RIZWANUL HAQUE

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ANN ARBOR SCIENCE

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ANN ARBOR SCIENCE
PUBLISHERS INC / THE BUTTERWORTH GROUP

Second Printing, 1980

230 Collingwood, P.O. Box 1425, Ann Arbor, Michigan 48106

Library of Congress Catalog Card No. 79-55141
ISBN 0-250-40301-3

Manufactured in the United States of America

This book consists of papers presented at the symposium entitled "Dynamics, Exposure and Hazard Assessment of Toxic Chemicals in the Environment." The symposium was held at Miami Beach, Florida, during September 11-13, 1978, and was sponsored by the Division of Environmental Chemistry, American Chemical Society. The content of this book does not necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does the mention of commercial products or trade names mean endorsement or recommendation for use.

PREFACE

The Toxic Substances Control Act of 1976 is a historic milestone for the environmental sciences. This legislation has far-reaching consequences, bringing many challenges and opportunities to the chemical profession and industry. The central issue is the evaluation of exposure, hazard and risk of toxic substances to human health and the environment. Because of the complexities involved, scientists possessing expertise in chemistry, biology, ecology, toxicology, engineering, mathematics, computer systems and agriculture must pool their talents to address this issue. Predictive techniques must be developed to assess what happens to a chemical once it is introduced into the environment, in what form it exists, where it goes and when it is finally destroyed. Techniques are also needed to predict exposure concentrations of the chemical in the environment so that this information, in conjunction with "effect" data, may be used to estimate risk.

Chemical technology has played a major role in the discovery, synthesis and trace-level identification of chemicals. In recent years, basic chemical-physical principles have been applied to develop techniques for predicting transport and transformation of chemicals in the environment. The transport and transformation studies in turn provide valuable information on the exposure concentration and potential hazard of chemicals to the environment.

This book describes the use of transport and fate studies in predicting exposure, hazard and risk of toxic substances to the environment. It comprises papers given at the symposium "Dynamics, Exposure and Hazard Assessment of Toxic Chemicals in the Environment" at Miami Beach, Florida, September 11-13, 1978. The symposium was sponsored by the Division of Environmental Chemistry of the American Chemical Society. Representing a broad spectrum of scientists from industry, academia and government, the contributors are experts of national and international reputation.

The first few chapters of this book deal with the historic events pertaining to transport and fate studies, as related to the Toxic Substances Control Act. The addresses by Etcyl Blair (Vice President Dow Chemical Co.), Warren Muir

(Deputy Assistant Administrator, EPA), Courtney Riordan (Associate Deputy Assistant Administrator, EPA) and Virgil Freed (Director, Environmental Health Sciences Center, Oregon State University) provide a good introduction to the role of transport and fate research and its potential in the industrial decision-making process, regulatory postures, federally supported research and impact on academic training.

Stephenson describes how transport and fate data has been used by the Interagency Testing Committee (formed under the Toxic Substances Control Act) in selecting toxic chemicals. His article is followed by introductory papers on analysis of chemicals (Keith), and review of transport and fate studies in exposure estimation and screening of toxic chemicals (Haque et al.). A number of chapters are devoted to a better understanding of the environmental transport and transformation process. They include the topics of photochemistry (Zepp; Dilling and Goersch), volatilization (Mackay et al.; Spencer and Farmer) hydrolysis (Wolfe), biodegradation (Alexander), transport in sediments (Weber et al.), humic substances (Khan), terrestrial microcosm (Gillett) and partition coefficients (Hansch). There are papers in which attempts have been made to integrate transport and fate information in developing models for predicting concentration, movement and persistence of chemicals (Neely; Mill; Eschenroeder et al.). Three papers are devoted to movement, accumulation and transformation in fish and animals (Bungay et al.; Barrows et al.; and Khan and Feroz). The paper by Fine et al. provides background information on the occurrence of toxic impurities in commercial products. Murphy describes toxicodynamics of chemicals and Linjinsky uses transport and fate concepts to predict carcinogenic potential of chemicals. The papers by Kimerle and Stern are concerned with the testing of chemicals for hazard evaluation. The concluding paper by Moghissi et al. is devoted to methodology for risk estimation of toxic chemicals.

It is hoped that this book will be of use to researchers, upper level college students and scientists involved in industrial and regulatory aspects of toxic chemicals. The opinions expressed are those of the authors, and credit must go to them individually. I would like to extend my personal gratitude to them for their contributions. I would also like to thank Virgil H. Freed and Warren Muir for their suggestions, and Courtney Riordan and Thomas Murphy for their support during the planning of the symposium, and editing of this book. I am grateful to the Division of Environmental Chemistry, American Chemical Society, for sponsoring the symposium. Technical assistance from Bill Vaughan and Lisa Yost during the editing of the book is also acknowledged.

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DYNAMICS, EXPOSURE AND HAZARD ASSESSMENT OF TOXIC CHEMICALS IN THE ENVIRONMENT: AN INTRODUCTION

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The development of modern technology has brought a dramatic increase in the production and consumption of chemicals. In a few cases, the benefits of chemical use have been accompanied by unexpected adverse effects. The persistence and bioaccumulation of mercury, polychlorinated biphenyls, kepone and dioxins are classic examples. Such cases have led to public concern that chemicals be fully evaluated in terms of potential risk before being approved for use. In 1976, the U.S. Congress enacted the Toxic Substances Control Act which requires the testing of chemical substances and mixtures for assessment of risk to human health or the environment. The evaluation of chemicals brings a dual challenge to scientists. First, a credible technology of risk assessment must be developed, and secondly, the toxic substances, which run into several thousands in number, must be evaluated rapidly with a cost-effective technology. This book addresses these important issues.

The "dynamics" of a chemical refers to what happens to a chemical, where it goes and when it degrades once it finds its way into the environment. The information of dynamics of chemicals is obtained via "transport and fate" studies. Transport and fate data play a key role in defining the exposure concentration of chemicals in the environment. The main objective here is to explore the full potential of transport and fate studies in the development of predictive techniques for exposure estimation of chemicals, and in defining the potential hazard of chemicals.

The estimation of chemical risk (R) requires a knowledge of its effects and exposure on humans and the environment, and may be expressed as:

$$R = f\ (\text{Effects, Exposure})$$

The data on effects are obtained via toxicological experiments. However, our current knowledge of environmental exposure concentration estimation is inadequate. Current methodology of exposure estimation involves monitoring techniques which are cost-ineffective and suffer from statistical limitations and unextrapolatibility from location to location. There is a need for the development of predictive techniques for exposure assessment. Transport and fate studies present good potential in developing such predictive techniques.

Transport and fate studies also play a role in evaluating hazards of chemicals. For example, the existence of a correlation between the octanol/water partition coefficient and bioaccumulation of chemicals in certain aquatic species may provide a screening method. Similarly, the persistence parameters of chemicals determined from transport and fate studies may also be useful in estimating potential environmental hazard. Finally, transport and fate studies provide a method of predicting in which medium (air, water, soil/sediment) of the environment a chemical is likely to accumulate and persist, thus presenting a red flag signal for that compartment of the environment. This in turn will aid the designing of complex monitoring experiments.

The progress of a chemical from its introduction in the environment to the production of exposure and risk, is depicted in Figure 1. As shown in the figure, the transport and transformation of the chemical in air, water or soil/sediment media is the first step in determining exposure concentration of the chemical. Once this concentration is determined, depending upon the toxicity of the chemical, its effect can be evaluated. This book will address important issues involved in defining the various steps leading to risk assessment. More specifically, it will focus on the following topics:

- the identification of important transport and transformation processes pertaining to air, water, soil/sediment and biota, the measurement of important parameters associated with the processes and investigation of factors influencing such parameters;
- how transport and fate information may be used in defining and building exposure concentration models for toxic chemicals in multimedia environments;

- the role of transport and fate parameters in testing of toxic chemicals, how this information can be utilized in defining hazard signals associated with toxic chemicals, and the utilization of transport and fate data in classification prioritization and selection of toxic chemicals; and
- interface and utilization of transport and fate data in performing ecological and toxicological investigations.

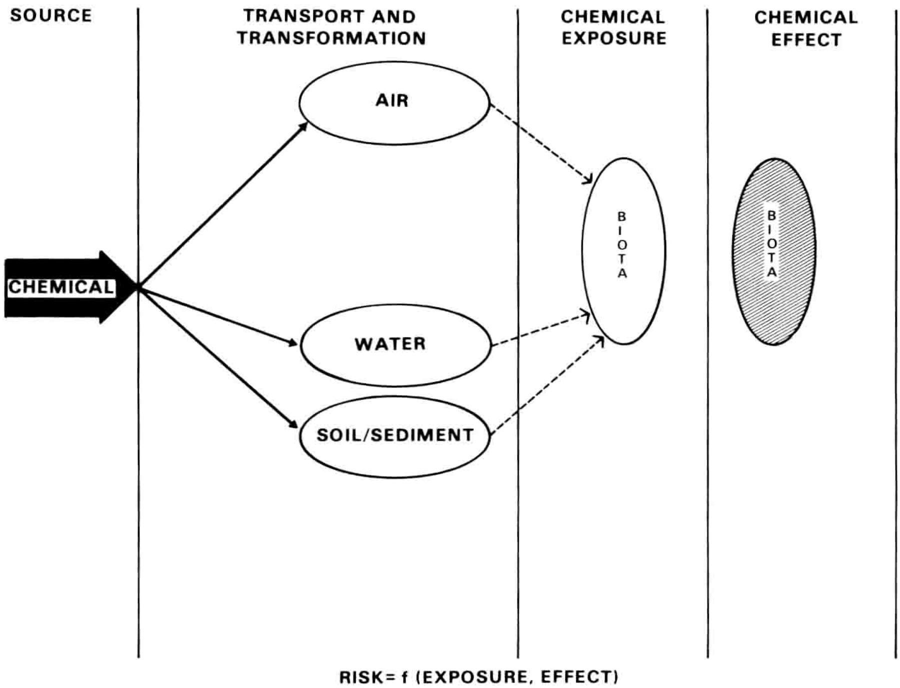

Figure 1. Toxic chemical: transport and fate, exposure, effect and risk.

In addition, the chapters by Muir and Blair delineate the importance of transport and fate research in the implementation of the Toxic Substances Control Act and its impact on the industrial decision-making process. Finally, it is hoped that this book will stimulate novel research ideas capable of solving complex environmental and health problems.

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A ROLE OF TRANSPORT AND FATE STUDIES IN INDUSTRIAL DECISION MAKING FOR TOXIC CHEMICALS

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A discussion of the decision-making processes dealing with the role of transport and fate studies cannot be limited to the specific role of these studies. Decision-making, from an industrial point of view, is much more complex and, to a large degree, encompasses a much bigger equation dealing with benefits and risks. This decision equation, of course, is not precisely defined, but it includes the varied benefits derived from the product or technology, counterbalanced against the varied risks—the risk to humans and the environment, the risk in capital investment and the risk of failure in the marketplace.

The role of the American chemical industry is to provide chemical products, intermediates, services and systems for the maintenance and betterment of society. Its origins can be traced from sulfuric acid, bromides and ammonia, to benzene, ethyl alcohol, phenol and formaldehyde; to the high polymers; and to the exotic and tailored structures in drugs, pesticides, photographic chemicals and space components.

Today, the American chemical industry is a high technology industry continuing to look for new products, new processes and innovative ways to support other emerging technologies—be they associated with energy production, the food industry, the housing industry, the clothing industry, the agricultural industry, the metals industry, the transportation industry, or, believe it or not, the U.S. government itself. Regardless of the customer, the product, the processes and the systems must meet a real and lasting need.

In an attempt to portray the role of transport and fate studies in industrial decision-making, it is necessary to understand a few of the events that lead from product development to marketing of an industrial chemical, paying particular attention to the broader aspects of safety to the public, to the manufacturer and to the handling of the products by customers.

The chemical industry generally accepts the mandates for more testing of old products, of careful evaluation of risk potential of new products, and of minimizing chemical incidents and unreasonable risk of injury to health and the environment. The industry is keenly aware of and is participating in the vast changes occurring in societal attitudes toward health and environment. Newly found skills and resources are now intensively channeled toward measuring minute quantities, coping with the uncertainties of government regulatory bureaucracies and explaining industry's actions and attitudes not only to the regulators, but also to the media, the public and even to the scientific community.

The chemical industry is, in reality, a segment of the American business sector with the capability of producing products which satisfy a need as expressed in the marketplace. Only in the western world do products originate by innovation and the supply and demand forces of the marketplace. All other parts of the world—the Communist Bloc, the developing nations and the awakening Third World—make use of western technology as they struggle to leave their primitive ways.

To adequately discuss decision-making on transport and fate, it seems useful to look at the ways that responsible industry has, for many years, paid attention to the concerns of the environment and public health and the systems it has evolved to ensure a minimum impact of its products and processes on the ecosystem.

Sound data are essential to every aspect of decision-making, and coupled with data are dependable technologies—technologies that are reliable and reproducible, and upon which industry can build plants for the present and for the future.

Data and technology, of course, include the research and development phases of commercial development. The manner by which most companies manage research and development is probably similar because of the common background of the scientists and engineers in the American universities, the commonality of business tradition, the rich heritage from those who pioneered the industry, and government regulatory policies.

As research progresses toward a commercial venture—be it in catalysis, in synthesis, in analytical methodologies or in process advancements—frequent assessment must be made of the value or the importance of the chemical substance, the formulation or the fabricated item. Although each company may have its own system for evaluation, it becomes mandatory that more and more individuals become involved. Multidisciplinary resources and talents are needed to deal with procurement, with the biological impact or potential hazards from the material, with the types of formulation or fabrication that may be needed, and even with how the product will be marketed and in what segments of society it will find a use. Thus, there is a need for managing broad ranges of resources–dollars, professional skills (people) and facilities (analytical equipment, pilot plants, etc.).

Industry makes use of planning tools to aid in managing the multidisciplinary resources required. Frequently, a modified critical path network system is employed. The critical path is the shortest time it takes to do the required jobs; it sets the schedule for the many different individuals and functions involved.

Funding and management of each of these factors affect the others. Various stages or phases of these operations have been developed in which there is an attempt to identify and quantify certain jobs that need to be done and the resources–people or dollars–that need to be applied to ensure that the project is conducted properly and on time.

A continuing part of the decision-making, of course, is a constant evaluation of the health and environmental aspects. Consideration is given to the plant site where the material is being made and to the customers who will be utilizing the product. Sophisticated data on transport phenomena and on the ultimate fate of a chemical are critical components of the decision-making process.

In industrial research, R and D activities are frequently segmented into four stages:

Stage I.	exploratory and synthesis
Stage II.	product and use characterization
Stage III.	pilot process and field development
Stage IV.	commercialization

It is in Stage I, the exploratory stage, that scientists initiate effort on a problem where the solution will contribute an economic benefit to the company and fill a need that the user is able to identify and for which he is willing to pay. The search is for new concepts, potentially useful compounds and new ways of modifying existing products; the tools are the processes of innovation and invention.

Stage II represents a selection point. More resources are targeted on a given product and/or technology. And Stage III is further targeting of resources–more facilities, more disciplines and involvement of those outside the company.

Several aspects of this four-stage process should be examined. The progression is from many ideas and chemicals to one chemical contained in one or a few formulations for one or a few uses.

Knowledge of the potential use becomes more sophisticated through this progression. For example, a concern for the simple property of tensile strength in a polymer, becomes more sophisticated and turns to brittleness, to adhesive characteristics, to light stability and many more. A dream for a broad use frequently targets on a narrower, but highly unique use.

Toxicological data similarly go through a progression. Newly synthesized compounds may be characterized only as to acute toxicity to the rat, or be screened only for unique drug or pesticidal activity. But as the progression proceeds, and commercial success becomes more likely, the toxicological data base is increased; more species are tested and longer-term tests are conducted.

Environmental data similarly go through a sequence. Considerable insight into transport and fate characteristics can be gained from simple chemical and physical data collected in Stages I and II. Vapor pressure, water solubility, dissociation constants and hydrolysis and oxidation half-lives, along with a simple test for biological oxidation, permit informed judgments on transport and fate.

During the past decade, the proportion of commercial chemicals involved in significant environmental problems has been very low. And if the biologically active and, frequently, persistent pesticides are excluded, the proportion of problem chemicals is quite small indeed. Very few people can name even 10 out of the reported 75-100,000 commercial chemicals. If the total population of chemicals is considered, there is a bell-shaped curve of risk distribution.

This is emphasized here because the intensive and sophisticated study of transport and fate has been and probably will continue to be a highly specialized or targeted area of investigation. The commercial development of most chemicals should encompass an emphasis on simple and essentially predictive tests.

Global monitoring and modeling studies, extension kinetic analysis of degradation, and long-term wildlife studies should be considered for those few large volume chemicals which have large environmental release, are relatively persistent and exhibit relatively high toxicity.

While product development has been broken into four discrete stages, it must be recognized that there is actually a phase-in and a phase-out from each of these stages and that, in reality, many more key steps are involved. This sequence involves many integrated activities with key planning and evaluation, or review points. The process may take up to five years if extensive testing is required.

As mentioned earlier, a new chemical compound is synthesized or a new formulation is developed by an industrial scientist, and the product or formulation is put through a biological activity screening program. Part of the purpose of the screen is to find if the new compound or composition exhibits unusual biological activity for other uses as a pesticide, an herbicide, an antimicrobial agent for fabric or even a drug. These tests frequently can provide qualitative relevance to the health and environmental impact of the chemical.

If the new compound exhibits enough promise to make it seem, even at this early stage, to be a possible product candidate, safety and health are the next immediate concerns, and mammalian toxicological range-finding tests are instituted. These studies are designed to determine the capacity of the material to cause injury from acute exposure if it is inhaled or swallowed, or if it comes into contact with the eyes or skin. These studies must be done to determine if there is any significant degree of danger from incidental exposure to the compound. This information is necessary so that chemists can handle the chemical safely, and it should be made available to engineers if they need to design pilot plants. And this information will become part of the package made available to the customer, to the government and possibly to other segments of society.

Data from these early tests are used to predict the potential effects, if any, from short-term human exposure to the compound. In turn, these tests guide further toxicological testing.

Further into the development process, about the same time that the mammalian toxicological range-finding test is being done, the physical properties of the compound, such as water solubility, vapor pressure, melting and boiling points, and any extreme reactivity, including shock sensitivity, flash point, and differential thermal analysis for decomposition temperature, are generally being determined.

By this time in the life of the new compound or composition, there are usually enough data available on safety and efficacy that a preliminary decision can be made on whether it might be a serious product candidate. If the decision is favorable, environmental testing begins. The environmental analysis includes tests which indicate the compound's tendency to evaporate from water. Its degradability—that is, whether it breaks down readily in soil, air or water—as well as its tendency for possible bioconcentration, are also checked, and an effort is made to determine the new compound's basic toxicity to an indicator aquatic organism.

It is at this point that the first key product review takes place. Up to this point, decisions are generally made by individuals—chemists, biologists, engineers—who are personally involved with the product. A group review takes place and a management decision is made as to what will be done.