CHAPTER 6

Managing the Risks of Hazardous Waste

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Summary Findings

1. Methodologies for risk assessment are not perfectly developed. If data are analyzed with care and uncertainties recognized, currently available tools can be used effectively in risk-management decisions. Continued research and development are needed to improve the methodologies.

2. Classification systems can be developed to group wastes by degree of hazard and management facilities by degree of risk. Although technical problems must be solved, classes of waste and management facilities can be matched to minimize risks to human health and the environment,

3. Advantages of a classification system include:
   - wastes would be assigned to appropriate levels of management to achieve a consistent level of protection without unnecessary expense;
   - government officials could set priorities for establishing standards and controls based on objective criteria; and
   - the system could provide the public with reliable information on the relative hazards of different classes of waste and the most appropriate ways of handling each to reduce risks,

4. Among the problems that must be solved in designing an effective classification system are:
   - criteria for classifying waste must be carefully selected to include the broad range of threats to public health and the environment (e. g., to include long-range effects such as reproductive impairment as well as short-range ones such as acute toxicity);
   - the combined, or synergistic, effects of waste constituents must be considered, not just the effects of single constituents alone;
   - the hazard of a waste may be changed by a management technology, thus the constituents that are released from a facility may be more (or less) hazardous than the original waste. Risks to public health are determined by the hazard of constituents leaving a facility (i. e., releases);
   - characteristics used to classify waste are not always the same as those that determine the appropriate management technology; therefore a mismatch of waste and facilities could occur; and
   - boundaries of waste and facility classes would have to be clearly defined, to achieve consensus among regulators, the industry, and the public.

5. Monitoring is a key component in regulation of hazardous waste. It is the only way to verify that a waste management system is operating correctly. Data on the chemical, structural, and physical characteristics of waste constituents can be used to predict their environmental fate. Knowledge about fate of constituents can be used to develop cost-effective programs.

6. Of five types of monitoring activities—visual, source, process, ambient, and effects–ambient monitoring provides the best evidence for judging whether risks of hazardous waste management are being kept at acceptable levels. If environmental contamination is prevented, human exposure will be reduced and public health protected. Therefore, ambient monitoring should receive greater attention in regulatory programs.

7. All monitoring has problems associated with sampling, data comparability, and limitations of methodology. Possible actions to correct the deficiencies include:

- a central monitoring activity, drawing on government and nongovernment resources;
- a nationally supported pilot project to develop a monitoring framework, including standard procedures for sampling, data storage, and analysis; and
- a coordination of monitoring efforts mandated in the seven major environmental laws. This would be especially beneficial for hazardous waste monitoring because of the multimedia nature of the risks.

8. Public opposition to siting of waste facilities stems from fears of health or safety effects, fears of economic loss, uncertainty of industry's ability to prevent adverse consequences, and lack of confidence in government regulations and enforcement.
9. Technical approaches to address public concerns include development of a comprehensive hazardous waste management plan, establishment of technical siting criteria, identifying a bank of suitable sites, and fostering open exchange of technical information (particularly on alternatives to land disposal) between the public, government officials, and the hazardous waste management industry.
10, Nontechnical approaches include assurance of public participation in siting decisions, compensation for victims of damage, a clear commitment by government to enforcement of regulation, and possibly, incentives for communities to accept proposed facilities.
11. The Federal role in answering public concerns might be expanded in several areas:
    - providing technical expertise for development of siting criteria and programs,
    - consideration of federally owned lands as suitable sites,
    - encouraging information exchange,
    - serving as arbitrator in disputes, and
    - assisting in the development of regional compacts for hazardous waste management,

Risk Management

Throughout history, people have had to find **ways** of coping with old and new risks. Most individuals- are-risk-averse and their responses to new risks may be to:

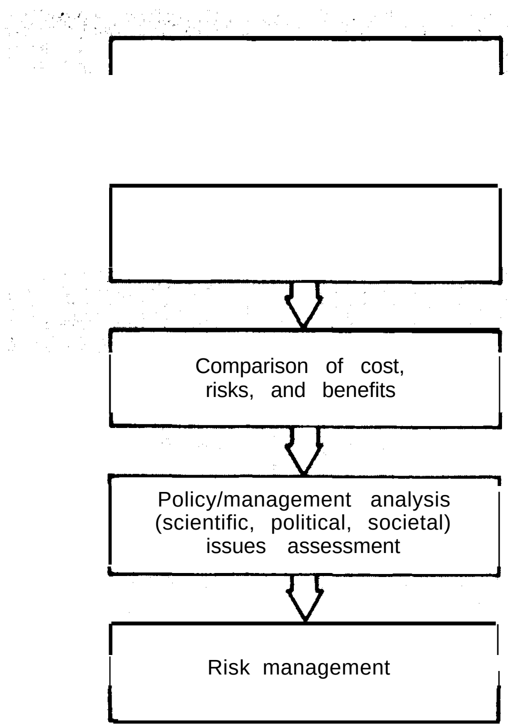
- retreat from it—attempting to return to a safer, more predictable environment,
- try to understand it—measuring the probability that a damaging event will occur and identifying risk/benefit tradeoffs,
- control it—applying various technical solutions, and
- prepare for it economically—insuring against the occurrence of the damaging event.

While these responses can help individuals and societies to cope with risks, none can produce a totally predictable or safe world. There is no such thing as zero risk. Risks must be assessed and courses of action decided. Individuals do this informally and often automatically. More formal decisionmaking usually is required in assessing risks for society.

Managing the risks from industrial hazardous waste is a highly complex task because of the diverse range of hazards involved and the many possible ways of handling the waste. Thus, a managerial framework is needed within which an expanding knowledge base can be accommodated and the risks of alternate courses of action analyzed Figure 14 shows the major components of such a framework.

The framework illustrates a systematic way of proceeding from evaluation of hazards, through risk assessment and a weighing of risks, costs, and benefits, to a final policy choice that includes consideration of value judgments and political factors. As discussed in detail below, there are uncertainties in this

Figure 14.— Risk Management Framework



SOURCE Office of Technology Assessment

process from the earlier steps based on scientific data as well as in the last, frankly judgmental, stage of policy decision. Quantitative estimates, such as those used in risk assessments, are helpful to decisionmakers, Indeed, "objective" measurement of risk is increasingly in demand by the regulated industries, public interest groups, and policy makers. But it is a mistake to accept numerical estimates generated by risk assessments uncritically. Decisionmakers must recognize that, at the current state of the art, all risk estimates inevitably contain uncertain data and debatable scientific assumptions.

Hazard Evaluation

The terms hazard and risk are often used interchangeably. This report maintains a distinction between them. Hazard is defined as the inherent capacity to cause harm. Harm could be physical damage (e.g., fire, corrosion, or explosion) or biological impairment resulting in the illness or death of an organism. Hazard evaluation concentrates on:

- the capacity to cause adverse effects, and
- the severity of that effect.

Hazard evaluation includes consideration of toxicological factors* as well as the transport and ultimate fate of materials in the environment, Hazard evaluation emphasizes probable causes and effects and explores possible worst-case effects on human beings, plants, and animals. At this first step in the decision framework, no attempt is made to quantify the probability that an effect indeed will occur.

Risk Assessment

Risk is defined as the probability that a given hazard will cause harm, of a specified nature and intensity, to a human population or ecosystem. For hazardous waste management, risk assessment means calculating the probability that constituents of a waste released from a facility will cause specified adverse effects to public health or the environment. The assessment assigns numerical risk values to the events that it analyzes.

Risk assessment consists of two stages:

- estimation of the risk value, and
- validation of that estimate,

In the first stage, quantitative probability estimates are made about the likelihood that a particular cause will lead to a specific effect. These estimates are based on the results of hazard evaluations and an identification of exposure routes that, in turn, suggest the populations or ecosystems at risk, Estimating exposures and the dose of a hazardous material that will have a particular effect is extremely difficult; this difficulty is not always acknowledged.

The second stage of risk assessment acknowledges its uncertainties and attempts to put the calculated value in a proper perspective. The validation stage uses statistical procedures to

*These toxicological factors are discussed in the next section, "Classification Systems."

give some indication of the confidence one can have in the risk estimate. Uncertainties do not invalidate the use of risk estimates in decision-making, but it is important to keep the confidence levels in mind. Too often, confidence levels are either reemphasized or ignored as the risk estimate is carried through the remaining steps of risk management.

The uncertainties of risk estimation result from the basic imprecision of hazard evaluation. The hazard may not be verified and exposure routes may be questionable; there may even be uncertainty as to whether a release will actually occur. An additional complication is that direct evidence of cause and effect between human exposure to harmful agents and damage to health is elusive.

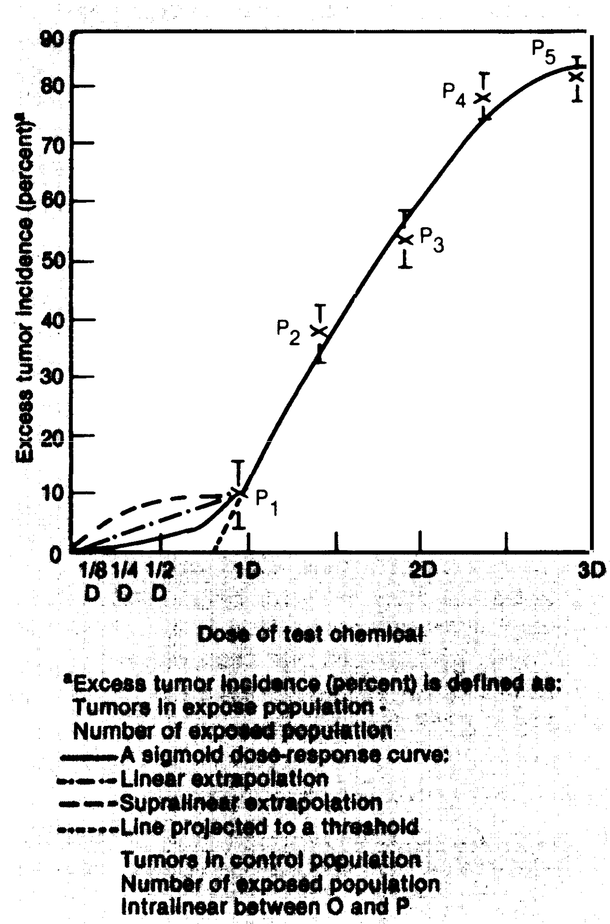
Assessment Models

Little scientific information now available indicate with any certainty the existence of cause-effect relationships between industrial hazardous waste and human health problems. Even with the amount of exposure documented for residents at Love Canal, the relationship between the exposure and health problems is not readily apparent at this time.[12] Thus, the data used in risk assessments are usually obtained from experiments with laboratory ani reals and environmental systems. The experimental data are used to develop quantitative estimates for other species through extrapolation.

These extrapolations have been criticized as not always reflective of actual exposures. Some consider it unwarranted to apply data from animal experiments using high doses to estimate risks to human beings and the environment from exposure to low doses. The main reason for experimental use of high doses is economic. Using low-dose exposures to obtain reliable data would require tests with tens of thousands of laboratory animals. Critics of animal data argue that because laboratory tests are conducted with specially bred animals, often originating from a single set of parents, the animals may not react to the exposure in the same way as humans or as organisms found in the natural environment. While such criticisms may be appropriate, they are also simplistic. Well-established human data are usually absent. Extrapolations from animal data are an inherent and unavoidable process for establishing acceptable levels of risk.

Dose-response curves are used to extrapolate the probabilities of response from experimental high-dose data to low doses. A stylized dose-response curve is presented in figure 15. Several mathematical models are available for ex-

Figure 15.—Stylized Dose-Response Curve With Extrapolation to Low Doses Using Different Models



SOURCE: Office of Technology Assessment, 1981

¹Environmental Protection Agency, *Environmental Monitoring at Love Canal,* 1981, pp. 1404-1407.
²D. T. Janerich, et al., "Cancer Incidence in the Love Canal Area," *Science* vol. 212, *1981, pp. 14041-1407.*

trapolating incidence for the low-dose range on such a curve (i. e., below ID, as shown in the figure). These models are based on combinations of biological theory, experimental evidence, and statistical conventions. q As the figure shows, the predictions of different models for the probable incidence of low-dose effects can vary considerably. For example, risk estimates for a dose level of l/2D (with D representing the standard dose) vary between O and 10 percent, Because of the very large number of animals required to test the theories behind these models, none of them have been scientifically verified. Thus, the risk value at low doses is very dependent not on actual dose-response data, but on choice of methodology.

Human experiments, providing direct evidence of damage to human health as a result of exposure to an agent, are rarely done for obvious ethical reasons. Evidence about human exposures and effects is drawn instead from epidemiological studies, which are beset with certain difficulties. Often the population size in an epidemiologic study is small. Moreover, identifying the actual dose and duration of exposures to a particular compound has problems. Because humans are exposed to a multiplicity of materials, it is difficult to determine that one particular compound or hazard is the only major cause of an effect. The mobility of the U.S. population adds to the problem. Americans relocate often, and few are exposed to the same environmental conditions for enough time to indicate cause-effect relationships. The difficulty of identifying cause-effect relationships also is compounded by the long-time lags between exposure and onset of many health problems (i.e., decades rather than months or days). Even for cancer or circulatory diseases, both subjects of concerted research attention, absolute certainty about causal relationships—that smoking causes lung cancer or that saturated fat damages the circulatory system—may not be universally accepted.

[3]For a discussion of these models see Technologies *for Determining Cancer Risks From the Environment* Washington, D. C.: U.S. Congress, Office of Technology Assessment, OTA-H-138, June 1981).

Limited data exist showing a relation between exposure to waste constituents in the workplace and health problems of workers. Even these data, however, do not indicate with certainty that a relationship between hazardous waste and health problems exists. For example, if exposures in the work environment are well defined and the health problem is otherwise rare, the causal relationship may be beyond question. An example is the relation between occupational exposure to vinyl chloride and angiosarcoma of the liver.[4] However, if the environment of the workplace is complex (e.g., multiconstituent exposures) it may be difficult to establish a causal relation between the presence of a single compound and a particular health effect. Extrapolation from these workplace exposure data has problems similar to those for extrapolating from animal data; concentrations of hazardous constituents in the workplace are usually considerably greater than in the general environment.

Recently interest has grown in determining relative risks rather than calculating specific risk estimates. Relative risks are derived from computer models that combine a variety of factors to simulate real situations (e. g., risks associated with a waste at a facility location on a particular site). Such assessments have been developed for ranking uncontrolled hazardous waste sites needing remedial action under the Comprehensive Environmental, Response, Compensation, and Liability Act of 1980 (C ERCLA). They are also being used to assess risks associated with specific wastes, particular environments, and individual technologies for the purpose of improving regulation under the Resource Conservation and Recovery Act (RCRA). The use of such models is attractive, since risk scores for different situations can be compared on the basis of common indicators without resorting to extrapolation models.

Appropriate Uses of Risk Assessment Models

As long as extrapolation models incorporate exposure doses that are close to those used in

[4]R. R. Monson, "Effects of Industrial Environment on Health," *Environment] Law,* vol. *8, 1978,* pp. **664-700.**

experiments, any conceptual errors in extrapolation procedures usually have only minor impacts. However, as the estimates of exposure doses move farther and farther from the experimental data, results of the model become more and more critically dependent on the validity of the scientific theory describing chemical-organism interactions, contained in the model. Thus, as the distance from experimental data increases, the predictive power of the models decreases,

The major goal of some extrapolations may not be accuracy of prediction, but assurance of adequate protection. For such purposes, the extrapolation model selected is conservative and predicts the greatest risk for lowest possible doses. When establishing protective limits, a poorer data base is usually associated with larger "safety" or "uncertainty" factors, Thus, risk estimates derived from uncertain data but assuring a high level of protection could be much greater than estimates based on more accurate prediction of health effects if such a prediction were available, It should be emphasized that most results of extrapolation currently published represent protective estimates. Unfortunately, these conservative estimates are often interpreted as predictions of incidence, When protective estimates are published or used in decisionmaking, they should be accompanied by a clear statement of the uncertainties they contain. Recent advances in the field of risk assessment are improving the precision and accuracy of predictive models. Significant progress is being made in extrapolations between: species, differences of time of exposure to effect, and different doses and response levels.

The use of computerized models can be appropriate for developing governmental priorities and policies. However, the limitations of these tools must always be recognized. Although the best models can only provide an abstraction of real conditions, three factors can contribute to more reliable results:

1. The indicators for risk should be relevant to actual exposure situations and should assist in identifying populations at risk. These indicators should not be arbitrarily chosen but should reflect as nearly as possible the range of hazards of the constituents of concern, the environmental fate of constituents, and realistic exposure factors,
2. The data base should include accurate and verified information insofar as possible. Every attempt should be made to obtain valid data. Uncertainties in data precision should be identified,
3. Biases incorporated in the model either through the choice of assumptions or the assignment of quantitative values to risks should be identified and the effects of these biases assessed. To give analyses using risk assessment proper weight, policymakers must be aware of the biases inherent in the models. If risk assessments are used in the description and evaluation of alternative options, it is essential to provide sensitivity analyses, showing the differences in risk values that result from changes in basic model assumptions and data bases.

Risk assessments can contribute to a variety of specific decisionmaking purposes. They can be used in setting forth regulatory standards, establishing priorities for research and development (R&D), identifying the risk levels of various disposal/treatment options, and determining appropriate locations for waste management facilities. Although progress continues in risk assessment methodologies, the quantitative estimates they produce are imperfect, and must not be used uncritically.

Comparison of Risk, Costs, and Benefits

The two stages of risk assessment are intermediate steps in the total risk-management framework, which also involves comparing the risks, benefits, and costs in various management alternatives, Different approaches can be used in making such comparisons. They include evaluation of relative risks among various options, comparing risks with benefits, or concentration on costs by evaluating either cost effectiveness or costs and benefits of management options.

1. Relative risks.—Risk estimates (either probability values or relative risk scores) for one option are compared with risks of another. For example, comparisons can be made between risks from land disposal and risks from incineration of a particular industrial waste stream.
2. Risk benefit.—This approach compares risks of an option with some expression of expected benefits, with the aim of maximizing benefits and minimizing risks. Different options then can be compared on the basis of relative risks and benefits, For example, risks and benefits of biological treatment of organic waste can be compared with risks and benefits of incineration of the same type of waste.
3. Cost effectiveness.—In this assessment method, a fixed goal is established and policy options are analyzed on the ability to achieve that goal in the most cost-effective manner. The goal is generally a certain level of acceptable risk and the options are compared on the basis of the dollar value necessary to reach that level of risk. Cost constraints can also be imposed so that the options are assessed on the ability to control the risk most effectively for that set cost.
4. Cost benefit.–This approach expands the risk-benefit framework to evaluate risk and benefit outcomes in dollar values. This method requires more information than any of the others and forces quantification of benefits, even when such quantification may not be accurate or valid.

The language of individual laws may dictate which risk-management approach can be used in regulation.[5] In the 21 statutes that regulate production, commercial distribution, and disposal of potential carcinogens, some specify protection of health "to the extent possible. " Other statutes restrict agencies to consideration of effects only. For example, RCRA states that the Environmental Protection Agency (EPA) ". ., shall promulgate regulations establishing standards . . . as may be necessary to protect human health and the environmerit, " thus constraining EPA from use of cost-benefit comparisons.

Although both Congress and the executive branch have expressed interest in cost-benefit analyses (CBA), there is some cent roversy about the extent of its use. Most experts agree that CBA does serve a useful purpose but caution against unlimited applications.[6 7 8]

Among the limitations are, first, the problems of expressing both cost and benefit values in dollar terms. George Eads, former member of the Council of Economic Advisors, recently stated:[9]

> The numbers casually tossed about by interested firms and industries no more represent the true cost of regulation than the overblown claims by regulation supporters reflect the likely actual benefits.

The reasons for the overestimates in cost arc:

- economies of scale, which arise when the demand for hazard control technology increases, are often ignored;
- learning curves, which reflect increasingly sophisticated industrial responses to regulatory requirements, are not anticipated; and
- the role of technological innovation as a factor in reducing costs is often not given proper attention.

Benefit values expressed in dollar terms also are often questionable. There is little agreement among experts using CBA on the appropriate dollar value to assign to human life or to society's willingness to pay for some perceived benefit. Thus, these values are dependent on the

[5]J. P. Leape, "Quantitative Risk Assessment in Regulation of Environmental Carcinogen s," *Harvard En vironmental La w Review*, vol 4, 1980, pp. 86-116.

[6]R. W. Crandall, "The Use of Cost-Benefit Analysis in Regulatory Decisionmaking, " *Management of Assessed Risk for Carcinogens* [New York. N,}'. Academy of Sciences, 1981), pp. 99-107

[7]M. S. Baram, "The Use of Cost-Benefit Analysis in Regulatory Decisionmaking is Proving Harmful to Public Health, " *Management of Assessed Risk for Carcinogens* (New York: N.Y. Academy of Sciences, 1981), pp. 123-128.

[8]W. H, Rodgers, Jr., "Benefits, Costs, and Risks: Oversight of Health and Environmental Decisionmaking. " Harvard *Environmental La w Review*, vol 4, 1980, pp. 119-226.

[9]G. C. Eads, "Research in Regulation, Past Contribut ions and Future Needs, " *Attacking Regulatory Problems, An Agenda for Research in the 1980s* [New York: Ballinger Press, 1981), pp. 1-18.

individual judgments made by an analyst, and will differ among analysts. Some benefits, such as improved quality of life, are very difficult to quantify.

A second limitation concerns the deceptive nature of cost-benefit methodology. The use of quantitative techniques may give the nonexpert an unjustified impression of neutrality and certainty, This impression is, of course, incorrect. As detailed above, the uncertainties surrounding risk assessment are numerous, and the dollar values assigned to costs and benefits reflect value judgments. For example, in applying CBA to hazardous waste management, a critical problem is the lack of information concerning the nature of risks in inappropriate disposal/treatment practices.[10] Assigning dollar values for unknown risks or benefits is of little value.

Much of the work in risk management has concentrated on the costs and benefits of controlling pollution to meet certain environmental standards (e.g., the cost of pollution control equipment and benefits of reduced health problems). Many analysts argue that for the purposes of risk management where specific benefits (e. g., protection of human health and the environment) are desired or mandated, the most appropriate methodology is cost-effectiveness comparisons. This seems particularly appropriate for hazardous waste management.

Policy/Management Decisions

Once hazard evaluations, risk assessment, and comparisons of risk, benefit, and cost have been completed, the results can be used to reach risk-management decisions. It must be emphasized that these steps in the decision framework are only tools to aid in analysis of alternative policy choices; the results are not the risk-management decision itself. In making policy or management decisions, many factors beyond these quantitative results must be considered. The decisionmaker must evaluate uncertainties, identify value judgments, recognize special interests, and consider political factors. As risk-management, decision-analysis proceeds, conflicts will arise. These conflicts have no right or wrong solutions. They represent differences in societal interests and perspectives and must be considered in the decisionmaking process.

Formalized approaches for making choices in complex situations, known as decision analysis, exist.[11,12] Decision analysis is designed to help decisionmakers choose from a set of specified alternatives in a systematic manner. Most risk-management situations involve large volumes of data, multiple conflicting objectives, and the unavoidable use of subjective judgments. If, in addition, adversary positions complicate the matter, a systematic approach can be very helpful in reaching appropriate solutions, Hazardous waste management is just such a situation .13 The use of decision analysis here might have merit. Most designs for multiattribute decision analyses do not incorporate estimates of risk, but there is no reason why risk assessment cannot be integrated into the technique.

When risk assessment is brought into policy decisions, it is important to identify all uncertainties and to couch the results with appropriate caveats that explain the limitations of the analysis. Risk assessment can be a useful tool for making broad decisions, if the choice of the appropriate methodology is well considered and the uncertainties in each of the alternative solutions clearly recognized.

Because the need for a better data base is critical to meaningful policy decisions, it is often implied that tradeoffs must be made between

[10] R. C. Anderson and R. C. Dower, "The Use of Cost-Benefit Analysis for Hazardous Waste Management," *Disposal of Hazardous Waste*, EPA 6th Annual Research Symposium (Washington, D. C.: Environmental Protection Agency, 1980), pp. 145-166.

[11] R. L. Keeney and H. Raiffa, *Decisions With Multiple Objectives: Preferences and Value Tradeoffs* (New York: John Wiley & Sons, 1976).

[12] K. R. MacCrimmon and J. K. Siu, "Making, Trade-off s," *Decision Sciences*, 5, 1974, pp. 680-704.

[13] T. H. Ess and C. S. Shik, " Multiattribute Decisionmaking for Remedial Action at Hazardous Waste Sites, " in *Risk and Decision Analysis for Hazardous Waste Disposal* [Silver Spring, Md.: Hazardous Materials Control Research Institute, 1981), pp. 196-209.

expeditious protection of public health and the need to obtain improved data before decisions can be made. This conclusion appears too pessimistic. Granted, present methods for deriving quantitative components in the risk-management framework are by no means perfectly developed. Nonetheless, with careful analysis of available data, existing tools can be used effectively. R&D should continue to improve risk-assessment methodologies. Integration of these tools in a multiattribute decision framework would provide a systematic approach for risk management in a hazardous waste regulatory program. The use of such a framework also would provide a means for open scrutiny of all aspects of a decision,

Classification Systems

RCRA regulations for the management of hazardous waste do not recognize differences in the level of risk associated with various waste and management technologies. Regulation based on degree of hazard has an obvious appeal. Few dispute its theoretical advantages. At issue, however, is the level of detail required to reguIate waste management by some method of classification, and whether the expected improvements would be great enough to justify the time, people, and money needed to develop a classification approach,

The challenge is to design a system that reflects real conditions, A design that is too simple would not represent the actual hazard posed by waste or the potential risk level from particular facilities. A more complex system might better represent the waste management situation. However, as the level of complexity increases, so does the need for extensive data development, Thus, the usefulness of a complex system may be questioned if it imposes greater burdens on industry (e.g., in furnishing large amounts of data on waste and facility characteristics) and on government (e. g., in enforcing submission of data by industry and verifying the data).

In the past, several States have considered hazard classification as a means of regulating industrial waste. A majority of those States submitting comments on the 1978 proposed regulations urged EPA to consider development of a formal classification system based on degrees of hazard.[14] The fact that States are interested in this concept and have attempted to include waste classification systems in their management programs suggests that further consideration at the Federal level might be justified.

Although most discussions of classification systems have focused only on categorizing waste by levels of hazard, an effective risk-management system must also include classification of the facilities handling the waste. Without consideration of both hazard and risks associated with all management options, optimal protection of public health and the environment will not be possible.

Waste Classification

A basic premise of a waste classification system is that a waste or its constituents can be grouped according to criteria that define quantifiable human and environmental effects, The principal distinction is between those wastes that pose a substantial threat to human health and the environment and those posing relatively less harm.

Technical Background

For industrial waste, hazard refers to those characteristics inherent to a specific waste or its constituents that could cause adverse effects

[14] *The RCRA Exemption for Small Volume Hazardous Waste Generators* (Washington, D. C.: U.S. Congress, Office of Technology Assessment, 1982),

in humans and other organisms. The hazard characteristics of concern in the RCRA regulatory programs are ignitability, corrosiveness, reactivity, and toxicity. Table 40 provides definitions of these four types of hazard, the commonly applied test indicators for each, and an indication of whether discrimination among hazard levels is possible.[15]

The information needed to evaluate degrees of hazard of different materials is illustrated in figure 16 and include:

- specific process waste and their constituents,
- toxicological characteristics, and
- chemical and physical factors that influence their environmental fate.

Specific Process Wastes.—In general, a waste from a single industrial process is composed of more than one type of chemical. Identification of the major constituents is needed to determine ignitability, reactivity, corrosiveness, and toxicity. The concentrations of major constituents also must be known, since these will determine the dose available 10 organisms. The physical state of the waste (e.g., liquid, sludge, solid, gas) influences potential levels of hazard by affecting potential routes of exposures. For example, if the waste is predominantly liquid, it may migrate through the environment more rapidly than if it were solid. The physical state of individual constituents is important as well; the harm posed by some compounds varies according to the extent of molecular complexity, or isomerization. For example, less chlorinated forms of PCBS (e. g., mono-, di-, and trichlorobiphenyl) pose less harm than the more chlorinated forms (e. g., penta-, hexa-, and decachlorobiphenyl). Also, the electric charge, or valence of ions influences chemical interactions (e.g., different valence levels of iron, Fe^{++} and Fe^{+++} react differently). Obtaining this information is not difficult. Accurate estimates of waste composition, physical form, and concentration of major constituents of a process waste can be derived by an analysis of feedstock information and of the reactions taking place during manufacture.

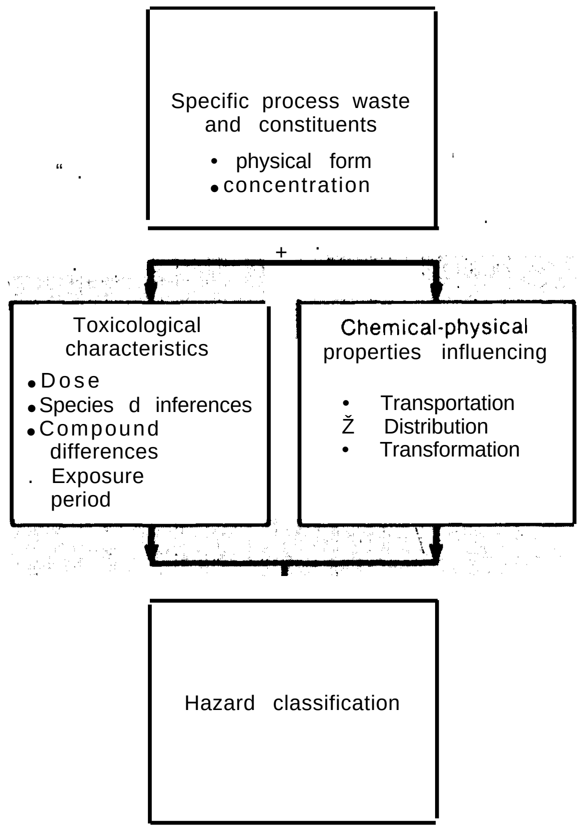
[15] S. L. Daniels, "Development of Realistic Tests for Effects and Exposures of Solid Wastes, " *Hazardous Solid Waste Testing* (Philadelphia, Penn.: American Society for Testing and Materia]s, 1981), pp. 345-365,

Table 40.-Waste Characteristics That May Pose a Hazard

Hazard definition	Commonly used indicators	Potential for hazard classification
Ignitability		
Direct—exposure to heat, smoke, fumes; indirect—dispersion of hazardous byproducts	Flash point, fire point autoignition temperature	Classification scheme used by the Department of the Interior and National Fire Protection Association; could use composition limits of ignitability, flash point, and ability to sustain combustion as criteria
Corrosivity		
Direct—destruction of living (tissue) and nonliving surfaces; indirect—influences volubility and transport of hazardous compounds	pH level—acid or base	pH expressed in logarithmic scale; could use pH, buffering capability, ionization potential, rate of corrosion of standard material (steel)
Reactivity		
Direct—evolution of heat, pressure, gases, vapors, fumes; indirect—encompasses several aspects of chemical reactions when compound/ solutions are mixed or initially interact	"Violent" reaction with water	Difficult to distinguish degrees of reactivity
Toxicity		
Produces adverse effect (e.g., death or nonreversible changes in living organisms)	Range of acute and chronic test results	Classification schemes have been developed by several States for managing either toxic substances or hazardous waste

SOURCE: Daniels, 1981

Figure 16.—Information Requirements for Hazardous Waste Classification



SOURCE" Office of Technology Assessment

Toxicological Characteristics .—The effects of industrial waste on humans and the environment range from innocuous, short-term impacts such as a mild skin rash to severe long-term problems like cancer. Four factors are important in determining the toxicity of a substance: dosage, species affected, type of compound, exposure period, and route.

1. Dose.—The 15th century alchemist Paracelsus noted: "All substances are poison; the right dose differentiates a poison and a remedy. " Dose is defined as a selected concentration of a substance or mixture of compounds administered over a specific period of time. For any material there is a dose that will produce adverse effects in a given organism. Similarly, there is a concentration sufficiently low that no adverse effect can be observed (i.e., the response observed in a test population cannot be distinguished from normal background incidence). Even the most innocuous compound (e. g., water), if taken into an organism in sufficient quantity, can result in some undesirable effect or death. A very harmful material (e.g., PCB) can be administered in a dose sufficiently low that no adverse effects can be observed. Concentrations of specific constituents within a waste provides a first, and possibly a worst case, approximation of the potential dose available to organisms,
2. Species differences.—The dose of a specific chemical required to cause some effect (e.g., death) will vary among species (e.g., monkey, dog, and human), For example, when laboratory animals are exposed to air contaminated with cyanogen, the dose required to produce an acute toxic effect varies—cats can only tolerate doses up to 98 parts per million (ppm), but rabbits do not experience toxic effects below 395 ppm.[16] Dosages that produce chronic effects also can vary among species. For example, the amount of Aroclor 1254 that results in some adverse effects on reproductive systems is 200 milligrams per kilogram (mg/kg) for pheasants, 10 mg/kg for mink, and 50 mg/kg for chickens.[17] The quality of the effects also vary among these species. In addition, individuals within a species respond differently to the same concentrations because of such factors as age, stress, and natural sensitivities. For example, nitrates in water can be ingested by an adult human with no adverse effect, but the same nitrates are toxic to infants at certain concentrations.
3. Compound differences.—The dose required to produce a given effect (e.g., death) in a given species (e.g., rats) varies with the type of compound being tested. Examples of differences in acute toxicity

[16] *Registry of Toxic Effects of Chemical Substances* [Washington, D. C.: U.S. Department of Health, Education and Welfare, 1980].

[17] National Research Council, *Polychlorinated Biphenyls* (Washington, D. C.: National Academy of Sciences, 1979).

are presented in table 41.[18] In these examples, the amount required to produce death in 50 percent of the test population varies greatly, ranging from 3 mg/kg for cyanide to 5,000 mg/kg for toluene.[19] Although these compounds vary greatly in acute toxicity, EPA has designed them as equally hazardous on the basis of a number of factors, including toxicity, carcinogenicity, mutagenicity, and teratogenicity.[20]

Just as the degree of acute toxicity is not equal among all compounds, doses for chronic toxicity can vary also; for example, not all carcinogens are equally potent.[21,22] In particular, Crouch and Wilson note that:

> . . . certain of the known carcinogens are intrinsically much more likely than others to cause cancer in test animals—they are more potent. The variation in potency may be as great as a million to one between different materials (depending to some extent on the definition used for potency). A small amount of aflatoxin B1 in the diet (100 parts/billion) gives cancer to a large fraction of the animals exposed, yet the same amount of saccharin in the diet causes no observable effect.

[18] *Nonnuclear Industrial Hazardous Waste: Classifying for Hazard Management—A Technical Memorandum* (Washington, D. C.: U.S. Congress, Office of Technology Assessment, OTA-TM-M-9, November 1981).
[19] *Registry of Toxic Effects of Chemical Substances*, op cit.
[20] 40 CFR, section 261, subpts. B, C, D, and app. viii.
[21] E. Crouch and R. Wilson, "Regulation of Carcinogens," *Risk Analysis in Environmental Health* (Cambridge, Mass.: Harvard School of Public Health, Short Course, 1982).
[22] R. A. Squire, "Ranking Animal Carcinogens: A Proposed Regulatory Approach," *Science*, vol. 214, 1981, pp. 877-880.

Table 41.—Toxic Doses for Selected Hazardous Waste Constituents

Compound	LD_{50}[a]
Cyanide	3
Phenylmercuric acetate	30
Dieldrin	46
Pentachlorophenol	50
DDT	113
Naphthalene	1,760
Toluene	5,000

[a] Amount (mg/kg body weight) that is lethal for 50 percent of the test population, In these examples following oral administration to rats

SOURCE Office of Technology Assessment, 1981

4. Exposure period and route.—Exposure to hazardous waste constituents can result from either expected* or unexpected releases to the environment. Releases of hazardous waste constituents can be continuous or intermittent and can go into air, soil, or water. The quality of a response to a waste constituent will depend on the route of exposure and the duration of exposure. For example, a large concentration given all at one time can result in severe effects including death. In contrast, harmful effects may be much less serious or not observed at all when the same amount is given over several days or a longer period.

   Also, the route of the exposure influences the quality of the effect. For example, some compounds are toxic if inhaled but produce no effect if ingested or if applied to the skin (e.g., fine-grained silica sand), The importance of exposure factors is recognized in regulation; different standards define different permissible levels of compounds in food, water, and air.

Chemical and Physical Factors Determine Environmental Fate.—Chemical and physical properties of waste determine both the movement of constituents through the environment and the incorporation of these materials into living and inanimate elements. Some of these properties are volubility, volatility, physical state (e. g., liquid or solid), pH (level of acidity), and adsorbancy characteristics. Because of their particular chemical and physical properties, some compounds may migrate rapidly through soil and air but accumulate in water sources. Others may bind strongly with soil particles and remain isolated from vegetation or other organisms, Still others may be incorporated into plant and animal tissue and become distributed throughout food chains. Such transfer and distribution of waste constituents is also influenced by physical conditions of environ-

*Releases from waste disposal and treatment facilities will depend on engineering design. For example, the release rate from an incinerator is influenced by the combustion efficiencies of a particular facility. For land disposal units this rate depends on the amount of liquid disposed as well as types of covers and liners. See ch. 5 for a discussion of various engineering designs.

mental media [e. g., type of soil and climatic conditions).

As a compound migrates through air, water, soil, and biota, changes in its structure can occur because of chemical, photochemical, and biochemical reactions. These changes may result in the complete destruction of the hazardous characteristic of a waste constituent, eliminating any threat to health and the environment. However, it is also possible that new, more hazardous compounds can result, The structural changes need not be large, even small rearrangements in molecular structures can influence either accumulation of a compound in tissue or its degradation.

Models for Classification of Waste

The degree of hazard of a specific waste or its constituents can be determined by analyzing data on the state of the waste, toxicity, environmental fate, and safety. Table 42 lists certain important factors in establishing criteria for waste classification. Categorizing materials on the basis of measures of hazard is not a novel concept. Several methods have been developed, These include formal classification systems and rank-order models.

Table 42.—Factors Important for Hazard Classification Criteria

Hazard characteristics	Measures to distinguish category boundaries
Physical data:	
State of waste	Solid, liquid, gas, vapor, mixture, etc
Concentrations . . .	Percent of total waste stream, actual measurement
Toxicity:	
Acute toxicity	Short-term responses, e.g., lethal dose ranges for terrestrial and aquatic species
Chronic toxicity	Long-term responses, e.g., severity of morphological and functional Impairments
Genetic Impairment	Carcinogenic and mutagenic potency
Environmental ***fate:***	
Persistence/degradation.	Half-life in soil, air, and water
Bioaccumulation	Affinity for water or lipids in tissue
Exposure potential	Distribution and partitioning parameters—solubiliy, volatility, sorption
Safety:	
Ignitablity ., ., . . .	Flash points, combustibility
Corrosivity	pH ranges, buffering capacity
Reactivity ... . .,	Immediate adverse (explosion) reaction with water or release of significant quantities of water

SOURCE Office of Technology Assessment

Formal classification models categorize waste constituents according to toxicological criteria or to a combination of toxicity factors, measures of environmental fate, and concentrations of waste constituents.[23] Threshold values are assigned for each criteria. In order to keep the systems simple and usable, most of these models rely only on measures of acute toxicity and identification of materials known or suspected to be carcinogenic. These criteria are rather limited for judging the overall hazard of a waste or its individual constituents.

Rank-order models were developed in response to the mandates of the Toxic Substances Control Act (TSCA).[24] Compounds of concern are assigned a separate score for each of several different criteria. The overall ranking is based on a combination of these scores. Included is a broad range of factors: acute toxicity, carcinogenicity, mutagenicity, teratogenicity, persistence, bioaccumulation, esthetics, and chronic adverse effects. A modification of these rank-order models incorporates an additional concept, commonly termed "red-flagging. "[25] Within each criterion a minimum score, termed a discriminatory value, is identified. This value serves to flag those chemicals that may pose severe threats to health and the environment.

To date, rank-order models have been used only to set priorities for actions affecting chemicals, rather than to establish classes of hazard. It has been suggested that the system can be used for ranking compounds by their carcinogenic potency for regulatory purposes.[26] Also, Michigan has developed a rank-order model to provide a way of identifying

[23] Appendix 6 presents examples of classification schemes developed by various States. For a discussion of each, see *Non-nuclear industrial Hazardous Waste: Classifying for Hazard Management-A Technical Memorandum,* op. cit.

[24] Public Law 94-469, 1976.

[25] S. L. Brown, "Appendix B. Systems for Rapid Ranking of Environmental Pollutants, " *Scoring Chemicals for Health and Ecological Effects Testing* (Rockville, Md.: Enviro Control, Inc., 1979).

[26] Squire, op. cit.

critical materials that may require the attention of State officials.[27]

Although rank-order models were not developed for classification of industrial waste, they might be adapted for such use. Critical factors contributing to the inherent hazard of a waste could be identified and an appropriate range of scores defined for each factor. Ranges of total scores could be grouped into hazard categories. Both hazard potential and environmental fate factors can be readily incorporated into the system.

Waste classification systems have certain problems that must be resolved. First, most of the available models rely heavily on measures of acute (short-term) toxicity and carcinogenicity. While these two criteria maybe important, there are other chronic (long-term) health effects and environmental impacts that should receive equal attention. The problem is that there are few reliable ways to measure such chronic effects as reproductive impairment, immuno-suppression, and physiological dysfunction or damage of organs (e.g., heart, lung, and liver). Criteria for these effects could be developed on the basis of animal experiments used to approximate human impacts, but data even from animal tests are scanty. Obtaining them will require long-term testing for several years. No reliable short-term procedures exist for measuring these chronic effects. Short-term bioassays for mutagenicity and genetic impairments are used as rough measures of propensity to cause cancer, but they do not always correlate with the results of longer term tests for cancer. Determining criteria for environmental effects is in its infancy. (This became a concern only with the passage of TSCA.) While some testing methodologies are available, considerable development work lies ahead.

A second problem arises from the analysis of individual constituents as a measure of the hazard of a waste. It may not be prudent to assume that the actual hazard posed by any particular waste is the same as the "collective hazard" of individual constituents. Most hazard models do not consider synergistic or antagonistic effects, nor do they evaluate degradation products, and possible major interactions. Some proponents of classification would argue that individual constituent analyses provide a conservative estimate of a hazard, but may not necessarily be true. Such an analysis may suggest medium or low hazard; if compounds interact, however, the actual hazard of a waste could be high. Some compounds that do not, individually, produce cancer in exposed animals, will do so in combination. Also, while a parent compound may be low in hazard, the degradation products could be more hazardous; degradation of certain compounds to nitrosamines is an example,

Finally, given the uncertainties in the analysis of hazards, a test result for any compound always will have a certain level of error associated with it. Discrepancies in hazard classification can result and must be addressed. If they are ignored, they could lead to endless litigation between waste generators and EPA over whether a waste really is highly hazardous or merely represents medium hazard. For example, an "extremely hazardous" criterion might be set at less than 50 mg/kg (the lethal dose for half the exposed population) for oral administration to mammals. Then questions might be raised if a waste with test results of 49 + 4 mg/kg is assigned to the extremely hazardous category. The questions could multiply if the test results for the waste were 49 for rats, 100 for mice, and 500 for dogs. While none of these species has exact correlations with human effects, all are legitimate test animals.

This last problem is not unique to classification of waste. It occurs with any standard, for any material, To resolve the problem, classification boundaries must be set with clearly defined limits. A precedent for such action was set in the regulations under the Federal pesticide law[28] where EPA not only designated standards, but also established criteria for

[27] See app. 6A for a description of each criteria used in this model. Department of Natural Resources, *Michigan Critical Materials Register* [Detroit, Mich.: State of Michigan, Environmental Protection Bureau, Environmental Services Division, 1980).

[28] The Federal insecticide, Fungicide, and Rodenticide Act, as amended in 1978.

determining confidence levels of test results and guidelines for including these in evaluations of compliance.

Facility Classification

The underlying concept for classification of waste management facilities is that the capacity to minimize release of harmful materials varies from one facility to another. Although the concept is new and highly speculative as to feasibility and design, a classification system has been proposed for management of low-level radioactive wastes.[29]

Technical Basis

The technical basis for facility classification is the concept of risk, defined as the probability that a defined event will occur under a specific set of conditions. In waste management, the event is the release of harmful constituents, given identified engineering designs and environmental conditions.

For each type of waste management option (e.g., thermal destruction, land disposal, and treatment facilities), ranges of design and environmental conditions can be identified. For example, the risk associated with landfills varies depending on the number of liners, the permeability of each liner, and geological conditions of the site. For thermal destruction, various designs (e. g., high-temperature incinerators, cement kilns, and boilers) offer different degrees of risk when a particular type of waste is burned, The efficiency of waste combustion is limited by process controls such as air flow, residence time, and function of the incinerator. Cement kilns, for example, can be used to incinerate certain wastes, but their original purpose is to produce cement particles, Similarly, industrial boilers are designed to produce heat, although they also can be used to incinerate waste. By contrast, the primary function of a high-temperature incinerator is destruction of combustible organics.

Determining the risk level associated with a facility design can be a complex task. The risk potential of a facility depends on more than the hazard level of the material being handled. It also depends on the type of environment surrounding a facility, meteorological factors for the site, the impact of the management option on the waste constituents (e. g., does it destroy the waste, reduce its hazard potential, sufficiently isolate it, or contain it for a specified period of time), and the technological limitations of the facility design and operating conditions.

The aim of facility classification is to match waste classes with appropriate categories of facility design and environmental conditions. For each type of facility (e.g., land disposal or incineration) an acceptable level of risk must be identified for specific environmental conditions. The match among wastes and facilities must not exceed this risk level. For example, the overall risk arising from the match of waste Class I and land disposal Class I must be the same as for waste Class 11 and land disposal Class II. Included in the match is the location and environment of the management facility. A waste class that would pose severe threats if allowed to escape might be managed in a facility where location and environmental conditions minimize exposure to humans and other living things.

Models for Facility Classification

Because facility classification is a new concept, few models are available for implementing the approach. Classification schemes for sites are available, but they have focused primarily on the hazard potential of abandoned dumps.[30] [31] With some modification these schemes could be applied to landfill, incineration, or treatment facilities as well,

Table 43 illustrates the type of criteria that could be used to classify management facilities.

[29] *Striking a Balance Toward a National Policy for Managing Low-Level Radioactive Waste: Kc}' Issues and Recommendations* [Washington, D. C.: Conservation Foundation, 1981).

[30] JRB Associates Inc., *Methodology}' for Rating the Hazard Potential of Waste Disposal Sites,* prepared for the U.S. Environmental Protection Agency, 1980.

[31] Mitre Corp., *Site Ranking Model for Determining Remedial Action Priorities Among Uncontrolled Hazardous Substances Facilities* (McLean, Va.: Mitre Corp., 1981).

Table 43.—Proposed Measures for Classifying Management Options

Characteristics	Measures to distinguish categories
Design	Measures of limiting process controls (e. g., combustion levels, number of liners, sophistication of instrumentation, monitoring programs)
Meteorological	Climatic conditions
Site characteristics	Distance to nearest drinking-water well
	Distance to nearest off site building
	Land use/zoning
	Critical environments
	Distance to nearest surface water
	Depth to ground water
	Net precipitation
	Soil permeability
	Bedrock permeability
	Depth to bedrock

SOURCE Office of Technology Assessment

The major factors include design characteristics, meteorological conditions, and site conditions. Appropriate design and meteorological characteristics vary with the type of facility. For example, containment capabilities adequate to the threat of floods or potential for earthquakes would be important for landfills. Incinerators would be classed according to combustion capabilities and chamber designs, together with consideration of wind patterns or air inversions. The critical environmental factors for any facility might include: distance to drinking water sources, distance to nearest population, existence of critical or endangered environments, distance to nearest surface water, depth to ground water sources, precipitation levels, soil permeability, bedrock permeability, and depth to bedrock.

Scores could be assigned for different levels within each of these factors. Separate classes may be designated based on some method of combining scores. It may be necessary to develop classification schemes based on environmental media—e.g., land (land disposal facilities), air (thermal destruction), and water (treatment facilities). The criteria could then be related to minimizing release of hazardous constituents to the relevant medium.

Once a technology/facility/site combination has been classified, waste groups then could be matched to it. Thus, a waste which is highly hazardous, moves readily through soil, and has a low potential for natural degradation would be restricted to facilities that could contain, completely destroy, or immobilize such waste. California has a scheme for classifying landfills. Permeability standards are used in conjunction with location of ground water sources to place existing landfills into one of three classes. It has recently completed a comprehensive study of hazardous waste and has restricted certain waste to particular classes of landfills.[32]

The basis for facility classification schemes is the ability of a facility to properly contain the waste for a specified period of time, and to match this period of time with rates for degradation or mobility of a waste. Thus, facilities that can contain a waste for a specified time, or can destroy it completely (e.g., by incineration), could be selected to handle waste that are highly persistent and nondegradable. If controlled release of the waste from a facility is likely and if there is potential for surface- or ground-water contamination at some time in the future, then the waste handled at such facility location must have degradation potentials that match the expected time of escape.

Feasibility of Classification: A Case Study

In an attempt to clarify some of the issues on classification of waste and facilities, OTA sponsored a study on the feasibility of such a system.[33] The study operated under several limitations. It used only currently available classification criteria and readily obtainable data. It examined only a selected group of hazardous wastes listed or proposed for listing by EPA for which toxicity and environmental fate data were available in EPA background documents; and it supplemented the EPA data with toxicity information from the Registry of

[32] Department of Health Services, "Changes in Regulations of the Department of Health Services Regarding Hazardous Waste Land Disposal Restrictions (R-32- 82)," (Sacramento, Calif.: State of California, Health and Welfare Agency, 1982].

[33] J. Harris, P. Strand, and T. Shea, *Classification by Degree of Hazard for Selected Industrial Waste Streams* (Washington, D, C.: Office of Technology Assessment, Materials Program, 1982).

Toxic Effects of Chemical Substances. The goal of the study was to determine at a very simple level whether classification is possible—i.e., to test a concept that had up to then been considered only conjecture. Even given its limitations in data, the study showed that **facility classification is possible.** While the limitations of the classification models now available must be recognized, it does appear possible to improve the national hazardous waste management program through classification systems (see ch. 3).

Structure of the Feasibility Study

Two models were chosen for the feasibility study. One was a model developed by the State of Washington for use in their waste management program.[34] The other was a ranking methodology formulated by Michigan for its critical materials registry.[35] Table 44 shows the characteristics used in each system. Appendix 6A provides descriptions of how waste constituents are scored in the two systems.

Nine wastes were chosen from the RCRA list for this analysis, representing a range of volumes and toxicity levels. The wastes are shown in table 45, Because no schemes for actual management classification exist, the feasibility study reviewed only classification of landfills, using environmental criteria developed by JRB Associates.[36] The capacity to distinguish, by this means, among three existing landfills was analyzed and used to indicate the feasibility of management classification in general.

Study Results

Although EPA treats the nine wastes included in this exercise as equally hazardous, it is apparent from table 46 that further classification by degree of hazard can be made. Even with the limited data available to the study, it was possible to distinguish these wastes into

[34] C. C. Mehlhaff, T. Cook, and J. Knudson, "A Quantitative Approach for Classification of Hazardous Wastes," *Solid Waste Management*, vol. 21, No. 13, 1979, pp. 70-86.

[35] Department of Natural Resources, *Michigan Critical Materials Register* (Detroit, Mich.: State of Michigan, Environmental Protection Bureau, Environmental Services Division, 1980).

[36] J R B Associates Inc., op cit

Table 44.— Hazard Characteristics of Case Study Classification Models

Hazard characteristic	Washington system[a]	Michigan system[b]
Physical data:		
State of waste	None	None
Concentration	Quantity/concentration formula	Quantity/concentration formula
Toxicity:		
Acute toxicity (LD_{50}, LC_{50})	Oral, aquatic	Oral, dermal, aquatic
Chronic toxicity	None	Reversible, irreversible
Genetic impairment	Carcinogenicity only	Carcinogenicity Mutagenicityy Teratogenicity
Environmental fate:		
Persistence/degradation	Presence of polycyclic aromatics and halogenated hydrocarbons	Persistent Degradable
Bioaccumulatlon	None	Accumulation coefficients
Exposure potential	Related to concentration of constituents in waste	None
Safety:		
Ignitability	RCRA criteria	None
Corrosivity	RCRA criteria	None
Reactivity	RCRA criteria	None

[a] Five hazard classes + A, B, C D (least hazardous)
[b] Four hazard classes A B, C, D (least hazardous)

SOURCE Off Ice of Technology Assessment

Table 45.—Case Study Wastes

Waste	EPA hazardous waste number	Volume[a] (tons)	Production sites (number)
High volume/high toxicity:			
• Bottom stream from an acetonitrile column in the production of acrylonitrile	KO13	337,000	6
High volume/low toxicity:			
• Wastewater treatment sludge from production of titanium dioxide pigment, using chromium bearing ores by chloride process	K074[b]	900,000	
Medium volume/high toxicity:			
• Brine purification muds from the mercury cell process in chlorine production, where separately prepurified brine was not used	K071	42,000 (dry)	27
Low volume/high toxicity:			
• Chlorinated hydrocarbon waste from purification step of diaphragm cell process, using graphite anodes in chlorine production	K073	?	?
• Wastewater treatment sludge from the production of toxaphene	K041	3,750	2
• Distillation bottoms from the production of nitrobenzene by nitration of benzene	K025	500	7
• Ammonia still lime sludge form coking	K060	1,000,000	30’
• Spent stripping and cleaning bath solutions from-electroplating operations where cyanides are used in the process, except for precious metal use	FO09	22,500 gals	10,000
Low volume/low toxicity:			
• Light and heavy ends from distillation of acetaldehyde in the production of acetic anhydride	Not listed	2,000	4

[a]Annual volumes taken from EPA background documents
[b]EPA delisted this waste stream
[c]Process being phased out by 1982 only 2 companies with a few plants remai n

SOURCE Off Ice of Technology Assessment

two to four classes of hazard. In most cases, the hazard class for individual constituents of a particular waste did not vary substantially; it was possible to designate an average classification for the waste. The method of averaging was arbitrarily chosen for the purposes of this study. The class designation for the majority of constituents determined the waste average rank. For example, K060 would be assigned to class B in the Washington State system only, since four of its six constituents have that classification. Depending on relative concentration levels for both cyanide and phenol, and the potential for separating these two constituents from the waste before treatment/disposal, the overall classification could be adjusted. For K073, an appropriate classification might be class C because of the distribution of ratings for individual constituents.

An important finding was that the actual class designation for a particular waste is dependent on the model used, as illustrated in table 47. It appears that greater discrimination is possible using the Washington State system. A sensitivity analysis would be required to determine which factors contribute to the greater discrimination in this system.

Ranking of landfills using criteria based only on environmental criteria was found to be possible, Though limited, this study shows that even simple classification criteria can distinguish differences in risks posed by different management facilities.

Limitations Encountered

Not surprisingly, the study found significant limitations in data availability, variability, and

Table 46.— Results of Case Study Classification of Wastes

Waste	Constituent	Washington system: Average for waste[a]	Washington system: Constituents	Michigan system: Constituents	Michigan system: Average for waste[a]
K071	Mercury[b]	X[c]	X[c]	A[d]	A[a]
K060	Arsenic[b]		B	A	
	Arsenic trioxide		B	A	
	Arsenic pentoxide	B	B	A	A
	Naphthalene		B	B	
	Cyanide[b]		X	B	
	Phenol		C	B	
FO09	Sodium cyanide	B	B	B	A
	Potassium cyanide		B	A	
K013	Acetonitrile		C	B	
	Acrylonitrile	C	C	B	B
	Hydrocyanic acid		A	B	
Heavy and Light Ends	Methyl acetate		—[e]	—[e]	
	Acetone		D	—[e]	
	Ethylidene diacetate	D	—[e]	D	B
	Ethyl acetate		D	B	
K073	Chloroform		C	A	
	Hexachloroethane		B	B	
	Carbon tetrachloride		C	A	
	1,1,2- trichloroethane	C	C	B	B
	1,1,1- trichloroethane		C	B	
	Tetrachloroethylene		C	B	
	1,2- dichloroethylene		D	B	
	1,1- dichloroethylene		C	B	
	1,1,2,2- tetrachloroethane		C	A	
K041	Toxaphene		X	A	
K025	Meta-dinitrobenzene	B	B	B	B
	2,4-dinitrotoluene		C	B	
K074	Chromium[b] (trivalent $CrCl_3$)		D	B	
	Chromium[b] (trivalent Cr_2O_3)	D	D	B	B
	Chromium[b] (hexavalent)		C	B	

[a]Where discrepancies occur among constituents, an arbitrary class designation for the waste was chosen by using the value for the majority of constituents (e g K060) or where constituents were evenly divided among classes, the average designation for the waste equaled the highest class ification (e g F009 rank-order)
[b]May be classified as EP toxic according to either scheme depending on concentration
[c]X represents most hazardous, D least hazardous
[d]A represents most hazardous, D least hazardous
[e]Insufficient data to determine category

SOURCE Office of Technology Assessment

Table 47.— Distribution of Wastes Among Classes

	Hazard classifications: X[b]	A	B	C	D
Washington system	K071		K060	K013	H Lends
	K041		FO09	K073	
			K025	K074	
Michigan system		K071	K013		
		K060	HLends		
		FO09	K073		
		K041	K025		
			K074		

[a]Left to right represents decreasing hazard levels
[b]This class Included only in the Washington system
HLends Heavy light ends

SOURCE Office of Technology Assessment

interpretation. Data availability is a chronic problem in the design and implementation of environmental regulations, and classification models are no exception. Both of the waste classification models used in this study required more data than was available for some of the waste constituents. Thus, the categorization of many wastes was based on no more than one or two data points. It should be emphasized that this problem is not unique to hazardous waste management, but occurs often in the evaluation of hazards or risks for any purpose.

Data variability also created some difficulties. Even when data were available, they were often not the types required in the models. Currently, there are no standardized methods for correlating test results across species or for different routes of exposure within a species. EPA correlations for cross-species test results compare surface areas of the test animals involved, although these comparisons are not generally accepted by the scientific community. Again, variability in data is a problem common to all areas of scientific inquiry; it arises from differences in the measuring processes and from variabilities in responses of organisms to chemicals. Although this type of variability can never be wholly eliminated, it can be accommodated by using appropriate ranges of data values for each critical factor in a classification model.

Because some of the defined categories in the models had very specific criteria, data interpretation became increasingly important. For example, the ranges of values defining a toxicity criterion were, in some instances, narrower than those given in the published data. Thus, it was necessary to represent data rather arbitrarily by a single point in order to assign it to a hazard class. Other problems arose in translating information from published data to the specific requirements of a classification model. For example, the scoring for chronic adverse effects in the rank-order (Michigan) model required information about the reversibility of an effect and concentrations at which reversibility is observed. While published descriptions of chronic effects are sometimes quite detailed, often they do not provide indications of reversibility; to fill in this blank requires expert judgment. Among other problems encountered were the correct interpretation of common labels, such as “potential animal carcinogen. ” Also, it was difficult to interpret differences in data resulting from variation in the structure of chemicals used in tests (e.g., chemical compounds that are identical except for a particular geometrical relationship in one part of the molecular structure can have substantially different toxicities).

A conclusion to be drawn from the case study is that scientifically defensible and technologically feasible standards and criteria would have to be developed for an acceptable regulatory program based on hazard classification. The criteria must be based on accurate characterization of waste and reliable toxicological information. The rationale for each hazard criterion and its range of values must be stated explicitly. Moreover, in designing a classification system, judgments must be made for such technical issues as:

- Absolute v. relative toxicity .–Whether actual values of acute and chronic toxicity should be used as hazard criteria, or whether a scoring system should be devised showing relative toxicity values.
- Equivalent concentrations v. single constituent concentrations as the basis for regulation.—Whether to evaluate the hazard of the waste as a whole by combining weighted values of its constituents.
- The need to develop short- and long-term bioassays for actual waste samples, rather than for single constituents of the waste—The interaction of constituents may result in a different hazard level from that of the constituents singly.

Problems and Advantages of Classification Systems

Several advantages in using classification systems are apparent. An industrial waste management system that successfully matches waste classes with facility classes would provide a consistent level of protection, while avoiding excessive regulation. Highly hazardous waste would be handled at facilities with the highest performance standards; but less hazardous waste would be handled at less cost in facilities designed to less rigorous standards. Other advantages are that government regulations could set priorities for establishing standards and controls on the basis of degrees of hazards for wastes and risks for facilities. In addition, the system could give the public reliable information on the most effective and appropriate ways of handling each class. This last point is particularly important, At present, the general public tends to consider all industrial waste equally hazardous. Moreover, many people be lieve that government is doing very little to protect human health and the environment against these hazards. These perceptions have played a part in the efforts of concerned citizens to halt or delay the development of new facilities, (The section on "Siting" includes a more detailed discussion of these problems.) Use of a facility classification system in regulation could help to inform the public about the broad range of hazards and risks related to hazardous waste management. Use of the system certainly will not eliminate public concern, nor perhaps, reduce it. But the result could be to focus public concern more closely on the level of hazard and the various technical possibilities for dealing with these hazards. For example long-term health and environmental consequences of incineration, chemical or biological treatment, and containment alternatives could be drawn to public attention and compared.

Several practical problems, some mentioned in the foregoing discussion, may make it difficult to design a successful system. The difficulties may be summarized as follows:

Mismatches of waste classified by hazard and facilities classified by performance standards might occur. In some instances it may be a mismatch to send only the most hazardous waste to those facilities rated highest in performance. Incineration is an example. Different classes of facilities could represent differences in combustion efficiencies, from 90 to 99 percent. There is no information to suggest that a medium-hazard waste, classed as such based on criteria of toxicity and persistence, presents an equal or lower risk when burned at 95 percent efficiency as compared to a high hazard waste burned at 99 percent efficiency. It is possible that a very hazardous material burns readily and could be incinerated in an industrial boiler, a low-performance facility, thus posing no risk. In contrast, a medium- or low-hazard waste burned in a similar facility may not be readily combusted. If the material is not completely destroyed or if it forms hazardous combustion products, overall greater risk may result than with incineration of the highly hazardous material.

The classification system might also mask critical environmental considerations. A particular waste may have different levels of hazard in different environmental media. For example, a waste constituent may be readily degraded in air but not in soil or sediment. Thus, if incinerated it might pose only a low risk, but for land or ocean disposal a very high risk level could result, A material classed as a medium hazard based on toxicity, genetic impairment, and persistence may be readily mobilized in a landfill. The hazard level results from a weighting of several criteria, and therefore, a waste may have medium hazard for cancer, be highly mobile, and perhaps a high hazard for chronic effect such as immunosuppression. The mobility factor, however, is most important for the risk at a water source. If placed in a medium secure landfill and allowed to migrate to water sources, a medium-hazard constituent can cause the same type of adverse effects on the exposed population as a highly hazardous constituent; it may simply require a higher accumulation of the material before the effect is observed.

A related problem is that the waste characteristics that define a hazard may differ from characteristics that determine the management choice. Waste classification systems include a diverse range of hazard criteria. The overall hazard rank is a combined weighting of all these criteria. However, from the management perspective one specific hazard characteristic often influences the potential risk associated with a particular management option. Such a characteristic could be the high potential for reactivity, which requires a management practice that protects against a short-term hazard. Or if the mobility of an organic waste is the prime concern, management must deal with long-term, cumulative effects. A hazard class could include various waste requiring different technologies. Judgments about the type of waste to be managed in a particular way currently are based on knowledge of the constituents of the waste and limitations of the facility. It is not clear how sophisticated analyses of the hazard potential of a waste before it enters a facility will improve these judgments.

The degree of hazard of a waste may be changed in a management facility. Although each generator can test for hazard characteristics of its particular waste stream, the results may not define adequately the real hazard of constituents released from a management facility. Most facilities are not "mono-" facilities, i.e., they do not accept only one type of waste from one source. Therefore, the hazard class of one type of waste may have little real meaning for the risk potential of a facility. Mixing of several kinds of waste could result in interactions that would change the hazard level of any one or all by either increasing the hazard or decreasing it. If the main concern is the risk to workers at a facility, it may be quite appropriate to focus on the hazards of materials as they enter a facility. But if risk to the general population and the environment is foremost, then the important hazard potential is in the materials that are released from a facility.

These difficulties can be resolved. It should be possible to design a system that addresses these problems but does not become overly complex and expensive and thus impractical to implement. OTA's feasibility study indicates that such a system is possible. Because of the advantages classification can offer for regulation of hazardous waste a further study to design an effective, practical system seems justified,

Monitoring

Monitoring provides information essential to reasonable and equitable decisionmaking. The importance of environmental monitoring in pollution-abatement programs is well recognized.[37] 38 The success of pollution control can only be judged by measuring the presence of constituents in all environmental media and comparing these data with measurements taken before the pollution controls were implemented.

Data collected for several purposes (i.e., both to assess environmental quality and to determine compliance with environmental regulations) must be coordinated and available to decisionmakers. Monitoring information is important for decisions on regulatory action by agencies in the executive branch and it is also important for congressional oversight functions. At a 1978 congressional hearing, Representative J. Jeffords (R-Vt.) emphasized this point:[39]

> As a result of . . . lack of an adequate national environmental quality monitoring program, those of us in Congress who are responsible for passing judgment on environmental statutes do not have a solid basis for assessing the success or lack of success of the laws we pass, Moreover, we continually face new environmental crises because we lack the environmental monitoring that might have warned us of emerging problems.

The several different but closely related purposes served by monitoring programs are illustrated in table 48.[40] Adequate data on concentrations of specific compounds, their distribution patterns in the environment, and cause-effect relationships are needed for informed judgments about contamination levels, compliance with regulations, and appropriate performance standards. Without monitoring data, judgments about the effectiveness of

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[37] U.S. Congress, House of Representatives, *Environmental Monitoring-II*, hearings before the Subcommittee on the Environment and the Atmosphere of the Committee on Science and Technology, No. 93 (Washington, D. C.: U.S. Government Printing Office, 1978].

[38] National Research Council, *Environment] Monitoring* (Washington, D. C.: National Academy of Science, 1977].

[39] U.S. congress, House of Representatives, Op cit.

[40] Council on Environmental Quality, *Interagency Task Force on Environmental Data and Monitoring* (Washington, D. C.: U.S. Government Printing Office, 1980).

Table 48.—Description of Monitoring Functions

Monitoring function	Description
1. Baseline information	Routine monitoring and collection of constituent information.
2. Standard development	Development of information bases for establishment or revision of constituent standards.
3. Compliance monitoring	Collection of constituent information to verify compliance with regulatory standards set by operations of Federal, State, and local governments and the private sector. Monitor status of environmental control regions.
4. Research and development	Provides information for model development, instrumentation R&D, development testing, or audit of measurement techniques.
5. Public or agency alert	Provides a warning system for agency action and/or public alert.

SOURCE Council on Environmental Ouality, 1980

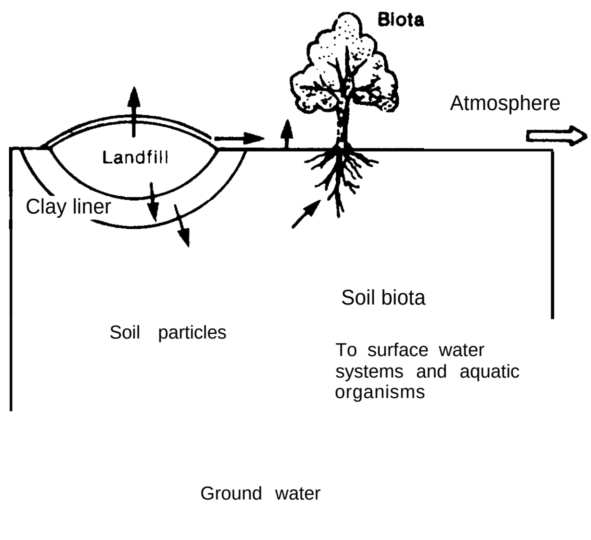
various waste management options may depend on political interests and individual perceptions.

Monitoring data also provide tangible evidence to a concerned public that human health and the environment are being protected. In the absence of monitoring data, the extent or success of protection offered to human health and environmental stability is only conjecture. In hazardous waste management, monitoring activities are the only means of verifying that a facility is operating properly.

Environmental Fate and Design of a Monitoring Program

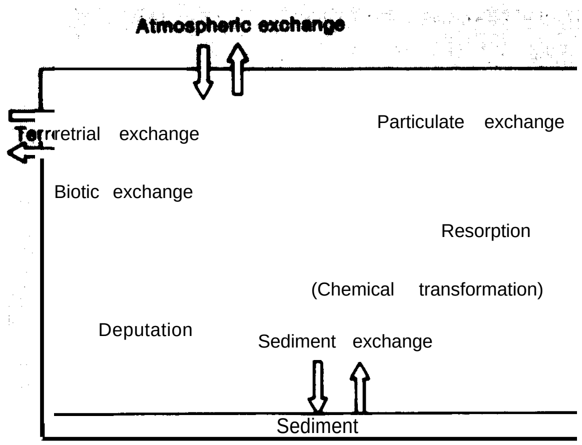
Several important distribution routes are available to waste constituents once they are released from a waste management facility, as illustrated in figures 17 and 18. The constituents may dissolve in water and percolate through soil into ground water supplies; if well water is drawn for domestic or agricultural use, humans, plants, and animals can be exposed to the contaminated water. Chemicals mobilized through the food chain can present a hazard to humans and higher organisms. (Methylmercury is a well-known example of this.) Chemicals dissolved in runoff water (e.g., materials released through accidental spills or pesticides applied in fields) may enter streams and accumulate in either sediment or aquatic organisms. These materials could be transferred via streams and rivers to sites far from the point of release. Those chemicals with sufficiently high-vapor pressure may evaporate at the point of release, and then maybe deposited nearby via rain or snow, or they may be transported long distances depending on prevailing wind currents. Airborne materials can be directly inhaled by organisms. Solid materials (e.g., as powders) stored in surface piles may

Figure 17.— Potential Transport and Points of Transformation for Land-Disposed Hazardous Waste Contaminants



SOURCE" Modified from G F Lee and R A Jones A risk assessment approach for evaluating the environmental significance of chemical contaminants in solid wastes, "Environmental Risk Analysis for Chemical s," R A Conway (ed), 1981

Figure 18.— Potential Transformations of Hazardous Constituents in Aquatic Systems



SOURCE Modified from G F Lee and R A. Jones A risk assessment approach for evaluating the environmental significance of chemical contaminants in solid wastes, "Environmental Risk Analysis for Chemicals, " R. A. Conway (cd.), 1981.

be blown about as dusts and consequently inhaled by humans and animals or deposited on plant surfaces. At any point in the transport of materials, a constituent can be transformed into other compounds that may pose either less or, of particular concern, greater hazards than the parent chemical.

The fate of any substance depends on its interaction with living and nonliving elements of the environment. As illustrated in table 49, each environmental medium (i. e., soil, water, air, and biota) has properties that may influence the way constituents are dispersed, their reactions with environmental components, and their ultimate deposition. Examples of transport and transformation processes that influence environmental fate are presented in table 50. In aquatic systems, for example, organic constituents may be adsorbed on suspended particles and deposited in lake or ocean sediment; thus, the amount of suspended particles and rate of sedimentation affects the availability of these constituents to plants and animals. Similarly in a terrestrial system microorganisms in the soil may degrade a hazardous waste more or less completely depending on the temperature and the availability of nutrients.

Table 49.—Environmental Media and Examples of Properties Influencing the Fate of Waste Constituents

Air	***Water***
Temperature	Temperature
Wind velocity	pH
Humidity	Suspended solids
Particulate levels	Flow rate
Soil	Sedimentation rate
Vegetation cover	Species composition
Species composition	Oxygen levels
Organic content	Salinity
Acid-base level	Biota
Soil composition	Species tolerance
Soil pore size	Age of individuals
Mineral content	Metabolic factors
Temperature	Mobility
	Species composition

SOURCE' Office of Technology Assessment

If the quality and quantity of waste constituents released from a facility can be identified, and if general characteristics of the environment to which they are released are known also, the potential for movement of the constituents can be estimated using fugacity equations.[41] Fugacity is defined as the escaping tendency of a substance from a heterogeneous system. Fugacity equations are mathematical models, incorporating data on particular compounds and environmental media, for estimating this tendency. These mobility or fugacity estimates can be used to develop profiles of environmental distribution.

Information needed for such profiles can be obtained through laboratory analysis of the chemical, physical, and molecular characteristics of a compound. Data. on physical characteristics provide indications of the relative affinity between a compound and environmental components (e.g., whether it is water soluble, insoluble, or highly volatile). Knowledge of the molecular structure permits estimation of the degradation potential by chemical or biochemical transformations. For example, predictions that a constituent will bind to organic components in soil rather than be transported

[41]D. Mackay, "Finding Fugacity Feasible," *Environmental Science & Technology,* vol. 13, No. 10, 1979, pp. 1218-1223; and National Research Council, "Chapter 2. Factors Influencing the Fate of Chemicals," *Testing for Effects of Chemicals on Ecosystems* (Washington, D. C.: National Academy Press, 1981).

Table 50.— Examples of Processes Influencing Fate of a Waste Constituent

Physical	Chemical	Biochemical
Transport phenomenon (flow path and rate) (D)		
• Diffusion (D)	• Acid-base reactions (D)	• Accumulation—concentration (D)
• Dispersion (D)	• oxidation—reduction (T)	• Mineralization (T)
• Filtration (D)	• Photolysis (T)	• Cometabolism (T)
• Sedimentation (D)	• Hydrolysis (T)	• Biotic transformations—polymerization, conjugation (T)
• Adsorption—disorption (D)		

(D) Distribution/transport
(T) Transformation

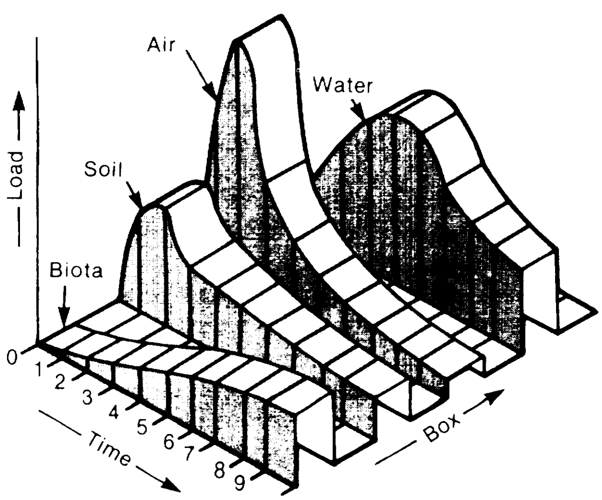
SOURCE Off Ice of Technology Assessment

to water or air can be made. Those constituents that dissolve readily in water or volatilize rapidly into air also would be identified.

It is unlikely that any waste constituent will be found solely in one environmental medium (i.e., only in soil, or in water]; instead it is likely to be distributed across media, albeit unevenly, Figure 19 illustrates a hypothetical profile of environmental distribution.[42] In this example, the chemical is more readily dissolved in water than bound to soil or organic material. Initial concentrations might occur in soil, air, and water. (In a real-world example, the initial distribution of a constituent would depend on the point of release.) As environmental residence time increases, major accumulation occurs in water and boiota. In contrast, if chemical analysis indicated strong bonding with organic particles (as illustrated in fig. 20), the profile would differ, with increased concentrations of the constituent occurring in soil or sediment over time. This compound might accumulate in biota at those sites where soil

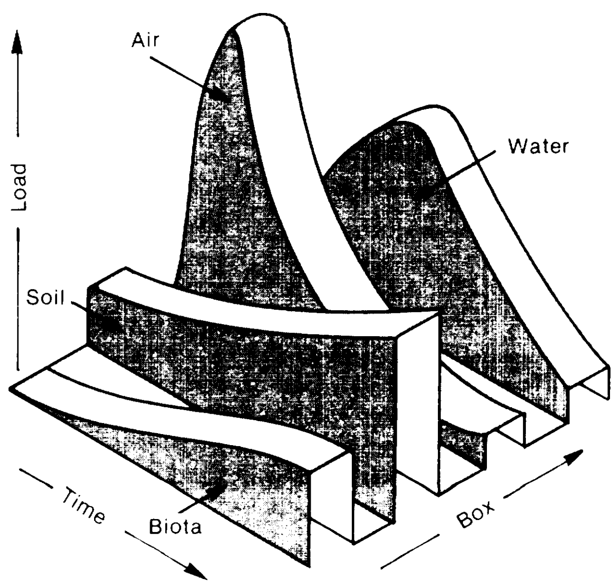
[42] R. Haque, J. Falco, S. Cohen, and C. Riordan, "Role of Transport and Fate Studies in the Exposure Assessment and Screening of Toxic Chemicals," *Dynamics, Exposure and Hazard Assessment of Toxic Chemicals* (Ann Arbor, Mich.: Ann Arbor Science Publisher, Inc., 1980).

Figure 19. —A Hypothetical Environmental Fate Profile of a Chemical That Binds Strongly With Lipid Material



SOURCE Haque Falco Cohen, Riordan, 1980

Figure 20.– Hypothetical Environmental Fate Profile of a Compound That Binds Strongly With Organic Material



SOURCE Office of Technology Assessment

or sediment-dwelling organisms are present. The final concentrations in air and water would probably be minimal.

Knowledge of this potential distribution is quite useful in designing a monitoring program for a particular site. For a profile such as figure 19, monitoring efforts initially would concentrate on sampling all media. Over time, greater efforts could be devoted to analysis of water and biotic samples with a reduced effort in soil and air sampling. Spot checks might be necessary to verify that there is not continual release of constituents from a facility. In the second figure, sampling of soil would have highest priority, with lesser and decreasing emphasis on water and air analyses. Thus, the ability to predict environmental fate of waste constituents using fugacity equations can promote development of cost-effective programs by indicating where sampling efforts may best be concentrated.

Monitoring Activities: Types and Strategies

Monitoring includes a variety of activities. It can refer to observation of the operation of an industrial process (e. g., the chemical treatment of a waste), the inspection of the integrity of a facility, or the effects of an industrial waste constituent on organisms. Five types of monitoring—visual, process, source, ambient, and effects—can be used alone or in combination with two different strategies—surveillance and assessment.

Five Types of Monitoring

Most types of monitoring that can be applied to waste management practices (i.e., all but effects monitoring) focus on identifying the occurrence and extent of releases of waste constituents to the environment. This monitoring may be part of an information feedback system for a facility operation; or it can provide data needed for developing standards and to identify research needs (see table **48).** Ambient monitoring also is used to establish baseline data. Ambient and effects monitoring provide data for setting research priorities and for measuring quality of public health and the environment. Effects monitoring is aimed at determining cause-effect relationships between hazardous constituents and adverse effects observed in humans or other organisms.

1. Visual monitoring is the simplest and least costly method of identifying releases of constituents from a waste management facility. Routine procedures—checking for container leaks and for proper storage of materials as well as containers—are useful in monitoring hazards associated with ignitable, corrosive, and reactive materials. Visual inspections immediately identify the potential for fugitive emissions, accidental spills, and generally unsafe conditions at a facility site.
2. The purpose of process monitoring is designed to determine that a process (e. g., waste recovery, incineration, or biological treatment) is operating in accordance with specific standards. Factors that control a process (e. g., temperature and flow rate in an incinerator) are checked for variations from an established level. Process monitoring is based on the principle that chemical, physical, and biological reactions are predictable, and that conditions under which they occur can be controlled. This type of monitoring therefore consists primarily of surveying normal engineering information provided on meters and gages. In many large industrial facilities, continuous monitoring is performed with the aid of a computerized system. If a specified condition (e.g., temperature) exceeds certain preestablished levels, the system automatically shuts down the process and sounds an alarm. Process monitoring can be extremely effective. Recordkeeping can be done on a routine basis and the skill level required is not high; the technician is required to read gages or computer printouts. Costs for this type of monitoring are primarily for equipment and technician time. The challenge is to channel the flow of this information from the plant operations level to the risk management level.
3. Source monitoring verifies that the flow of material from a facility to air, soil, or

water does not contain harmfu1 or unex - pected constituents, In general, indicator compounds and conditions, rather than specific chemicals, are monitored continuously with such measurements as pH, temperature, total organic content, specific metals, and oxygen levels (for water sampling). If significant variations in these measurements are detected, more comprehensive analytical tests can be conducted to identify the specific problem. The presence of unexpected constituents or increased concentrations in an industrial effluent (e.g., increased levels of total organics) would signal that the facility may not be operating correctly.

This type of monitoring activity is a second-stage alert system for an industrial operation, with visual inspections and process monitoring the first stage, With appropriate indicators, source monitoring can be very effective. EPA has required it for monitoring compliance of industries with certain environmental regulations (e.g., regulations promulgated under the Clean Air and Clean Water Acts.) Automation and remote control of sampling and analysis have made second-level monitoring activities relatively simple, as long as outflow constituents can be identified for analysis. More highly skilled personnel are needed than in process monitoring; special training is required in sampling and analytical methodologies.

4 Ambient monitoring is the third level of activity. It can provide baseline data for a specific area, and also provide data after the release of hazardous constituents into the environment for comparison. Ambient monitoring is much more complex than the first two levels, requiring carefully controlled sampling and analysis of a diverse set of materials (e. g., soil, water, air, plant and animal tissue). The environmental components are themselves variable, which can complicate interpretation of results. With the availability of complex analytical equipment (e. g., the gas chromatograph-mass spectrophotometer), the identity and concentrations of many different constituents can be detected at very low levels (parts per billion).

The cost of ambient monitoring is a function of the degree of knowledge desired regarding the fate of constituents. After a release of constituents into the environment, the precise form, concentrations, and locations of constituents becomes harder to determine with time. A greater number of samples is required to assess the full extent of contamination over time. The level of detail and precision desired also affect costs. Some relatively simple analytical techniques can detect classes of constituents by measurement of chemical and physical processes. To determine more precisely the qualitative identity of a single constituent, or the extent of its distribution, requires more complex, costly equipment. The skills required for these types of testing requires several years of training in technical fields and extensive training on specific analytical equipment,

5 Effects monitoring entails observing humans and other organisms for adverse: or beneficial, effects resulting from the presence of, or exposure to, constituents above naturally occurring levels. It is expensive and time-consuming, since it often takes several months or years for an effect to appear (e. g., as illness or death in the human population, or decreases in animal population sizes). As discussed previously in this chapter, it is very difficult to determine direct relationships between the presence of a contaminant and particular adverse effects for human health. Because cause-effect relationships have not been established for most waste constituents, data from this type of monitoring can be used to set research priorities and to evaluate environmental quality,

Of the five types of monitoring discussed above, ambient monitoring has the greatest potential to serve as evidence that risks associated with hazardous waste management are kept to acceptable levels. Visual inspections along with process and source monitoring, if effectively carried out, can reduce the amount of ambient monitoring needed; however, they cannot serve as substitutes. Only by taking representative samples from potentially affected environmental media and analyzing them for a broad spectrum of indicators is it possible to control risks reliably and realistically. Increased use of fugacity predictions can contribute to more cost-effective ambient monitoring programs. Greater use of multimedia monitoring programs are needed.

Public health can best be protected by preventing hazardous releases and minimizing contamination of the environment. Should releases occur, ambient monitoring of the environment can produce early warning of threats to public health. The environment can serve as a protective barrier. If contamination of the air, water, and land is detected early (before widespread contamination and actual damages), corrective action can be taken, and human exposure reduced. For example, a persistent hazardous compound might be detected in soil surrounding a waste management facility, but nowhere else. If it can be removed, or in some way immobilized before reaching water or critical points in food chains, then exposure to humans and other organisms is prevented, Ambient monitoring, therefore, should be given a prominent role in monitoring programs.

Two Monitoring Strategies

Monitoring programs serve two different types of strategies: surveillance or assessment. Surveillance monitoring usually is used to verify compliance with regulatory standards; it provides only limited information on trends or changes in broad categories of monitoring indicators. It could include visual, process, source, and ambient monitoring activities. Sampling efforts for surveillance strategies should occur close to the source of constituents for three reasons:

1. to reduce the number of environmental processes that can interact with and thus change the constituents of concern,
2. to restrict the number of sites that need to be monitored, and
3. to allow early warning of contamination problems.

Surveillance methodologies usually incorporate indicators for broad categories of contamination. The resulting lack of detail, however, limits the usefulness of these data. Surveillance monitoring indicates changes in broad categories of constituents or environmental conditions, but does not provide detailed information on specific constituents or potential impacts. Surveillance strategies are usually focused on specific requirements for environmental regulations, e.g., monitoring requirements in RCRA regulations.

Assessment monitoring serves two purposes: to show the extent of contamination from release of hazardous constituents and to indicate cause-effect relationships. Assessment monitoring generally involves detailed ambient and effects monitoring. Sampling techniques and analytical procedures are more detailed for assessment than in surveillance monitoring. A wide range of sample types is collected for analysis and very carefully designed protocols are used. Reference standards and quality control procedures are essential to assure that the data are valid and can be statistically verified.

Major Technical Issues in Monitoring

Several problems affect any monitoring effort. If valid conclusions are to be drawn from an analysis of data, the analyst must recognize and resolve problems of sampling frequency and preparation, data compatibility, and limitations of analytical methodology.

Sampling

Sampling is one of the most critical and most inexact steps in the monitoring process. The objective in sample collection is to obtain a number of samples that is both manageable and representative of the system being monitored. The choice of medium (air, water, soil, and biota) is a critical factor. Despite care in the selection of samples, however, the inherent variability of ecosystems, and the variations in interactions of hazardous waste constituents and elements within a system, result in a minimal level of uncertainty that can never be overcome.

As discussed previously, fugacity profiles can determine major areas of concern and thus simplify choices of sampling air, water, or soil. Obtaining representative samples of biota is complicated, Different species have different reactions to waste constituents. Furthermore, the site of accumulation in plant and animal tissue varies. For example, certain crops such as beets, lettuce, and tomatoes accumulate toxic metals more readily than do beans or cabbage; also, the foliage of such plants will contain higher concentrations than do the root structures.[43]

Location of the sampling effort is very important. Ecosystems are dynamic. For example, conditions along a large river may vary considerably. Changes in temperature, even of only a few degrees—depending on the amount of shade along river banks—can affect the river ecosystem and the impacts of constituents. Changes in rate of flow may be observed and may have similar effects, Thus, to properly monitor a river, factors such as distance to shore, water depth and flow, and type of constituents of interest will influence the optimal sampling location. The desired frequency of sampling depends on temporal variations. Environmental conditions fluctuate with the season, month, day, and even hour. Random weather events, such as storms, can affect the quality and representative nature of samples.

Sampling techniques must also consider the type of ecosystem being monitored. Because there is less mixing in ground water aquifers than in surface waters, a nonuniform distribution of constituents can be expected in the former, thus requiring vertical sampling over several horizontal locations to obtain a truly representative picture. Surface water sampling may, on the other hand, require only horizontal sampling if the water body is shallow.[44]

Data Comparisons

An effective monitoring program must have baseline or control data available against which comparisons can be made. At present, there are insufficient data to establish baseline values for hazardous waste constituents in the environment. Therefore, it is difficult, but not impossible, to determine trends in human-caused releases vis-a-vis contributions of these constituents from natural sources. In the absence of preexisting baseline information, the preferred course is to monitor at the site of concern before and after new sources of environmental contamination are expected or new facilities are established, thus establishing baseline data for the new site. The alternative is to obtain control data in a nonaffected area (without industrial development) that has environmental characteristics similar to the affected site. Monitoring programs for existing facilities must rely on this method.

Both approaches require the use of comparable standardized sampling and analytical procedures. If noncomparable protocols are used, observed difference in the data could be interpreted as resulting from different sampling and measurement methods rather than from changes in environmental concentration of hazardous waste constituents.

Unfortunately, standardized protocols are usually unavailable.[45] The few that have been developed are not often uniformity applied. Even though a laboratory may rely on standardized methodology, modifications can be expected based on new research results or personal preferences of the staff.[46] Analytical variations can arise even when different persons perform the same procedures using the

[43] E. Epstein and R. L. Chancy, "Land Disposal of Toxic Substances and Water Related Problems," *Journal of Water Pollution Control Fed*, vol. 50, No. 8, 1978, pp. 2037-2043.

[44] U.S. Environmental Protection Agency, "Procedures Manual for Ground Water Monitoring at Solid Waste Disposal Facilities," SW-611, 1980.

[45] National Research Council, *Environmental Monitoring* (Washington, D. C.: National Academy of Science, 1977).

[46] U. S. Environmental Protection Agency, "Procedures Manual for Ground Water Monitoring at Solid Waste Disposal Facilities," SW-611, 1980.

same equipment. Interlaboratory variation caused by slightly different procedures and different equipment create even larger and more complex problems for data comparisons.

A review of Federal monitoring programs by the Council on Environmental Quality (CEQ) indicated that quality assurance efforts within a monitoring program were inadequate.[47] Of particular concern was the lack of quality control regarding siting criteria, field methodology, sample preservation, and sample storage. The report states:

> Although various quality assurance programs have been adopted by Federal agencies with monitoring programs, many of these programs lack basic policy endorsement by agency management, suffer from insufficient commitment of resources, do not provide specific guidance to field monitoring organizations, and are not coordinated when more then one agency is involved. Until these deficiencies are corrected, a significant number of agency decisions and policies will be based on data of questionable and/or unknown accuracy.

An attempt to develop national quality assurance programs for hazardous waste analyses is currently underway in the Environmental Monitoring Support Laboratories of EPA.[48] The aim of this new program is to develop standardized analytical methodology and to provide reference standards for analytical results. The problem of quality assurance, however, is far from being resolved through this effort and continued work is needed. Two critical areas require further development:

- standardized methods for sample collection, analysis, storage, reporting, and field verification of results, and
- certification of laboratories and development of suitable reference standards to increase the comparability of interlaboratory data.

It should be emphasized that the purpose of quality assurance programs is to provide the user of the data with an estimate of its accuracy or uncertainty.

Degrees of accuracy, precision, and uncertainty of data are not always acknowledged; nor are acceptable levels of precision and uncertainty always identified for the particular uses of the data (e. g., for policy or regulatory compliance and enforcement). Not all programs or uses of monitoring data require the same level of precision; this varies according to the purpose of a particular program. For example, the precision required for surveillance programs may be less than that required for assessment efforts. Two questions might be asked to determine the appropriate level of precision:[49]

1. How will the data be used?
2. What are the consequences of obtaining imprecise data?

For data being placed in national data banks some indication of the data's precision is especially important. If data. leave a laboratory without proper caveats, these data may be misused. It may be necessary to require this information for Federal data banks, as data are incorporated into the system.

Limitations of Analytical Methodology

Analytical methodology used for samples from one environmental medium cannot be easily transferred to another medium. For example, considerable R&D has been directed toward developing analytical techniques for water quality analysis. Before these techniques can be used for hazardous waste surveillance or assessment efforts, however, they must be modified to suit the specific conditions and materials of concern in hazardous waste management. Methods for air, soil, and biota can be decidedly different in sampling techniques, handling, preservation, and analysis because

[47] Council on Environmental Quality, *interagency Task Force on Environmental Data and Monitoring* (Washington, D. C.: U.S. Government Printing Office, 1980).

[48] S. Miller, "Quality Assurance, Analytical Methods, and Hazardous Wastes, " *Environmental Science and Technology, vol.* 16, No. 6, 1982, pp. 332A-336.

[49] D. Friedman, "Validity and Reliability of Sampling Data, " unpublished paper (Washington, D. C.: U.S. Environmental Protection Agency, Office of Solid Waste, Waste Analysis Program, 1981).

of the quality and quantity of sample that may be required in each situation. The development of proper methodologies and protocols is not an impossible task, but it will require both added funds and trained personnel—both currently in short supply in hazardous waste management.

Some attention should also be given to defining general test indicators for the diverse range of hazardous constituents. For example, RCRA monitoring requirements for land disposal require consideration of more than 387 compounds that are currently considered as hazardous by EPA (discussed in ch. 7). Current capabilities for the detection of a majority of these compounds with state-of-the-art analyses is questionable. In some cases, appropriate analytical protocols are not available for waste constituent analysis. In others, the detection limits of analysis may be higher than concentration of constituents in waste. Depending on the type and sophistication of the analytical equipment, it is possible that a constituent could be present but not detected by laboratory analysis.

The use of indicator test compounds (i.e., one or two compounds selected to represent the presence or absence of a class of compounds) has been suggested, While such methods provide economic advantages, continued environmental contamination may occur if the hazardous compounds in any waste do not behave environmentally in the same manner as the indicator compounds. Also, because of the nature of many of these compounds (e. g., the complex organics) equally hazardous degradation products may result from environmental transformations. Only limited information concerning these transformations currently is available.

Monitoring efforts developed in response to the Clean Air and Clean Water Acts have emphasized chemical analyses, and RCRA requirements followed these precedents. Because of the extensive number of hazardous constituents that may require analysis even at the level of surveillance efforts, reliance on chemical analyses alone can become very expensive. Therefore, it maybe prudent to investigate the use of biological indicators. There has been research on advantages and limitations of biological monitoring programs, but specific applications for hazardous waste management must be explored. [See reviews of biological monitoring applications.[50])

Institutional Approaches to Technical Issues

Scientists, both in the public and private sectors, recognize the importance of proper sampling techniques, data compatibility, and limitations in the methodology. Yet, no major governmental policy has been directed towards developing solutions. These problems are not unique to hazardous waste management. They are relevant to all regulations intended to reduce undesirable levels of contaminants in our environment. Effective protection of human health and the environment requires concerted efforts to develop adequate monitoring programs. Three activities could help to correct the current deficiencies.

First, it may be prudent to centralize monitoring activities responsible to resolve the technical issues addressed here by drawing on the help of government and nongovernment laboratories and personnel, EPA's Environmental Monitoring Laboratory, for example, might be charged with developing standardized sampling protocols, while the National Bureau of Standards would continue its work of developing reference test standards. The American Society of Testing Material (ASTM) could develop methodological protocols for

[50]J. Cairns, Jr., et al., "Suitability of Some Fresh Water and Marine Fishes for Use With a Minicomputer Interfaced Biological Monitoring System, " *Water Resources Bulletin, vol.* 16, *No. 3, 1980,* pp. 421-427; J. Cairns, Jr. and D. Gruber, "A Comparison of Methods of Instrumentation of Biological Early Warning Systerns, " *Water Resources Bulletin,* vol. 16, No, 2, 1980, pp. 26 1-266; J. Cairns, Jr., "Biological Monitoring—Concept and Scope, " *Environmental Biomonitoring, Assessment, prediction, and Managemen t—Certain Case Studies and Related Quantitive issues* (Fairland, Md.: International Cooperative Publishing House, 1979), pp. 3-20; D. Gruber and J. Cairns, Jr., "Industrial Effluent Monitoring Incorporated Recent Automated Fish Biomonitoring Systern, " *Water, Air, Soil Pollution,* vol. *15, 1981,* pp 471-481, J. M. Thomas, D. H. McKenzie, and L. L. Eberhardt, "Some Limitations of Biological Monitoring, " *Environment International, vol. 5,* 1981, pp. 3-Io; and W. H. Van Der Schalile, et al., "Fish Bioassay Monitoring of Waste Effluents," *Environmental Management,* vol. *3, No.* 3, 1979, pp. 217-235.

analytical work, and the National Science Foundation (NSF) and universities could be called on to help establish compatible and coordinated baseline data.

In 1978, the U.S. House of Representatives, Committee on Science and Technology, Subcommittee on Environment and the Atmosphere, held hearings on a proposal to provide for a demonstration of a coordinated management system for environmental monitoring efforts.[51] The testimonies presented at subcommittee hearings strongly supported such an effort, indicating that it was both possible and desperately needed. All the witnesses agreed that cost-effective programs can be developed.

Because of the multidisciplinary and multimedia approach necessary to meet environmental monitoring needs, a second activity might be the establishment of a pilot project (as suggested by testimonies at the hearing), Its purpose would be to identify the most effective strategy and to develop standard protocols for sampling, analytical procedures, and data storage. Such an effort is essential when addressing monitoring needs for hazardous waste management, Standardized monitoring practices are imperative for identifying contamination and verifying concentration levels, Because of the possibility of widespread environmental contamination with only limited resources for pursuing monitoring activities, carefully designed and cost-effective programs are the only means of providing information to verify that the public and environment are being protected under RCRA.

Monitoring programs have been established for the seven major environmental statutes and data collection activities are extensive, but lack coordination. The third activity for institutional improvements would be coordination of environmental monitoring programs. During the late 1970's, the executive branch expressed concern about deficiencies in national monitoring programs, and an interagency task force was formed to study the situation, The report of this task force was released in 1980 by CEQ.[52] It concluded that agencies generally develop a monitoring program to meet a specific legislative need and do not consider how the data might be used by both the public and private sectors. The report concluded that:

> This absence and / or lack of widespread user awareness of the existence of the various systems is causing the development of new systems which overlap existing systems. In short, there is a lack of government-wide efforts to ensure that both existing and new Federal systems and data standards are properly coordinated to minimize duplication and to ensure that such systems provoke the broadest possible services to users in the most cost-effective manner.

There has been some effort to coordinate certain programs such as water monitoring data and climate and ocean monitoring programs. But the extent of this coordination is limited.

Many current monitoring efforts are designed for a single environmental medium. For example, water data are collected for the Clean Water Act, air data for the Clean Air Act, and soil data are collected by the U.S. Geological Survey (USGS), Because of widely differing methods used for sample collection, analysis, and storage, it is very difficult to assess exposure and contamination across media, Such an effort is particularly needed in waste management because of the multimedia nature of risks associated with hazardous waste.

As illustrated in figure 21, the scope of environmental monitoring efforts within the Federal Government is wide ranging. Each of these programs could augment a hazardous waste management system, particularly in a national scheme aimed at risk management. If properly selected, focused, analyzed, and integrated, the data could provide a scientific basis for regulatory action on waste management. Without a nationally coordinated data-gathering and storage effort, and without proper quality assurance guidelines, the current data bases will

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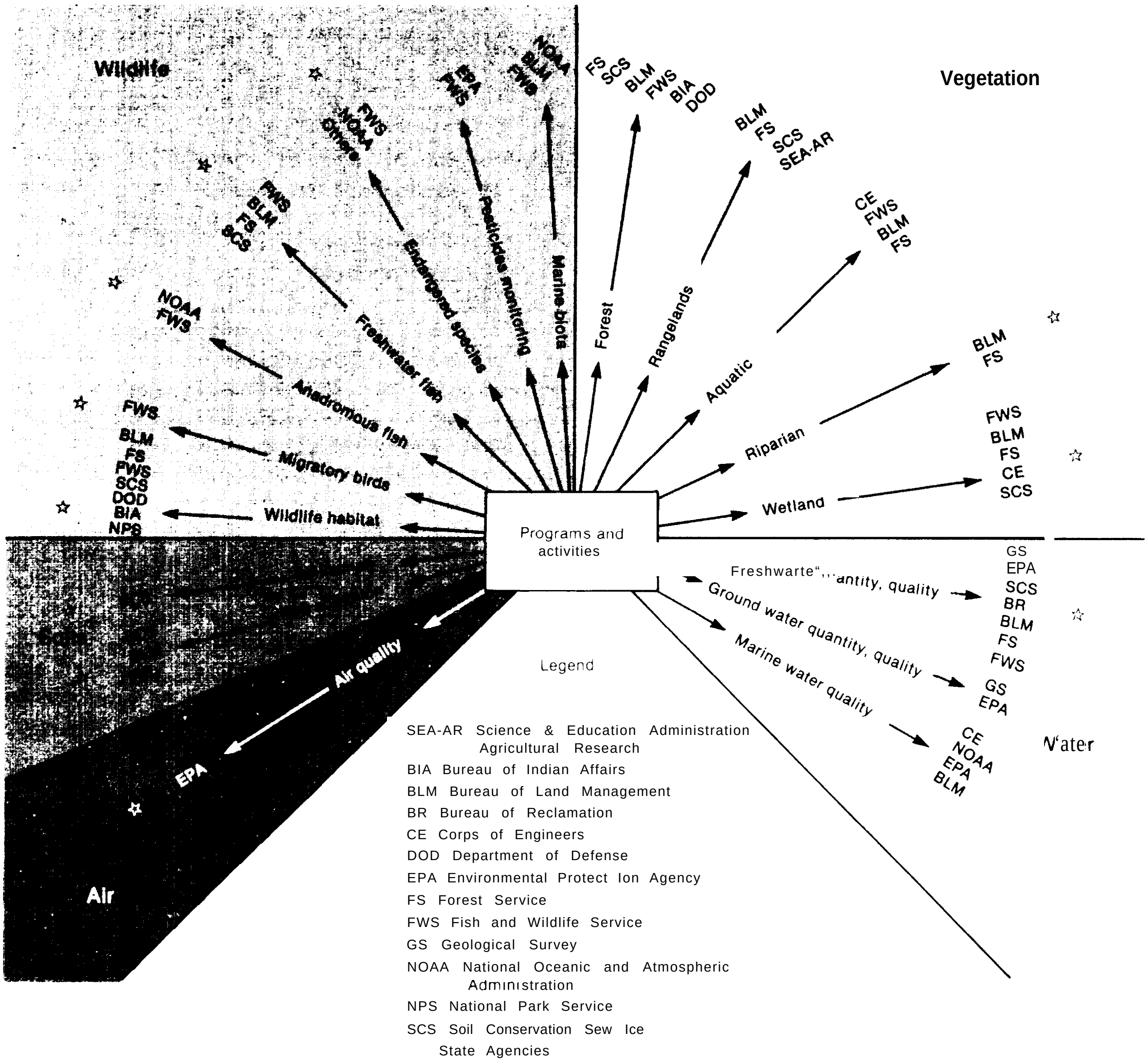
[51] U.S. Congress, House of Representatives, *Environmental Monitoring—II,* hearings before the Subcommittee on the Environment and the Atmosphere, Committee on Science and Technology, No. 93 (Washington, D. C.: U.S. Government Printing Office, 1978).

[52] Council on Environmental Quality, op. cit.

Figure 21.— Ecological and Living Resource Information and Data Gathering Programs Within the Federal Government



SOURCE Council on Environmental Quality, 1980

remain inadequate for broad applications of environmental assessment, including the management of hazardous waste.

The following recommendations made by the Interagency Task Force have direct application to the monitoring needs and problems for hazardous waste management. No action has been taken on these recommendations.

1. Establish a national program to provide a governmentwide scientific focal point for environmental information and analysis related to environmental assessment. A national program that coordinates data collection, assesses its quality, and encourages its distribution would help eliminate problems of expensive, overlapping

Federal and State hazardous waste monitoring programs, inadequate environmental assessments, delays in formulation of regulations, and poor intergovernmental conditions.

2. The existing interagency coordination of water data collection should be strengthened. The current emphasis on water data related to hazardous waste management is for ground water only; surface water monitoring is also needed. By strengthening the existing data bases (e. g., EPA's STORET) and coordinating data collection efforts, duplication of monitoring activities by Federal and State Governments, universities, and industry could be avoided. At a time when staff and financial resources are limited for hazardous waste management, a coordinated monitoring program has much to offer in the way of reduced costs.
3. Establish a standing interagency group to deal with the coordination of environmental and health effects data. This recommendation is especially important for hazardous waste management. Currently, the extent of integration of these two types of data is very limited, but, if a management program is to protect human health, this integration is necessary.
4. Quality assurance should be a major part of any monitoring effort and should receive substantive consideration for design and funding. Without the existence of data standards and definitions, it will be very difficult to enforce the RCRA regulations uniformly. Industry has the right to be assured that compliance requirements are uniform nationwide and that a decision of noncompliance truly represents noncompliance rather than differences generated by monitoring methodology.
5. Implement an integrated Federal environmental data system that can be used in making broad policy decisions. Such a data base would provide the means for multimedia analysis related to hazardous waste contamination, Such analyses are currently not possible.
6. NSF should initiate a program to support projects that are aimed at long-term data collection at a series of locations. These should represent a cross-section of major ecosystems in the United States. Such a monitoring effort would provide baseline measurements to which hazardous waste monitoring data could be compared,

Siting

A paradox exists between the public desire for safe hazardous waste management and public rejection of sites for specific hazardous waste facilities. The reasons for the dilemma are easily identified; solutions are more elusive. The reasons for the almost universal opposition to hazardous waste facilities in one's own neighborhood include:

- fear of health or safety effects,
- fear of economic losses,
- uncertainty of industry's ability to prevent adverse consequences, and
- lack of confidence in government.

The overwhelming reason for public opposition is a fear for personal health and safety. This fear is not based on objective evidence of cause-effect relationships between exposure to hazardous waste and adverse health effects, Rather, it comes from perception of uncertainties surrounding these cause-effect relationships. As discussed previously in this chapter, scientific data suggest a potential for long-term chronic health efects from exposure to hazardous waste. Most people do not wish to take the risk, uncertain as it may be. Thus, the public opposes siting and permitting of facilities near residences and workplaces.

The economic concern is twofold: the fear of a decline in property values and knowledge that compensation for any damage that may occur to property or health is limited or nonexistent. Expeditious compensation for personal injury directly related to the operation of a waste management facility is by no means assured. In fact, the barriers to recovering some sort of damages through litigation are substantial. Lawsuits are long and costly, and it may be exceedingly hard to prove either cause-effect relationships or negligence by the facility owner. Under CERCLA, the owner of the facility is liable for government costs of cleanup, but not for compensation of personal or property losses to third parties.

Because of past problems with the waste management industry, the public appears reluctant to take a chance on new technologies. This is particularly true for the siting of land disposal facilities. Uncertainty about the capability to prevent adverse consequences extends to other management facilities as well (e. g., incinerators). Concerns that the personnel at waste management facilities are inadequately trained and that good "housekeeping" practices will not be followed voluntarily, contribute to public fears,

Lack of confidence in governments stems from several causes, First, many citizens are concerned that Federal and State regulatory programs are not stringent enough. (These programs are discussed in ch. 7.) There is concern that government monitoring and enforcement efforts are inadequate. Government responses to citizen complaints have contributed to this concern. For example, a waste facility in Wilsonville, 111,, was approved by the State several years ago, despite strong public opposition. Opposition continued and the site was recently closed by an order from the State Supreme Court. The company has been ordered to exhume all materials, but unfortunately, toxic organic solvents have already leaked from the disposal site, At another site, in Sheffield, 111,, organic solvents have passed through a barrier wall within a few years, although the State regulatory agency claimed that the barrier would prevent migration for **500 years.**

Public mistrust of regulatory agencies is aggravated by government actions following the discovery of hazardous waste pollution, which often seem too late, ineffective, or unresponsive to concerns of citizens. For example, homeowners near a large landfill in southern California (the BKK landfill in West Covina, Calif.) have complained for years about the nuisance and danger to drinking water supplies posed by waste disposal at that site. The State response was less than rapid.[53] Another example is the actions of EPA and Colorado in granting interim status to the Lowry Landfill near Denver, despite citizen legal action to close the landfill based on the charge that toxic waste leaking from it were contaminating Denver's drinking water supply.[54]

A final, though less obvious, reason for public skepticism about the ability of government to deal effectively with hazardous waste concerns is the lack of a real commitment by government to reduce the production and toxicity of hazardous waste. Many hazardous waste management programs place great emphasis on waste disposal, rather than on other management options. The public's reluctance to accept new land disposal facilities may well be linked to the limited attempts by government to promote preferable treatment alternatives and waste reduction.

Approaches to Addressing Public Concern

There are two approaches to answering public concern over siting of particular facilities. The "technical" approach is based on requirements that sites meet protective siting standards, and the provision of enough technical information to increase public understanding of proposed facilities. The "nontechnical" approach includes assurance of public participation in siting decisions, compensation for victims of damage, a clear com-

[53]State of California, Office of Planning and Research, "Improvements in Siting Hazardous Waste Facilities, Recommendations of the Department of Health Services Advisory Committee, Sacramento, Calif , June 1982.

[54]C. Maclennan, testimony before the U.S. House of Representatives Subcommittee on Commerce, Transportation, and Tourism, Committee on Energy and Commerce, Apr. 21, 1982.

mitment by government to enforcement of regulation, and possibly, incentives for communities to accept proposed facilities.

That public opposition to hazardous waste facilities will be wholly eliminated is unlikely. But if public concerns are seriously addressed, some sites may become acceptable. The most important ways to do this are to involve the public early in the process (possibly at the point of establishing siting criteria) and to make sure that all relevant technical information is readily available to the public, Already, the importance of public access to information during the siting process is generally accepted. Procedures are established for making information available, and if trade secrets must be withheld, the reasons and the conditions for secrecy are generally agreed on in advance. Public involvement could be further encouraged. Especially important is education in hazardous waste management, participation in the siting decision, and continuing "watchdog" review to ensure government and industry accountability after the site is approved and the facility is in operation.

Commitment to public participation seems to have been the key to acceptance of several proposed hazardous waste facilities. Many State governments have recently established siting procedures that are especially tailored to hazardous waste issues and that include public participation. For example:

- Minnesota is one of 10 States with a siting board which is solely responsible for locating and acquiring suitable sites for hazardous waste disposal facilities within the State. Citizens unaffiliated with government or the hazardous waste industry are on Minnesota's Waste Management Board, and the State's siting process offers frequent opportunities for public participation.
- California is one of several States where local government approval is a prerequisite for the siting of a hazardous waste facility.
- Massachusetts has a hazardous waste siting process that stresses negotiations between the community and the hazardous waste facility developer and/or binding arbitration.[55] Because the system is still in the early stages of development, its success has not yet been demonstrated.
- New York has a streamlined State permit process leading to a Certificate OF Environmental Safety and Necessity for hazardous waste facilities. These permits are issued by the State and supersede, or preempt, local permit requirements. At least six States have similar programs.

Different States take widely different approaches to siting. No one system is demonstrably superior, Success in siting appears to correlate more with public understanding of the process and public involvement in decisionmaking, than to the particular type of siting process.

Technical Methods

One vehicle for improving public involvement in siting is the adoption of a comprehensive hazardous waste plan, jointly developed by industry, government, and the public. The purpose of the plan would be to provide accessible technical material. It would include accurate and detailed information on hazardous waste quantities and types, sources of waste, environmental conditions of the proposed site, and potential adverse impacts on health and the environment of the waste or its constituents. Most of the opposition to siting hazardous waste facilities has to do with sites for land disposal. In these cases, opposition may be less if it can be demonstrated convincingly that all options for waste management have been pursued (e.g., that waste reduction, recycling, and treatment facilities have been evaluated prior to the siting application). This close consideration of alternatives should be one of the requirements in a comprehensive waste management plan.

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[55] *The Siting Book, A Handbook for Siting Hazardous Waste Facilities in Massachusetts*, Department of Environmental Management, Bureau of Solid Waste Disposal, October 1982.

Another way of responding to public concerns is to establish technical siting criteria. The criteria might ban certain kinds of facilities from specified areas (e.g., within a 100-year flood plain or above a ground water recharge area). If high-risk sites are eliminated by the technical criteria, facilities may be sited in areas more acceptable to the public.

Some States are considering the use of criteria and the siting process to identify a "bank" of suitable facility sites. Some analysts have suggested that the potential risks from a new facility should be compared and related to risks posed by other land uses in the community, such as existing manufacturing plants that discharge pollutants, airports, fuel storage tank farms with the potential for explosion, etc. The comparison might shed a more favorable light on a waste facility siting proposal, or it may help to identify an area in the community where the additional risks posed by a new hazardous waste facility are compatible with other land uses.

An important part of openness in siting programs is the provision of information on the roles of the major regulatory agencies involved and on the companies in the waste disposal business. Documents provided might include applicable regulations, descriptions of current and past enforcement efforts, reports on State and Federal hazardous waste programs, annual reports of leading companies in the industry, and publications from industry trade organizations describing typical waste management policies and practices.

Economic and Institutional Mechanisms

Several nontechnical measures can be taken to address public concerns about hazardous waste siting in the communities. For example, information can be provided on the economic advantages to the community. A community may benefit from higher revenues, through a tax on the gross receipts of a facility, property tax, or treatment disposal fees.

Another potential economic benefit could be new industrial growth attracted by the availability of waste management capacity. This might increase regional employment, Similarly, a waste facility could help existing local industry by offering reasonably priced and reliable waste management services. A proposed facility that presents clear-cut benefits to local existing industry is more apt to win favor than one that serves a wider area. This was demonstrated recently in New Jersey. A proposal to construct an onsite landfill for hazardous waste generated by a local chemical company (and employer) was approved, while a similar proposal for an offsite chemical waste landfill serving a large geographical area was vociferously opposed and defeated.

A problem with economic benefits, however, is that the risks and the benefits do not always coincide. The community or neighborhood nearest the waste facility may be running the greatest risks, while the benefits are spread out over a much larger community, even to society as a whole. This conflict is not unique to waste facility siting, but because of the potential for adverse impacts, the disparity may be seen as greater in waste management than in other activities.

Another nontechnical means of answering public concerns is for government to show convincingly its intent and ability to enforce hazardous waste regulations. Government officials can explain its monitoring and enforcement activities, and emphasize opportunities for public involvement, such as provisions for citizens' lawsuits. Evidence of a firm commitment in terms of funds and personnel can be particularly meaningful in times of restricted Federal and State budgets.

The California "superfund," enacted in 1981, establishes a tax-supported fund for compensatingse victims of hazardous waste activities for their medical expenses and loss of income. New Jersey also provides a fund for victim compensation as part of its comprehensive hazardous waste siting strategy.

Even when the best waste management technology is proposed for use at the most carefully

[56] Carpenter-Presley -Tanner Hazardous Substances Account Act, Statutes of 1981, ch. 756, California Health and Safety Code, Div. 20, ch. 6.8.

chosen location for a hazardous waste facility selected after the most open siting process, a residual of perceived adverse environmental and economic impacts is unavoidable. To compensate a community for these real or perceived risks, some form of incentive might be provided, unrelated to the hazardous waste facility itself. For example, government or the developer of a waste disposal facility could offer to finance public services for the community, for instance, as the purchase of fire equipment or the construction of a new community building, or the gift of land for a park. A developer can also take steps to prove a commitment to act as a good corporate citizen, e.g., by holding informal discussions to provide information or engage in negotiation, or by promising periodic public inspection of a waste management facility after it is operating.

Role of the Federal Government

Direct Federal involvement in hazardous waste facility siting is virtually nonexistent. Few EPA regulations address siting issues. Some general site location standards are included, and the Agency has published a few reports describing the nature of siting problems. An expanded Federal role in siting is possible to assist States. EPA could develop model siting criteria, for example, or publish information on different approaches States have taken to the siting issue. These model siting criteria could include both technical and nontechnical means to address public concerns about siting. Alternatively, EPA could include siting criteria as a required element of State RCRA programs. The Federal Government, particularly the USGS, could play a stronger role in providing States with hydrogeologic information necessary to determine the suitability of locations for waste management facilities. Section 3005 of RCRA allows EPA to establish location standards for hazardous waste facilities. Establishment of national mandatory siting criteria, however, would probably require enabling legislation.

It has been suggested that Federal lands could be used for regional waste management sites thus facilitating site approval .57 Because Federal lands are often remote, public opposition might be reduced. Long-term security of the site could be assured as the Government is unlikely to go "out-of -business." On the other hand, siting on Federal land maybe viewed by many as an unfair subsidy to the hazardous waste management industry. It would shift some some costs of and responsibilities for waste management from private industry to the Government. In any case, siting facilities on Federal lands is primarily an option for Western States, as there is little available Federal land in the East. The idea is of little help to the east coast areas that have an immediate need for new facility sites.

A major function the Federal Government could serve is to facilitate exchanges of information among all the parties. Conferences, newsletters, information clearinghouses, and the like, give people the o portunity to learn from other's experiences. The Waste Alert Program funded by EPA was a good model for such an information exchange, but Federal funding has been discontinued.

Representatives of the Federal Government could act as formal or informal mediators arbitrating siting disputes. The Federal Mediation and Conciliation Service offers one model of Federal involvement, in its program of mediation and voluntary arbitration as a means of settling labor-management disputes. Similar dispute-resolution approaches have been suggested for environmental and land-use decisionmaking. The Massachusetts siting program includes, an as yet untested provision for negotiation and arbitration in facility siting agreements.

Another Federal role might be to help in the development of interstate hazardous waste management compacts, to ensure adequate disposal and treatment capacity regionwide. RCRA provides for the recognition of such interstate compacts for solid and hazardous waste management. They could be very useful

[57]U.S. Environmental Protection Agency, "State Decisionmakers Guide for Hazardous Waste Management, " SW-612, 1977.

in areas of the country where interstate transportation of hazardous waste is common. A precedent for Federal involvement is the assistance given by the Federal Government for negotiation of the multi-State water compacts to allocate rights to water from the Colorado River. It has been suggested that the Federal Government might require States to provide adequate management capacity for all waste generated in the States.

Finally, the Federal Government might assist in the development of adequate compensation systems for victims of hazardous waste releases. The CERCLA 301(e) study group recently reported to Congress on the barriers to recovery of damages by victims of hazardous waste exposure under current law, and recommended the creation of a two-tier compensation system. The first tier would provide an expeditious Federal administrative compensation system. The second tier would improve existing State remedies by reducing the burdens of proof for injured claimants. The study group observed that the adoption of such a system might promote public acceptance of hazardous waste facilities.

Appendix 6A. –State Classification Efforts

The following tables provide examples of classification criteria developed by Washington, Texas, California, and Michigan.

A summary of the classification systems used in the feasibility study is presented. Further details can be obtained in the report prepared for OTA.[58]

The criteria for selecting these schemes addressed potential applicability to national regulations. Schemes that presented unique dimensions of hazard assessment were sought.

The Washington and Michigan schemes have several elements in common, including:

1. provision of management designations that prequalify facilities,
2. employment of toxicity rating systems that are based on waste constituent properties and not the entire waste stream,
3. provision of criteria and standards for evaluation, and
4. consideration of concentrations.

The Washington scheme is unique in that it involved the calculation of a single summary value representing the relative toxicity of a waste stream with multiple constituents. This summary value is called the waste's "equivalent concentration. " Waste constituents are categorized according to their toxicity as defined by five classes related to four measures of acute toxicity, This method did not consider synergistic or antagonistic effects of constituents. Equivalent concentration is calculated by applying weighting factors to the five classes and summing concentrations of constituents. These concentrations are plotted against waste quantity using a graph that represents levels of regulation. Carcinogenicity is evaluated in a similar fashion based on the presence of halogenated hydrocarbons and polycyclic aromatic hydrocarbons. Three management levels are identified: undesignated, dangerous waste, and extremely hazardous waste.

The Michigan scheme involved the calculation of a hazard value for single constituents that is based on several waste characteristics other than just toxicity. This system used numerical ranking formulae that address acute toxicity, carcinogenicity, hereditary mutagenicity, teratogenicity, persistence, bioaccumulation, and other adverse chronic effects. Each constituent receives a score for all using available data. The formula applies a weighting scale to determine classes of toxicity. The constituents are not ranked according to accumulative scores, There are no provisions for lack of data. Once toxicity scores are assigned the constituent concentrations are plotted against waste quantity volumes on graphs specific for hazard categories,

The JRB system emphasizes environmental factors and waste management practices and was originally designed to evaluate land disposal sites containing hazardous waste to rank them for remedial action priority. This system involves the consideration of 31 site- and waste-specific variables which are grouped into four categories:

1. Waste characteristics.—The consideration of types of potential hazards posed by the waste.
2. Waste management.—The consideration of quality of the facility design, construction, and operation.

‘Harris, Strand, and Shea, op. cit.

3. Pathways.—The consideration of mechanisms of contaminant migration.
4. Receptora.-The identification of potential targets of chemical hazards.

A site is assigned a score of O to 4 for each of the 31 parameters. Each has an assigned weighting factor. A sum for all factors is calculated for each of the four evaluation categories. They are divided by the maximum possible score and multiplied by 100. The higher the score the greater the hazard posed by a facility.

Table 6A=l.—Criterla for the Washington System of Degree-of-Hazard Classification

	Extremely hazardous	Dangerous
Oral, rat, LD_{50}[a]	<500 mg/kg	<5,000 mg/kg
Aquatic fish, LC_{50}	<100 mg/1	<1,000 mg/1
Halogenated hydrocarbons	>1'Yo	>0.01 0/0
Polycyclic aromatics	>1 0/0	None
Concentration of heavy metals in EPA leach test	10,000 x DWS[b]	100 x DWS
Nonbioaccumulative carcinogens	—	IARC[c] human or animal: positive or suspected
Corrosivity, reactivity, ignitability	—	EPA definition

[a]For pure compounds or simple mixtures book designation using the NIOSH Register and the designation diagram are possible, see appendix.
[b]DWS = drinking water standard.
[c]IARC = International Agency for Cancer Research. This group weighs published studies on suspected cancer causing ● gents and issues findings.

SOURCE: Provided by E. W. Tower, Solid Waste Management Division, Off Ice of Land Programs, Department of Ecology, State of Washington, Olympia, Wash.

Table 6A=2.—Crlteria for the Texas System of Degree-of=Hazard Classification

	Class I	Class II	Class III[a]
Hazard index[b]	<50	>50	>50
LD_{50} measures[c]	<500 mg/kg	>500 mg/kg	>500 mg/kg
pHd	<2.5, >12	2.5-12	2.5 –12
Corrosion rate”	<0.25 in/yr	>0.25 in/yr	>0.25 in/yr
Flash point[f]	<140° F	>140° F	>140° F

● - text for compositional differences between Class II and Class III.
[b]Represents the potential hazard to the environment if Improperly disposed, baaed on measures of toxicity and volubility of the substance.
[c]Median lethal dose; dose required to kill 50 percent of a population exposed to the chemical of concern.
[d]Measure of acidity or alkalinity; pH 7 indicates neutral solution; <pH 7 indicates acidic solution; >pH 7 indicates alkaline or basic solution.
[e]Corrosion rate on steel (SAE 1020) ● t a toot temperature of 130 °F as determined by NACE.
f Determined by ● Pensky-Martens Closed CUP Teatar using ASTM Std. D-93-73.

SOURCE: sterling Hoba Corp. (12).

Table 6A-3.—Toxicity Criteria in the California System of Degree-of-Hazard Classification

	Limits[a]	
	Extremely hazardous	Hazardous
Mammals		
Oral **administration. . . . .**	**< 50** mg/kg[b]	<2000 mg/kg
Exposure to skin	<200 mg/kg	<1200 mg/kg
Inhaled	<200 mg/1	<4000 mg/1
Aquatic animals	—	< 500 mg/1
Carcinogenicity.	Defined as carcinogen by California law	Defined as carcinogen by California law or suspected carcinogen by NIOSH listing
Tests in ***animals indicate . .***	Carcinogenicity, high chronic toxicity, persistence, or bio-accumulative properties	Chronic toxicity, persistence or bioaccumulative properties

[a]Amounts that result in mortality for 50 percent of the test population The lower the concentration the more toxic the material Is to test organisms LD_{50} for mammals and LC_{50} for **aquatic animals**
[b]Mg of material/kg body weight of organism

SOURCE Sterling Hobe Corp (12)

Table 6A.4.—Michigan's System for Rank-Order Assessment of Critical Materials

I. Acute toxicity

Score	Category: Oral LD_{w} mg/kg	Dermal LD_{w} mg/kg	Aquatic 96 hour LC_{w} mg/l
7	<5	<5	<1
3	5-50	5-200	1-10
2	>50-500	>200-500	>10-100
1	>500-5000	>500-5000	>100-1000
0	>5000	>5000	>1000
•	Insufficient Information		

II. Carcinogenicty

Score	Category
7	Human positive; human suspect; animal positive
3	Animal suspect
2	Carcinogenic by a route other than oral or dermal; strong potential carcinogen by accepted mutagenicity screening tests or accepted cell transformation studies
1	Potential carcinogen by accepted mutagenicity screening tests or accepted cell transformation studies
0	Not carcinogenic
•	Insufficient information

III. Hereditary mutagenicity

Score	Category
7	Confirmed
4	Suspect - multicellular organisms
2	Suspect - micro-organisms
0	Not a hereditary mutagen
•	Insufficient information

Iv. Teratogenicity

Score	Category
7	Confirmed
3	Suspect
o	Not teratogenic
•	Insufficient information

V. Persistence

Score	Category
4	Very persistent
3	Persistent
2	Slowly degradable
1	Moderately degradable
0	Readily degradable
•	Insufficient information

V1. Bioaccumulation

Score	Bioaccumulation	Log P
7	>4000	>6.00
3	1OOO-3999	5.00-5.99
2	700-999	4.50-4.99
	300-699	4.00-4.49
9	<300	<4.00
•	Insufficient information	

VII. Esthetics

Score	Category: Fish tainting/taste and odor (threshold level In water - mg/1)	Foaming, floating film, and/or major color change
3	O.0001 -0.0'01	
2	>0.001-0.01	
	>0.01-0.1	Yes
0	>0,1	No

VIII. Chronic adverse effects

Score	Category
4	Irreversible effects
2	Reversible effects
1	Adverse effects by route other than oral, dermal or aquatic
0	No detectable adverse effects
•	Insufficient information

SOURCE. Michigan Department of Natural Resources (27).