low	Highly unstable in air, water, and soil, likely to persist less than 48 hours following environmental release.
medium	Stable in at least one environmental medium for periods of up to 2 months following release to the environment.
high	Stable in at least one environmental medium for periods of up to 100 years.
high	No available information on persistence in the environment.

4. Do the physico-chemical properties of the chemical indicate a potential for biological concentration and/or magnification in organisms and food webs?

Hazard Rating	Description
low	No properties compatible with selective bioaccumulation by organisms.
medium	Known metabolic role in certain organisms with likely accumulation in tissues at high dose rates.
high	High probability of bioaccumulation due to high solubility in fats, inefficient excretion mechanisms, etc.
high	No information available on potential for bioaccumulation.

5. Does the interaction of the chemical with the environmental

media produce secondary chemical products which could be more detrimental to organisms than the original material?

Hazard Rating	Description
low	Secondary products, if any, are not likely to be detrimental to organisms.
medium	Secondary products could be detrimental to organisms on a local scale (radius of 10km. from point of formation).
high	Secondary products are likely to form which could have a detrimental impact on regional or global ecology either directly or indirectly (*e.g.* climate change).
high	No information available on environmental chemistry.

III Identification of potential critical receptor organisms or populations in relation to most likely exposure pathways.

Hazard Rating	Description
low	Hazard only if taken on a continuous basis by oral ingestion.
medium	Uptake can occur via oral ingestion or drinking water.
high	Major pathway for uptake is gaseous contact with skin and through inhalation.

IV Acute and chronic toxicity in the environment.

1. Estimate the acute toxicity to potential target organisms in the environment under conditions of maximum likely dose rates.

Hazard Rating	Description
low	Acute toxicity hazard likely at concentrations greater than 10 per cent of the environmental medium.
medium	Acute toxicity hazard likely at concentrations between 10 per cent and 0.1 per cent of the environmental medium.
high	Acute toxicity hazard likely at concentrations less than 0.1 per cent of the environmental medium.
high	No available information on acute toxicity.

2. Will the release of sub-lethal amounts of the chemical pose a risk of detrimental chronic effects to any of the likely receptor organisms?

Hazard Rating	Description
low	Existing information indicates that chronic risk is negligible.
high	No information on chronic effects to likely receptor organisms.
high	Known or highly likely chronic risk at any concentrations which exceed natural background levels.

3. Is the chemical under investigation likely to contain any contaminants which may be more toxic than the parent material?

Hazard Rating	Description
low	Chemical produced in pure form.
medium	Chemical can contain toxic contaminants as a result of

	malfunction in production process.
high	Chemical likely to contain toxic contaminants.
high	Quality of chemical not well defined.

V Possible consequences of accidental release during production, distribution, use, and disposal.

1. Estimate the bulk or volume of the chemical at any time:

(a) points of production –

Hazard Rating	Description
low	Total quantity less than 500 kg.
high	Quantities exceeding 50 000 kg.

(b) along routes of transportation –

Hazard Rating	Description
low	Total quantity less than 500 kg.
high	Quantities exceeding 50 000 kg.

(c) at points and/or areas of use –

Hazard Rating	Description
low	Total quantity less than 500 kg.
high	Quantities exceeding 50 000 kg.

(d) at points and/or areas of disposal or recycling –

Hazard Rating	Description
low	Total quantity less than 500 kg.
high	Quantities exceeding 50 000 kg.

2. Estimate the relative technological complexity of control and containment of the chemical in the event of an accidental release:

(a) at points of production –

Hazard Rating	Description
low	Simple one-stage containment and control effective.
high	No control technology available.
high	No information on control and containment.

(b) along routes of transportation –

Hazard Rating	Description
low	Simple one-stage containment and control effective.
high	No control technology available.
high	No information on control and containment.

(c) at points and/or areas of use –

Hazard Rating	Description
low	Simple one-stage control and containment effective.

high	No control technology available.
high	No information on control and containment.

(d) at points and/or areas of disposal or recycling –

Hazard Rating	Description
low	Simple one-stage control and containment effective.
high	No control technology available.
high	No information on control and containment.

3. What is the availability of monitoring systems for the chemical under investigation?

Hazard Rating	Description
low	Any release of the chemical detectable where concentrations exceed natural background values.
medium	Available monitoring systems can only detect concentrations which exceed natural background values by at least 25 per cent or more.
high	No available monitoring system at present.

4. Estimate the maximum environmental exposure likely in the event of an accidental release of the total amount of the chemical at any point in the material cycle (worst possible case).

Hazard Rating	Description
low	Exposure restricted to area within 10 km. of point or area of release.

medium	Regional exposure of an area within 1000 km. of point or area of release.
high	Global exposure in the event of the worst possible accident.

5 Estimate the possible extent of irreversible damage to the environment in the event of an accidental release of the total volume of the chemical at any point in the material cycle (worst possible case).

Hazard Rating	Description
low	Permanent irreversible damage restricted to immediate vicinity (within 1 km. of point of release).
medium	No information on the possible nature and extent of irreversible damage to the environment under accidental release.
high	Irreversible damage is likely to occur on a regional or global scale (*e.g.* climate change) in the event of a worst possible case accident.

ANNEX 2

DATA REQUIREMENTS FOR EVALUATING POTENTIAL CHEMICAL HAZARDS IN THE ENVIRONMENT.

Many of the factors in the proposed hazard evaluation methodology (Annex 1) are assessed either directly or by extrapolation from standard data on the physical and chemical properties of chemicals. Economic data are also required and generally must be obtained directly from industry market forecasts. Fortunately, most of the data needs for the proposed evaluation methodology will be available through the International Registry of Potentially Toxic Chemicals (IRPIC) or from regional data centers such as the European Community Environmental Chemicals Data and Information Network (ECDIN). The following indicates the data for specific factors in the evaluation:

Data Requirements	Evaluation Factor
1. Chemical nomenclature	II (all)
2. Proposed market name(s)	I-1, I-2, I-3, I-4
3. Chemical structure	II (all)
4. Chemical indicators (state, colour, smell)	III
5. Solubility in water, solvents, tissue analogues	II-1, II-3, II-4, III
6. Vapour pressure	II-1, II-2, II-3, III
7. Melting point	II-1, II-2, II-3
8. Boiling point	II-1, II-2, II-3
9. Vaporization point	II-1, II-2, II-3, III
10. Density	II-1, II-2
11. Viscosity	II-1, II-2
12. Surface tension	II-1, II-2
13. Ion exchange properties	II-1, II-2, II-4
14. Chemical analysis data and methods	I-5, II-4, II-5
15. Percentage purity of the market product	IV-3
16. Impurities (data and methods)	II-5, IV-3
17. Natural metabolites and chemical reactions	II-1, II-2, II-3, II-4, II-5
18. Role in biological processes (uptake, excretion, etc.)	II-1, II-2, II-3, II-4, III, IV
19. Economic production data	I-1, I-2, I-5, V
20. Trade data (transport and storage)	I-3, I-4, V
21. Uses	I-3, I-4, I-6, V

22.	Methods of disposal or recycling	V
23.	Existing regulatory data	I-1, I-2, I-4, V
24.	Toxicity data (ref. methods)	II-4, IV, V
25.	Chemical Abstracts Registry Number	All