MANAGEMENT OF TOXIC SUBSTANCES IN OUR ECOSYSTEMS

Edited by
Barney W. Cornaby

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Taming the Medusa

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Preface

The symposium "Taming of the Medusa: Toxic Substances in Our Ecosystems" was held in Columbus, Ohio, March 7–8, 1980. It was one in a series of ecology symposia under the auspices of the Ohio Academy of Science (Ecology Section), Battelle Columbus Laboratories and other institutions to explore important trends in ecological and environmental sciences. Each symposium has provided a forum of well-informed nationally and internationally recognized experts and has resulted in an enlightened thumbnail sketch of a given topic. Since toxic substances had come of age, so to speak, plans in early 1979 called for a symposium on the ecology of toxic substances.

The ecology symposia, with a legacy of interesting and useful topics, are usually held in late winter at Battelle's auditorium. Previous themes have been: Ecological Succession (1973), Biological Implications of Strip Mining (1974), Energetics and Fitness (1974), Environmental Impact Assessment: the Role of Biologists (1976), Stress Effects on Natural Ecosystems (1977), and Training and Personnel Trends in Ecology and Environmental Sciences (1978). Because we wanted a larger readership for this vital topic, the outlet for the 1980 proceedings is different. The new policy of the Academy permitted me to work with Ann Arbor Science Publishers in preparing this volume and bringing this timely symposium proceedings to the attention of biologists, engineers and other interested persons in government, industry and academia.

The sponsors of the 1980 symposium deserve mention. In alphabetical order they are: Battelle Columbus Laboratories (Bioenvironmental Sciences Section), The Ohio Academy of Science (Ecology Section), Kent State University, Miami University (Institute of Environmental Sciences), Oberlin College, The Ohio Biological Survey, The Ohio State University (Environmental Biology Program and Department of Zoology) and The University of Akron. I was assisted by a program committee: Dr. G. Dennis Cooke (Biology, Kent State University), Dr. Barbara A. Schaal (Botany, The Ohio State University) and Mr. Lynn E. Elfner (executive officer, Ohio Academy of Science). Drs. Kenneth M. Duke, Gerald L. Fisher and Anna D. Barker of Battelle arranged financial support for my role in both the March 1980 symposium and in editing all the manuscripts and preparing the book. Dr. Kenneth M. Duke critically reviewed all of the manuscripts.

This volume presents the opening remarks and the six papers given at the symposium. The third paper, by O'Neill and Waide, was not presented orally because Dr. O'Neill became ill on the day preceding the meeting and could not travel. The papers generated a great deal of interest, with lively question-and-answer periods following each three presentations. Although this dialog is not printed, it is available on tape from the Ohio Academy of Science. I prepared the concluding remarks in March 1981 from notes made at the symposium, after I had edited all of the manuscripts and considered their impact.

Barney W. Cornaby

Barney W. Cornaby is a Senior Research Scientist with Battelle Columbus Laboratories. He received his PhD in ecology/entomology from the University of Georgia, his MS in zoology/statistics and his BS in zoology/Portuguese from Brigham Young University. He has also studied at the University of Utah and Universidad de Costa Rica.

Dr. Cornaby's research interests at Battelle have been concentrated on technical evaluation of health/ecological effects from dams, pipelines, highways, chemical plants and power plants. Previously, he conducted environmental research in all major ecosystem types in the United States, including wetlands, estuaries, deserts, grasslands, alpine systems, forests and farmlands. He recently directed a large project involved with toxicological and ecological research in Venezuela. His current research is focused on the development and use of nonhuman organisms in early warning systems to protect humans at waste disposal and other sites, and on the design and evaluation of new products, especially those involving toxic substances.

Dr. Cornaby is a member of the American Association for the Advancement of Science, Ecological Society of America, Entomological Society of America and the Tropical Biology Association. He has published 18 articles in professional journals and numerous technical reports, and has presented more than 30 papers at national and international meetings.

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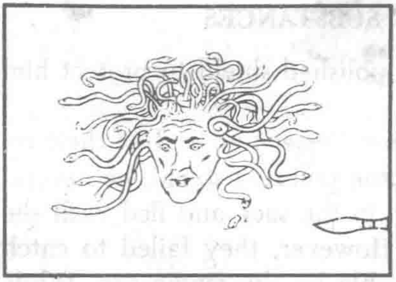

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Opening Remarks

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THE MEDUSA MYTH

The three terrible sisters from Greek mythology, the Gorgons, one of whom was named Medusa, were winged creatures, having the form of young women with glaring eyes, tusks for teeth and serpents for hair. Theirs was a petrifying power, because their appearance was so hideous that whoever looked at them was turned to stone.

Medusa was mortal, while her sisters, Stheno and Euryale, were immortal. The myth is thousands of years old, and according to some writers the sisters lived on the Atlantic side of Africa. At their living place, one could imagine rain-worn shapes of men and wild beasts whom they had petrified. Clearly, it would require astuteness and perhaps even the help of deity to control them.

Perseus, son of Zeus, was sent to fetch Medusa's head. Perseus was aided in his quest by various mythical persons who gave him winged sandals, a large sack and a cap that made him invisible. He also received a special curved sword to use for his gruesome task and a highly polished shield to protect him from the sisters' gaze.

The Gorgons were asleep when Perseus arrived at their retreat. Looking at them through the polished shield, he decapitated Medusa. He put her head in the sack and fled with the other two Gorgons in pursuit. However, they failed to catch him because he was made invisible by the magic cap. While flying over present day Libya, blood from the head seeped through the sack and dripped onto the desert floor, where the heat spawned many snakes.

Later, the head of Medusa, which retained its petrifying power, was placed on warriors' shields and elsewhere as a protective talisman. Athena's shield, for example, showed the Medusa head.

Paintings and sculptures depict Medusa with a variable number of and range of conditions for the snakes. In some cases the snakes were many and well-fed; in other cases the snakes were few and skinny. Regardless, there were always sufficient snakes to provide a frightening experience to the viewer.

TOXIC SUBSTANCES AND THEIR PROBLEMS

Our major concerns with toxic substances are as numerous as the snakes on Medusa's head. There are about four million registered chemical compounds, and more than 30,000 of them are used in commerce. However, the kinds and quantities of potentially toxic chemicals appearing on the market are increasing each year. In 1976 about 243,000 chemical substances were recorded in the Inventory Candidate List for the U.S. Toxic Substance Control Act, and hundreds of substances have been added since then. However, the 1977 edition of the Registry of Toxic Effects of Chemical Substances contains data for only 26,000 entries, pertaining mainly to humans and laboratory animals. Clearly, there is a growing backlog of chemicals whose toxic potential is not known.

Likewise, the volume of chemicals produced is increasing. Figures from the U.S. International Trade Commission show that annual production of synthetic organic chemicals in the United States increased 50 to 184 billion pounds from 1959 to 1974. Production of other chemical products has similarly increased. For instance, pesticide production in the United States has more than doubled—from 0.6 to 1.4 billion pounds—annually during the same period. These trends continue.

One of our civilization's major challenges is to manage properly this rapid proliferation of new substances. True, these new substances provide many benefits:

- pesticides to enhance agricultural production
- synthetics to replace more expensive raw materials
- pharmaceuticals to extend life
- fuels to provide more energy.

The list of contributions is long. However, these substances also provide new sources of potentially hazardous effects: toxicological problems are surfacing with alarming frequency. Almost daily, we learn disturbing accounts:

- high concentrations of heavy metals being found in fish
- small children being exposed to lead-containing paints
- workers in a Kepone chemical plant and nearby residents displaying symptoms of poisoning
- the chemical TRIS (used in flame-resistance pajamas) as a possible link to cancer
- the perils of improper chemical waste disposal rising to haunt us at tens-of-thousands of locations worldwide.

The list of problems is long.

THE ANALOGY

How can we battle this contemporary Medusa? These proceedings provide some of the answers. First, the enormity of the problem will be sketched by George M. Woodwell. He describes, as it were, the head of the Medusa and gives the charge for battle. Then, one by one each successive speaker symbolically severs the head of a snake. The first two speakers discuss different but interrelated perspectives on the toxic substance problem: human populations and ecosystems. They deal with the snakes of epidemiologic studies and extrapolation from animal toxicity and chemical data to the intervention of human cancer patterns (Nancy A. Reiches) and the hierarchical and biogeochemical cycles approach to measuring toxic effect to ecosystems at the system, not the component, level (Robert V. O'Neill and Jack B. Waide). With this preparation, three more snakes are attacked. They follow: synergistic and antagonistic effects of chemical mixtures (Perry D. Anderson), protocols of biological tests for documenting effects of emissions (Kenneth M. Duke and Raymond G. Merrill, Jr.) and management strategies for controlling certain substances (Gary D. Rawlings). Together these papers provide a logical series that explain how toxic substances are being or can be managed in our ecosystems. Finally, I return to provide a synthetic view of all the papers and to evaluate how successful we were in taming the Medusa in the Closing Remarks.

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Toxic Substances: Clear Science, Foggy Politics

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In 1972 Humpstone examined contemporary pollution problems through the eyes of a lawyer [1]. He observed that in the middle eighteenth century, more than 200 years ago, another lawyer, Blackstone, had drawn on an ancient Christian maxim as the foundation of the law of nuisance: *sic utere tuo ut alienum non laedas* (use your own property in such a way as not to injure another's). Blackstone offered examples: "To build a house so close to another's that rainwater from your roof spills onto his, is to commit a nuisance." So is keeping hogs so close to another's house "that the stench of them incommodes him and makes the air unwholesome." One responsible for a nuisance was "to find some other place to do that act where it will be less offensive."

In 1980 we live with 4.4 billion other humans, a complex technology and almost infinite aspirations on a small, green planet. Our 4.4 billion people will become 6.0 billion in less than 20 years, barring nuclear war or other catastrophe. Those now living who have a 50-year life expectancy can look forward to living in a world with 9.0 billion people, if current trends are not changed. Places to hide are already few; what was remote and therefore safe in the past is no longer safe. There is no more powerful example of the limits we are now encountering than that offered by toxic substances.

The 1979 Annual Report of the U.S. Council on Environmental Quality [2] reports that more than 4 million chemicals have been registered with the American Chemical Society since 1965; that more than 43,000 chemicals, not including pesticides or drugs, are listed by the U.S. Environmental Protection Agency (EPA) as subject to the Toxic Substances Control Act (TSCA); and that there is a continuing rise in deaths from cancer of 0.5% annually, with the number of new cases of cancer rising at 1.6%/yr (80–90% of these are attributed to environmental factors). Industrial activities that produce toxins at such a scale are an obvious threat to life itself. How are such materials to be managed? What experience can we invoke in their management?

NATURE OF THE PROBLEM

Examples of the problems with toxins are overwhelming. One of the most spectacular in recent years has been the Love Canal incident in Niagara Falls, NY, where a chemical company dumped and buried diverse toxic wastes over a period of years. Houses were built on the land, and in a time of heavy rains, toxins moved with the groundwater into cellars and ultimately seeped to the surface to foul air and water and to threaten human health. There may be several thousand such dumps in the United States and several hundred that could offer similar problems. Love Canal alone had cost the taxpayers more than $27 million by the early months of 1980: money spent to move the families who bought houses on this land, to control the toxic substances and to make limited restitution. The problem continues, and many more families seem certain to be affected. Furthermore, the money spent to date has done nothing to remedy the biotic effects. To emphasize the magnitude of the problem, the federal government attempts to control some 43,000 different pesticides produced by 7400 manufacturers, whose output is an estimated 1 billion pounds of toxins with a total value of $2 billion [2]. The management of sewage and industrial wastes is not included in these statistics.

The problems in controlling these substances embody nearly all the elements of the contemporary crisis of environment: growth, profits, and economic and political power. The issues reach further to challenge what many consider as reason itself, even to challenge compromise, the very basis of politics in the democracies. Small wonder that the topic is contentious.

The root of much of the uncertainty among those who attempt to manage toxins lies in the fundamental assumptions on which management is usually attempted. A common approach is to emphasize that toxicity is a matter of concentration or quantity, not quality, or an intrinsic characteristic of the substance. Pollution, too, is considered a question of degree. Implicit in the analysis is a system of thresholds below which tolerance exists, sometimes formalized in specific instances as "assimilative capacity." This concept is applied to organisms and to nature as a whole. Although convenient, attractive and apparently reasonable, I suggest that the concept is misleading, if not simply wrong, and that it is especially misleading when used in nature. I argue, moreover, that the present system for managing toxins is inadequate to protect man from toxication and the biota from impoverishment.

The key point should be sufficiently well known to be trite: the world is a biotic system, the product of a biotic evolution that has produced 3–10 million different kinds of plants and animals, each very precisely attuned for survival to a narrow set of physical, chemical and biotic conditions. Despite man's success in turning nature to his own purposes, we still live as guests in a biosphere dominated by natural communities that operate according to a complex and poorly recognized set of laws that have their basis in evolutionary processes. We are learning now that the organisms in these communities may respond to one another through chemical signals that are effective even when concentrations are as low as one part per trillion. In addition, we know that evolution breeds diversity in form and function: virtually every circumstance and every resource that can be exploited to sustain life has been exploited in the fullness of four billion years of constant evolutionary testing. Sudden changes in environment, whether they are physical, chemical or biotic, will bring sudden changes in the biotic systems of that place. Sudden change is as disruptive and as expensive in natural systems as it is in a watch, a factory or a transportation network.

TWO EXAMPLES

The best examples are from experience with two groups of toxic substances: ionizing radiation and pesticides. Ionizing radiation is an example of an inadvertent waste product of technology that happens to have powerful biotic effects. Pesticides, in contrast, are produced and used because of their biotic effects.

Ionizing Radiation

Our experience with radiation as an important worldwide contaminant began with the discharge of the first fission bombs in 1945 [3]. The scale of the problem did not become clear until almost ten years later, when, in the spring and summer of 1954, the United States completed a series of tests of bombs at Bikini Atoll in the western Pacific. The first of these tests, BRAVO, was especially notable because the fallout moved eastward instead of westward and reached Rongelap Atoll, where 65 Rongelapese received about 50% of a mean lethal exposure before they could be evacuated. In all, the series of tests that spring contaminated 10,000 mi^2 of the Pacific with fallout that would have been lethal to man had he been there. For many weeks, fish landed in Japan could not be sold because they were sufficiently radioactive from the oceanic contamination to be judged inedible. Oceanographic surveys by Japan and the United States confirmed the extent of the contamination and the fact that radionuclides were being accumulated by the fish. Continued testing of bombs in the atmosphere introduced sufficient additional radioactivity into the troposphere that radioactive rains were detected in various parts of North America.

The tests, whatever one may think of them in hindsight, offered a remarkable series of tracers for study of atmospheric and oceanic circulation. Elaborate research programs started by the Atomic Energy Commission over a period of more than 10 years provided a wealth of information about the circulation of the atmosphere, including the transport of particles and their deposition on the earth's surface. The evidence showed, for example, that small particles introduced into the troposphere in the middle latitudes are carried around the world in two to three weeks. Particles are removed from the atmosphere by precipitation, with the amount of removal diminishing as the rainfall continues. Even small particles, (e.g., pollen grains), that can be windborne, travel in these atmospheric patterns. Deposits of radioactive debris were greatest in the middle latitudes because precipitation is high there. Areas that lie in common storm tracks, such as New England, receive especially large deposits of materials that are carried in the atmosphere. Finally, the transfer of particles in the atmosphere between the Northern and Southern hemispheres is limited; the deposits of radioactivity in the Southern Hemisphere were approximately 10% those in the Northern Hemisphere for many years. Apparently, latitudinal exchanges of air and particulate matter between hemispheres are very much slower than longitudinal transport within the hemispheres.

There is ample reason to believe that any substance that can be vaporized or distributed as small airborne particles can be expected to have a regional, possibly a worldwide, distribution. Thus, there is no mystery as to why traces of pesticides or polychlorinated biphenyls (PCB) are found in mountain lakes and in glacial ice many miles, sometimes thousands of miles, from where they could have been used.

But even more important, we learned that radioactive elements, such as strontium-90, cesium-137 and iodine-131, that are similar to elements essential for life can be accumulated from very low concentrations in nature to high concentrations in living systems. The lesson should not have been necessary because we know that living systems exist by processes that result in the accumulation of elements necessary for survival. That, too, is an evolutionary legacy.

All of this evidence emphasizes that toxins that have a residence time in the atmosphere of hours to days can be carried worldwide in days to weeks by atmospheric transport alone, and that biotic mechanisms, in addition to physical mechanisms, act to return toxins to places where they again affect man directly. This experience alone should have been enough to destroy the arguments about dilution, including the use of the sea for disposal of persistent toxins. It was not.

There were further lessons from radioactivity. They lie in the realm of effects. The biotic hazard from ionizing radiation is in the ionization of biologically important molecules. The most important biotic molecules are those that carry the information for operating the organism, the genes. The production of mutations in man is commonly thought to be deleterious because we consider each individual important and are unwilling to sacrifice lives in favor of genetic improvement of the group as a whole. Mutant genes, most of which are deleterious, are not systematically eliminated from the population by selective pressures operating against individuals, at least not in places served by modern medicine. We make extraordinary efforts to avoid the loss of individuals, and the mutants may, therefore, accumulate. Man is unique in this respect among other species of the earth. All other species are subject to elimination of mutants through early death of the individuals that carry them. The objective in managing the hazards of radioactivity is to protect man, not from somatic effects, but from an increase in the rate of mutation in his germ cells. If we are successful in protecting man, all other species will have been protected. The emphasis on human safety is appropriate and provides adequate insulation for the rest of the biota. This relationship is special