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A METHODOLOGY FOR ECONOMIC ANALYSIS OF HAZARDOUS WASTE MANAGEMENT ALTERNATIVES

by

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ABSTRACT

This research develops and presents a methodology for analyzing the economic and social effects of alternative approaches to hazardous waste management. It is concluded that the techniques of economic analysis that have been developed for conventional pollutants are not always appropriate or feasible for hazardous wastes, and that a new approach is desirable. The approach proposed involves the generation of a series of environmental "threat scenarios" that might arise from the use of different hazardous waste management techniques, and identification of "parties-at-interest" to these techniques. By examining how the parties-at-interest are affected by alternative approaches to hazardous waste management, it is possible to make decisions that are based on economics, but which recognize sociological factors.

This approach is applied in a generalized manner to the various techniques that can be used to manage hazardous wastes, and is illustrated in an example of a hazardous

waste management decision situation. It is shown that many decisions will be dependent on the degree of risk aversion that is favored.

* * * * *

The technical details included in this thesis are applicable to the management of industrial process wastes. Management of these wastes is of concern to minerals economists because wastes from petroleum refining and the primary metals industries account for almost half of the process wastes that have been identified as hazardous. In addition, the general methodological approach could be applied to a wide range of waste management decisions, including those relating to mining wastes, and wastes from electric power generation.

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INTRODUCTION

Prelude

For years, the Love Canal in upstate New York had been used as a dumping ground for chemical wastes. This had been done legally, according to the practices of the 1940's and 1950's. Recently serious pollution problems became apparent. the State Health Commissioner urged immediate evacuation of young children and pregnant women. Evidence of miscarriages and birth defects was reported, and homes in the area became virtually unsaleable (Anon., 1978a). The problem attracted international attention when it became the subject of an article in The Economist after President Carter declared the Love Canal a disaster area in August 1978 (Anon., 1978c). At the same time the subject of hazardous waste management was given considerable national television exposure.

The incident described above is not an isolated one. In fact, Time (Anon., 1978a) reports that U.S. Environmental Protection Agency (EPA) officials believe that more than 1,000 disposal sites comparable to the Love Canal exist in the U.S. The management of hazardous wastes has been of growing concern to environmental agencies for some time. In December 1977, the Council on Environmental Quality stated:

> The problem of hazardous waste has grown to serious proportions in recent years for several reasons: as a nation, we are increasing our consumption of all materials, including hazardous materials; several toxic substances have been banned from use, and existing stocks are "thrown away"; and as air and water pollution controls increase, hazardous waste residues result. (Council on Environmental Quality, 1977:45)

Incidents such as that of the Love Canal and the Keypone tragedy at Hopewell, Virginia, in 1976 (Council on Environmental Quality, 1977:46) are, however, likely to intensify the pressure for public involvement in environmental management decisions, and for careful consideration of public attitudes in these decisions. Indeed, when discussing the nuclear power issue, Electronics and Power (the journal of the Institution of Electrical Engineers) stated in an editorial that "The need to pay constant attention to public attitudes may well become a feature of all engineers' lives." (Anon., 1978b:333.)

Research Objectives

The EPA has been concerned with hazardous wastes since 1970, when it was directed by Congress to study the problem (U.S. Environmental Protection Agency, 1974b:1). Early EPA research concentrated on determining the scope of the problem and on developing techniques for the safe management of hazardous wastes. However, the Agency is also concerned that hazardous waste management alternatives are evaluated using sound economic principles, and that public attitudes are given due consideration in decision-making. Consequently, the EPA awarded a research grant to the author to develop a methodology for the analysis of hazardous waste management alternatives that was based on economics and was cognizant of sociological factors.

The methodology was expected to take the form of an analytical framework that could be adapted by decision-makers to suit a particular problem or situation. The research was expected to throw some light on the attitudes of the public and special interest groups toward hazardous waste management alternatives, and toward taking environmental risks. It was also expected to provide some generalized analysis of the various costs and risks associated with the various techniques (i.e. technical options) for hazardous waste management.

The research described in this dissertation constitutes a first step toward fulfilling the above objectives. The methodology is designed to permit the identification of costs and other effects associated with alternative approaches to hazardous waste management. It encourages a decision-maker to consider attitudes and equity as he makes trade-offs among alternatives. As exemplified by incidents such as the Love Canal disaster, the effects that may arise from some hazardous waste disposal practices are often ill-defined or virtually unknown. The methodology encourages a decision-maker to identify possible "threats" and to evaluate the costs of whatever degree of risk aversion that he favors.

Scope and Limitations

This disseration deals only with wastes and their management. It does not address the broader question of whether or not the economic activity that generates the waste should be undertaken.

The research was oriented toward industrial process wastes, as opposed to special wastes such as hospital wastes, pesticide containers, Department of Defense wastes, sewage sludge and mining tailings. (The latter two wastes are not normally considered hazardous.) The research specifically excluded radioactive wastes, although research on radioactive waste disposal was reviewed for its applicability to non-radioactive wastes. However, although the technological and environmental aspects of these special wastes were not analyzed, the evaluation methodology could be applied to any category of waste.

The methodology is intended to be used to evaluate alternative approaches to hazardous waste management on a local or regional basis, but could also be used to evaluate specific problems [e.g., the disposal of polychlorinated biphenyls (PCB's)] on a national basis. Its role is that of an aid to decision-making; because hazardous waste management decisions contain many normative elements, a human must usually make the final choice between alternatives.

Organization of the Dissertation

This dissertation comprises a main text and four appendices. The main text concentrates on presenting original analysis, while the appendices provide the reader with additional detail and with entries to the appropriate literature. The main text discusses the unique features of hazardous waste management, develops the general analytical methodology, and demonstrates the methodology using a simple example. This is followed by a summary of the findings. Separate appendices deal with (a) the techniques that can be used to control hazardous wastes, (b) the environmental threats that may arise from the use of these techniques, (c) the valuation of the effects of hazardous waste management techniques, and (d) risk and decision-making.

CHAPTER 1

HAZARDOUS WASTE MANAGEMENT IN THE U.S.A.

Unique Aspects of Hazardous Waste Management

As a first step towards developing a methodology for the analysis of hazardous waste management alternatives, an economist may ask the question "what is special about hazardous wastes, i.e., how does the management of these wastes differ from that of other wastes or pollutants?" A clear-cut answer to this question is difficult to find, but the definition of hazardous waste provides some indications of their special characteristics. One definition[1] is that any waste is hazardous if it

> . . . pose[s] a substantial present or potential hazard to human health or living organisms because such wastes are nondegradable or persistent in nature or because they can be biologically magnified,

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(1) This definition is based on the proposed Hazardous Waste Management Act of 1973 and serves as a general definition for this study. This statute was not enacted, and was replaced by Subtitle C of the 1976 Resource Conservation and Recovery Act. However, although the definition used in that Act is basically similar, it is slightly narrower and less illuminating for the purposes of analysis since it reflects the need to dovetail various statutes.

> or because they can be lethal, or because they may otherwise cause or tend to cause detrimental cumulative effects. [Emphasis added.] (U.S. Environmental Protection Agency, 1974b:3)

Several distinguishing characteristics relevant to economic analysis, and in particular to the damage function, emerge from this definition. First, a hazardous waste can pose a substantial or strong threat to man or the environment, suggesting that hazardous wastes need more careful management than inert wastes or conventional pollutants such as an organic waste that creates a biological oxygen demand (BOD). If an organic waste is discharged into a river, the level of dissolved oxygen below the discharge point will fall as bacteria degrade the waste. However, provided the BOD of the waste does not cause oxygen to fall to a level where fish are threatened, and provided nutrients released from the waste do not cause eutrophication, little harm is done to the river which will essentially return to normal downstream. (Freeman, Haveman & Kneese, 1973:53-58.) This illustrates a management technique that may be acceptable for conventional pollutants, i.e., using the natural environment (particularly air and surface waters) to assimilate the waste, while accepting some local degradation.
In contrast, with a hazardous waste the potential for damage may be so great or the environment may have so little

capacity to assimilate the waste, that uncontrolled discharge to the environment may be unacceptable because of the damage that the waste could cause.

Secondly, hazardous waste management will be more concerned with "threats" or risks, as opposed to readily anticipated environmental impacts. If, for example, a paper mill discharges an organic waste to a river, the level of dissolved oxygen in the water will fall as described above. The effect of discharging this waste to the river can be comparatively well predicted, and waste management decisions will be based, in part, on these effects. On the other hand, if a heavy metal waste is injected into a saline aquifer as a means of disposal, the intention is that the waste remains in the aquifer and thereby causes no harm to the environment. One must, however, be concerned about threats that may arise from the use of this disposal method. The saline aquifer may, for example, be interconnected with an aquifer used as a source of fresh water, which thereby becomes contaminated. Unlike the comparatively predictable effects from non-hazardous waste management techniques, it is usually difficult to estimate the probability that a threat will materialize, and the magnitude or cost of the potential damage may also be hard to predict.

Thirdly, hazardous wastes are often persistent or nondegradable. This is significant because (i) effects may be irreversible, and (ii) time scales of interest can span more than one generation. Injecting a heavy metal waste into an aquifer may be essentially irreversible.[2] Should the aquifer later be needed as a water or mineral resource, or be found to be interconnected with a fresh water source, decontamination might not be feasible. Irreversibility can also introduce "option value" and associated concepts that relate to the benefits of not foreclosing future courses of action, or options. Further, when today's decisions affect future generations, it raises the difficult problem of whether or not discounting is appropriate. These two topics are discussed later.

Fourthly, hazardous wastes include those that are biologically magnified[3] or have cumulative effects. These

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(2) In real life there are degrees of reversibility and irreversibility, and some irreversible changes are more significant than others (see Fisher and Krutilla, 1974: 97-103).

(3) Biological magnification (or "bioconcentration") is the ability of organisms to accumulate chemical contaminants to levels that are higher than those in their food sources. Such magnification can occur at several stages in the food chain, with the possible result that a contaminant which is present in insignificant concentrations at the lower end of the food chain could concentrate to toxic or lethal levels higher in the chain. (Van Hook, 1978)

factors compound the difficulties of estimating damages due to exposure. It should, however, be noted that this problem is not unique to hazardous wastes, as pollutants that are not normally regarded as hazardous may also have cumulative effects [such as urban air pollution on human health (Lave and Seskin, 1970:723-733)].

A final characteristic of hazardous wastes (one that is not apparent from the definition) is that the composition of wastes can vary substantially, not only because of different sources, but also from day to day for a given source. This complicates treatment to reduce the hazard and can inhibit resource recovery activities. Furthermore, it may mean that the degree of hazard posed by the waste is not well defined(4). Again, this characteristic is not unique to hazardous wastes.

To summarize, hazardous wastes are characterized by strong potential adverse effects, and their management may involve irreversible decisions and intergenerational time scales. The threats that these wastes pose to man and the environment are often difficult to specify because insufficient information is available. Waste composition

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(4) This statement is based on the author's discussion with representatives of the hazardous waste management industry.

variability, biological magnification and cumulative effects compound the problem.

The Nature Of Hazardous Wastes

There are two aspects to a hazardous waste. First, that it is an unwanted material, and secondly, that the material has hazardous properties.

Wastes and the Environment

As Ayres and Kneese have pointed out, except for increases in inventory, all materials that enter the economy end up as wastes [or residuals as they are commonly termed in the environmental economics literature (Ayres and Kneese, 1969)]. The inputs to the economic system are fuels, foods, and raw materials, and these inputs are partly converted to final products and partly discarded as process residuals. After the final products have fulfilled their role, they too are discarded. While final consumption products provide services to man, wastes usually provide disservices. They either consume resources to achieve disposal without environmental degradation, or they may cause pollution which results in such effects as fish kills, increased difficulty of water treatment, reduced public health, etc. (Ayres and Kneese, 1969:284.)

Figure 1 illustrates the routes by which wastes can affect the environment, and also shows that there are several stages or points at which wastes can be controlled, as follows:

(1) the waste stream from the manufacturing process can be changed to reduce the generation of hazardous wastes;

(2) some waste streams can be treated to reduce the hazard;

(3) the initial disposition of the wastes in the environment can be controlled;

(4) subsequent interchange between environmental media can be restricted.

This helps to

(5) control the interaction between the wastes and living receptors (i.e., organisms that may be affected by the wastes).

However, if the wastes have reached some living receptors, one may

(6) control waste migration to other receptors, especially man.

While society's primary concern is to control the extent to which living organisms are exposed to hazardous waste, in practice this can be achieved indirectly by controlling at points (1) through (4), as well as by direct

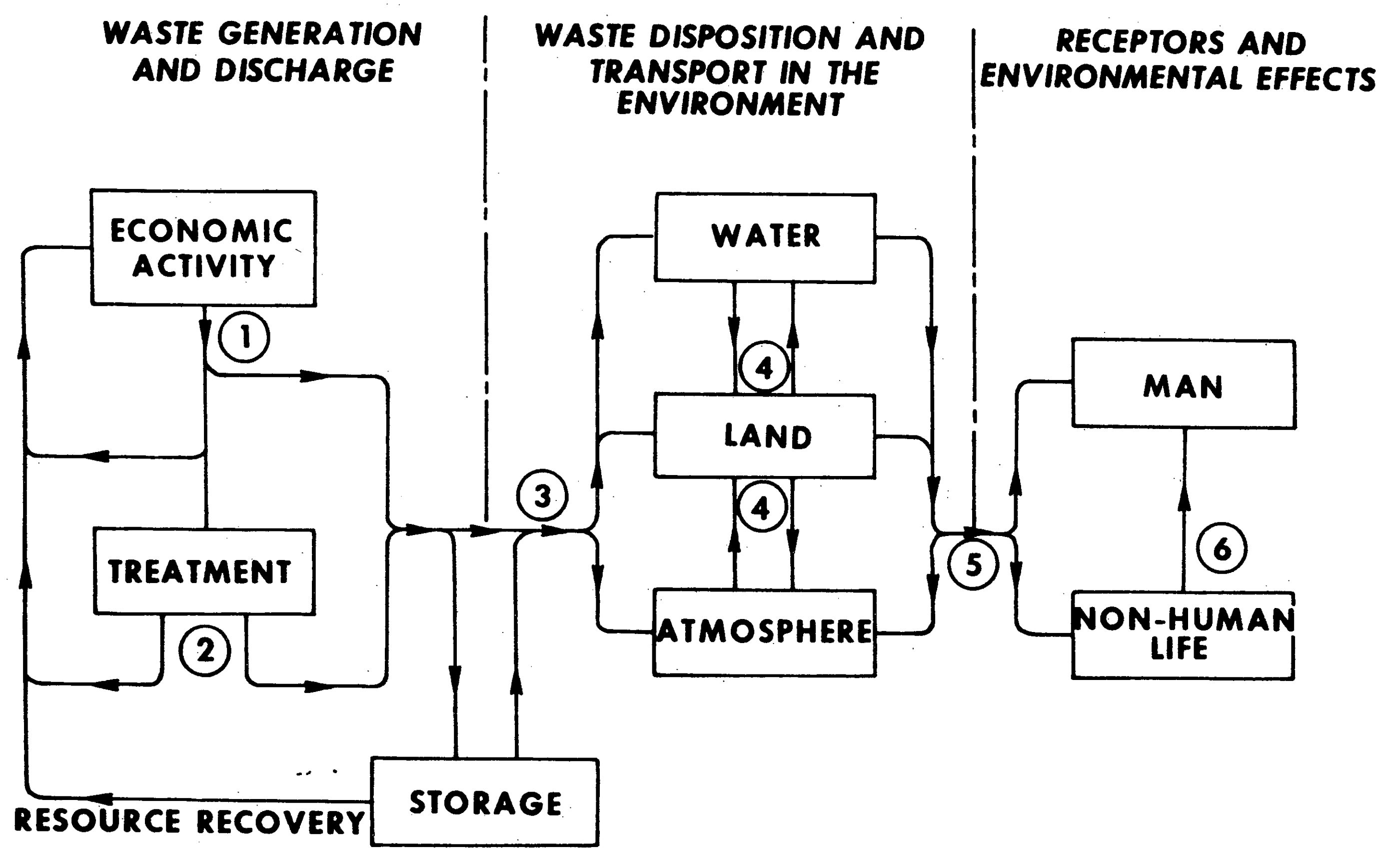

FIGURE 1: Hazardous Wastes and the Environment
(The numbers refer to points at which control can be exercised.)

control at point (5). However, there may be some wastes, especially those that are generated on an irregular basis (such as off-specification batches of products, clean-up wastes, discarded laboratory chemicals, etc.) for which control at point (1), and in some cases at point (2) is not feasible. This underscores the importance of controlling waste disposition in the environment [point (3)], even though the strategy of control at an earlier stage has been deemed to be more desirable by the U.S. Environmental Protection Agency (EPA) (1976a).

Hazardous Attributes

According to Kohan hazardous substances generally fall into one or more of the following categories: toxic to human and/or lower life forms, radioactive, flammable, reactive, explosive, oxidizing, irritating, genetically active, strongly sensitizing, subject to bioconcentration (Kohan, 1975:2). However, although all classification systems reviewed by Kohan include toxicity as one criterion for designating a material as hazardous, there is considerable variation between different systems with respect to the choice of other attributes which can render a material hazardous. This variation may, in part, stem from the differing use orientations of the classification systems, and also from overlap between attributes. For example, flammable and explosive wastes are generally toxic, while many radioactive and some biological wastes are also toxic (U.S. Environmental Protection Agency, 1974b:4). A comparison of some of these classification systems is provided in Table 1.

The problem of deciding what makes a material hazardous is not of course restricted to the attributes to be considered, but also encompasses the potential magnitude or severity of the effect.(5) While some materials are universally regarded as hazardous, there is a "gray area" in which authorities will disagree as to whether or not a material should be classified as hazardous. In many cases, the problem is compounded by inadequate data about the potential effects of the material on man and the environment.

The approaches adopted towards identifying hazardous materials fall into two general categories:

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(5) The term hazardous may be regarded as having two connotations, one of which relates to the intrinsic properties of the waste itself, i.e., the amount of damage that it is capable of rendering to man or the environment. The second relates to extrinsic factors, such as the degree of exposure to the hazard, e.g., the quantities and circumstances surrounding the exposure (Battelle N.W. Laboratories, 1974:31, vol.1). This discussion focuses on the intrinsic properties, but it will be noted that the quantity of waste (an extrinsic factor) is included in several of the systems summarized in Table 1.

TABLE 1. HAZARDOUS MATERIALS CLASSIFICATION CRITERIA

System	Toxicological	Flammability	Explosive	Corrosive	Reactivity	Oxidizing material	Radioactive	Irritant	Strong sensitizer	Bioconcentration	Muta/tetra/carcinogenic	Sufficient quantity
	Criteria											
Title 15, U.S. Code, Sec. 1261	X	X		X			X	X	X			X
CPSC-Title 16, CFR, Part 1500	X	X		X			X	X	X			X
Food, Drug, and Cosmetic Act	X									X	X	X
DOT-Title 49, CFR, Parts 100-199	X	X	X	X		X	X	X				X
Pesticides-Title 40, CFR, Part 162	X	X								X	X	
Ocean Dumping-Title 40, CFR, Part 227	X									X	X	X
NOISH-Toxic Substances List	X										X	
Drinking Water Standards	X									X	X	
FWPCA Sec. 304 (a)(1)	X									X	X	
Sec. 307 (a)	X									X	X	X
Sec. 311 (b)(2)(A)	X											X
Clean Air Act-Sec. 112	X							X			X	
California State List	X	X	X	X				X	X			
National Academy of Sciences	X	X			X							
TRW Systems Group	X	X	X	X			X			X		X
Battelle Memorial Institute [N.W.]	X	X	X		X	X	X	X		X	X	
Booz-Allen Applied Research, Inc.	X	X	X		X							X
Dept. of the Army	X											
Dept. of the Navy	X	X	X	X	X	X	X					
National Cancer Institute	X									X	X	X

Source: Kohan, 1975:2

(i) specific rules ("decision models") for determining whether or not a material is hazardous, and

(ii) listings of materials deemed to be hazardous (the "pure compound" approach).

There are difficulties associated with both approaches.

The decision model approach involves specifying levels of hazardous attributes, such as flash point, degree of toxicity, etc. A major problem is that it is not easy to decide upon the criteria to be used. As Flinn, Thomas and Bishop (1974:2) point out, most classification systems in use are deficient in that they focus on acute effects to the neglect of chronic effects, have a limited domain of concern and are not designed to handle degradation products and synergistic effects when one material mixes with another.

The resources required for testing waste streams could be considerable, especially with respect to toxicity and genetic effects. Estimates of costs ranging up to $750,000 for animal toxicity testing of a single chemical have been suggested (Portney, 1978:136). Furthermore, variations in the composition of a given hazardous waste stream could make it difficult to obtain a representative sample.

Enormous resources could also be required to evaluate hazardous materials using the pure compound approach, as Flinn, Thomas and Bishop (1974:5) indicate that some quarter million chemical entities may be identified each year, and that several hundred are introduced into commercial use annually. The pure compound approach also raises the problem of defining the concentration at which the presence of a given substance renders a waste stream hazardous, while extrapolation from laboratory animal studies to effects on man is fraught with difficulties (Rall, 1975). These problems are compounded by the observation that low concentrations of some elements may be essential to certain forms of life, whereas higher concentrations may be toxic or lethal (Venugopal and Luckey, 1975:5,6). Furthermore, the approach does not allow for synergistic or antagonistic effects that may occur when mixtures of chemicals are present in a single waste stream.

Williamson (1975:27-36) includes a detailed discussion of the advantages and disadvantages of a number of versions of these two general approaches; while Battelle N.W. Laboratories (1974:29-54, Vol.1) comprehensively discusses the attributes that could make a waste hazardous.

Of various hazardous waste decision models, that developed by Battelle N.W. Laboratories (1974:43, Vol.1) is probably the best known. This model was included in the Report to Congress: Disposal of Hazardous Wastes (U.S.

Environmental Protection Agency, 1974b) and is illustrated in Figure 2. While the usual purpose of decision models of this type is to provide a "yes/no" answer (i.e., either a waste is hazardous or it is not), some designate two degrees of hazard [e.g., "dangerous" and "extremely hazardous" (Mehlhaff, Cook and Knudson, 1977)]. In addition, some models have been designed to produce a hazard rating or ranking. Klee (1976) has reviewed three such models, and points out that, because each represents a different evaluator's utility function, the correlation between results obtained from each model is poor. More detailed analysis of the characterization of hazardous waste is beyond the scope of this research.

Categories of Hazardous Waste

There are numerous ways of classifying wastes into generic groups. Bases include:

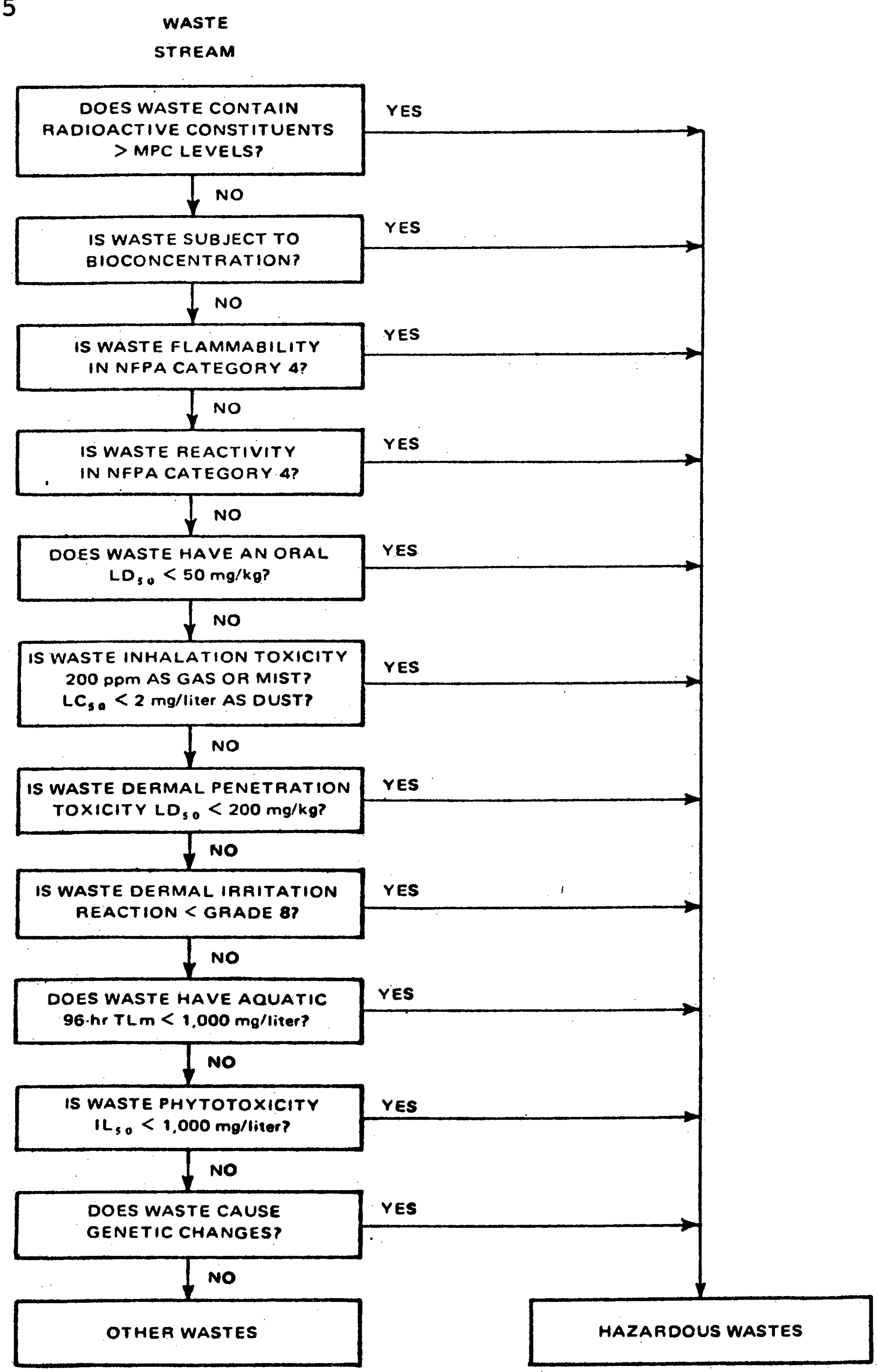
(i) hazardous attributes;

(ii) material or chemical classifications (e.g., metals, organics, inorganics, etc.);

(iii) state of matter (i.e., gas, liquid, sludge/ slurry, solid);

(iv) geographic occurrence;

(v) industrial origin [e.g., either Standard Industrial Classification (SIC) or process origin];



SOURCE: U.S. Environmental Protection Agency, 1974b:57.

FIGURE 2: The Battelle N.W. Hazardous Waste Decision Model

(vi) amenability to different forms of resource recovery treatment and/or disposal;

(vii) the nature of significance of the threat that they pose to the environment[6]; and

(viii) control by existing and/or proposed regulation.

With some classification schemes, there may be difficulties in allocating wastes to specific categories due to overlap problems--for example, if classified by hazardous attributes a waste might be both toxic and flammable, or if classified by chemical composition, a waste might be basically organic but with low concentrations of heavy metals that cause it to be hazardous.

In practice, hybrid classification systems are often used; for example, Berkowitz, March and Horne (1975:S-2,3) classify all industrial wastes (including, but not limited to, hazardous wastes) into 29 general waste streams based largely on the states of matter and the materials present or chemical composition. These same authors also propose a hierarchical classification system that has 21 "dimensions," including such items as geographic and SIC origins, on-site

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(6) Although similar to classification by hazardous attributes, this approach would take into account the waste's interaction with the environment; e.g., the ease with which it could be biodegraded, transported and/or changed to other forms by natural processes. It might also take account of the "background level" of the material in the environment.

treatment received, mode of transport to disposal, hazardous attributes, and properties related to "recyclability" and "decomposability" (Berkowitz, March and Horne, 1975:III-5). In contrast, Perna (1977) suggests the use of eight basic categories, one of which is "hazardous wastes."

In dealing with hazardous wastes, it may sometimes be useful to distinguish between wastes from different sources, as follows:

(i) Industrial process wastes
(ii) Radioactive wastes
(iii) Hospital wastes (pathological)
(iv) Chemical laboratory wastes
(v) Surplus pesticides and pesticide containers
(vi) Obsolete explosives
(vii) Chemical and biological warfare wastes
(viii) Other special wastes

The distinction is made on the grounds of the approaches that may be used to control the disposition of the wastes. For example, radioactive wastes are already subject to different regulations from chemical wastes, while regulations developed to deal with industrial process wastes might be very cumbersome if applied to small quantities of laboratory wastes, or "empty" pesticide containers.

Although post-consumer wastes undoubtedly contain hazardous components on occasions, they are not usually regarded as a source of hazardous waste. Mill tailings can have concentrations of heavy metals that are in excess of background levels, and could therefore pose a possible hazard (Midwest Research Institute, 1975). However, except where they are radioactive, such wastes are not generally regarded as hazardous, and due to the large quantities of materials involved there are few feasible management alternatives for such wastes.

"Treatable" and "Non-treatable" Wastes

Although much general analysis can apply to all hazardous wastes, there is perhaps one hazardous waste classification that could usefully be employed in general economic or policy studies. This is to distinguish between "treatable wastes," i.e., materials that can readily be detoxified or rendered harmless (by physical chemical or biological means) and "non-treatable wastes" which are those that cannot readily be detoxified. For example, waste sulphuric acid and phenol-contaminated waste water may qualify as hazardous wastes,[7] but the former may be neutralized

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(7) Sulphuric acid and phenol are listed as hazardous substances under the Federal Water Pollution Control Act (U.S. Environmental Protection Agency, 1974a) and by Booz-

by reaction with a low-cost, widely available alkali, such as lime; while the latter is readily biodegradable at low concentrations (Rosfjord, Trattner and Cheremisinoff, 1976). Thus, these "treatable" wastes may usually be simply and inexpensively rendered harmless.

In contrast, the toxic properties of a heavy metal are fundamental to that element, and hence if a waste contains heavy metals in significant quantities it is necessary to find ways to prevent the release of the element if the environment is to be protected. This could, for example, be achieved by physical containment or by insuring that the waste remains in a highly insoluble form. However, a waste of this "non-treatable" category remains a permanent threat, and must be considered as a candidate for "perpetual care," whereby man must watch over the waste for evermore. This is an important distinction from a "treatable" waste.

Inevitably there is a zone for uncertainty or overlap between the two catergories. For example, PCB's exhibit serious chronic toxicity, are subject to bioaccumulation

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Allen Applied Research, Inc. (1972). Both waste streams are known to qualify as hazardous waste under the Battelle Decision Model (Battelle N.W. Laboratories, 1974:42-54, Vol.1) when typical concentrations are present [Stradley, Dawson and Cone, 1975 (including data sheets prepared in conjunction with their report)].

and are highly persistent in the environment (U.S. Environmental Protection Agency, 1976b). However, as synthetic organic compounds, they are capable of degradation to a harmless form by incineration. Unfortunately, the required incineration parameters (high temperature and long dwell time) are such that appropriate thermal degradation is very costly, especially compared with simple treatments of the type discussed above. A viable alternative might be some form of perpetual care, and hence waste PCB's do not readily fit into either the "non-treatable" or "treatable" category, since although technically treatable, economic considerations may result in them not being treated.

Techniques For The Management Of Hazardous Wastes

The term "technique" is used in this dissertation to denote a technical means of changing, treating or disposing of a hazardous waste. The term is restricted to direct physical activities and does not imply anything about its economic or social effects or the policies that might encourage or discourage the use of that technique.

The techniques that are available fall into four groups, as follows:

(i) techniques that change the composition or magnitude of the waste stream itself;

(ii) techniques that recover values (materials or energy) from a given waste stream;

(iii) techniques that treat the waste stream in order to render it less harmful;

(iv) techniques that store or dispose[8] of the waste.

A waste may be sequentially subjected to more than one technique; for example, a disposal technique may be preceded by some form of treatment.

The available techniques are listed in Table 2, and are described in Appendix A.

Legislative Background

In the past decade significant advances have been made in legislative controls of most of the major sources of environmental degradation. Amendments to the Clean Air Act in 1970 (PL 91-604) established a system of air quality and emissions standards that has resulted in marked reduction of pollutants discharged into the air. The Federal Water Pollution Control Act passed in 1972 (PL 92-500) instituted a similar system for controlling effluents passing into the nation's watercourses. Both of these statutes include

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(8) Since matter cannot be destroyed, the term "disposal" (or sometimes "ultimate disposal") is commonly used to denote removal of the waste from the immediate location of generation to some other location where it is put into permanent storage (as in a landfill), diluted or dispersed (as may occur in ocean dumping).

TABLE 2. TECHNIQUES FOR THE MANAGEMENT OF HAZARDOUS WASTES

Technique	Location*	Comment
(a) Change in Waste Streams		
(i) Process change	on-site	To generate wastes that are less hazardous
(ii) Source reduction	on-site	To generate less of hazardous wastes
(iii) Waste separation	usually on-site	To separate hazardous waste from non-hazardous waste
(b) Resource Recovery		
(iv) Materials recovery	on/off-site	
(v) Energy recovery	on/off-site	
(c) Treatment to Reduce Hazard		
(vi) Physical treatment	on/off-site	Variety of processes available (See Table A.1.)
(vii) Chemical treatment	on/off-site	
(viii) Biological treatment	on/off-site	
(ix) Thermal treatment	on/off-site	
(x) Encapsulation	--	To immobilize wastes
(d) Storage or Disposal		
(xi) Land application	usually off-site	
(xii) Landfilling	on/off-site	
(xiii) Mine disposal	usually off-site	
(xiv) Lagooning	on/off-site	For storage, liquid volume reduction by evaporation; may also involve treatment
(xv) Deep well injection	on/off-site	Liquids only
(xvi) Ocean dumping	off-site	
(xvii) Engineered storage	usually off-site	
(xviii) Space disposal	off-site	

SOURCE: Adapted from U.S. Environmental Protection Agency, 1974b:9: Kovalick, 1975:Appendix A; and other sources.

* Location at which technique is used, relative to site of waste generation.

provisions designed to prevent hazardous pollutants from being dumped into the respective environmental media with which they are concerned. Hazardous air pollutants are controlled by establishing stringent stationary source emissions limitations for designated pollutants (Arbuckle, et al., 1976:169). Discharges of hazardous or toxic pollutants into surface waters from point sources are controlled in several different ways in the Federal Water Pollution Control Act but the basic idea is to establish limitations on the amounts and types of these effluents. In some cases standards of performance are set for certain industries, while effluent standards for hazardous pollutants are set in others (U.S. Environmental Protection Agency, 1974b:18-20.

Ocean dumping, commonly used in the past, has now been virtually eliminated as a technique for the disposal of hazardous wastes (U.S. Environmental Protection Agency, 1977a). Under the Marine Protection Research and Sanctuaries Act of 1972 (as amended), the dumping of any radiological waste is prohibited; and a permit is required before any other material can be dumped. It is the policy of the Act to regulate all ocean dumping, and to prevent or strictly limit the ocean dumping of any material that would adversely affect the marine environment (U.S. Environmental Protection Agency, 1977a:9). Also, in 1974, the U.S. ratified the 1972 International Convention on the Prevention of Marine Pollution by the Dumping of Wastes and Other Matter. This Convention prohibits the deliberate ocean disposal of certain waste materials (which are additional to those listed above), and requires that special care be taken in issuing permits for specified others (U.S. Environmental Protection Agency, 1977e).

In addition to the data mentioned above there are thirteen other federal statutes that have some bearing on the treatment, storage, transportation and handling of hazardous wastes (see U.S. Environmental Protection Agency, 1974b:15-17. Much of this legislation applies to the specific wastes or categories of wastes, e.g., explosives).

At the beginning of this decade it was realized that (a) increasingly stringent control of air and surface water pollution was diverting wastes to various forms of land disposal which were largely uncontrolled, and that (b) although some aspects of hazardous wastes were addressed piecemeal by a variety of federal and state statutes, some comprehensive control was needed. These two forces prompted Congress to enact Section 212 of the Resource Recovery Act of 1970 (PL 91-512) which directed the EPA to undertake a study to better identify the nature and scope of the hazardous waste problem with special orientation toward establishing a system of "national disposal sites" (NDS) (discussed later in this chapter) for hazardous wastes. The resultant report delivered to Congress in June 1973 (U.S. Environmental Protection Agency, 1974b) strongly emphasized the need to regulate hazardous wastes in a comprehensive manner.

The initial legislation proposed subsequent to this report provided for identification of hazardous wastes, establishment of standards for treatment and disposal of such wastes, the establishment of guidelines for State programs for implementing such standards. It did not, however, propose a system of federally-controlled NDS. After several years of deliberation, similar legislation was finally passed in October 1976 as Subtitle C of the Resource Conservation and Recovery Act (PL 94-580). The objectives of this Subtitle are as follows:

> The basic thrust of the hazardous waste title, is to identify what wastes are hazardous and in what quantities, qualities, and concentrations and the methods of disposal which may make such wastes hazardous. The title requires that the Administrator promulgate regulations applicable to generators. Such regulations include record-keeping, informing those that transport or dispose of such hazardous waste of the characteristics of such waste and the initiating of a manifest system so that the waste generated can be traced to the site of ultimate disposal. . . .

> Regulations are imposed on transporters of hazardous waste. Most important is the initiation of a manifest system so that the hazardous waste can be traced from the generator to a facility that has an approved permit. . . .
>
> Other regulations required to be promulgated relate to those who treat, store or dispose of hazardous waste. Such regulations are to consist of compliance with the manifest system, recordkeeping requirements and inspections.
>
> The Administrator is also empowered to recommend methods of treatment, storage or disposal of hazardous waste, and the operation of such facilities, to assist the operators in safely handling such hazardous waste.
>
> Finally, those who store, treat, or dispose of hazardous waste are required to receive a permit either from the Administrator or from the appropriate state agency authorized by the Administrator to grant such a permit. . . . [Emphasis added.] (U.S. House, 1976:6-7)

At the time of writing (late 1978) the EPA is promulgating regulations under PL 94-580. At least 25 states have some legislation or regulations that control hazardous waste management activities to some degree (U.S. Environmental Protection Agency, 1974b:17-18), but only a limited number have comprehensive hazardous waste management legislation (Lehman, 1976), and in most cases this is not yet fully implemented. Even California, which has been a front-runner in hazardous waste regulation, is still developing its program (Storm, 1977).

Previous Research On Hazardous Waste Management

Federal Research

Prior to 1970, when Congress passed Section 212 of the Resource Recovery Act, little attention had been paid to the problems of hazardous wastes, although the risks and procedures involved in the transportation of hazardous material had been studied (Smith, 1976). Following the 1970 Resource Recovery Act, the EPA commissioned a number of wide-ranging research studies.

In an initial study, Booz-Allen Applied Research Inc. (1972) compiled a candidate list of hazardous materials and attempted to obtain a "feel" for the nature and magnitude of the problem. This was followed by an in-depth study, which included developing profile reports (summarizing quantities generated and hazardous properties) on over 500 potentially hazardous materials, and analysis of a variety of treatment and disposal techniques that might be used in hazardous waste management (Ottinger, et al., 1973). All this work was predisposed towards the concept of a system of national disposal sites for hazardous waste, and another EPA-sponsored study examined alternative approaches to the use of such disposal sites. Three basic approaches were considered: on-site waste processing (i.e., treatment and/

or disposal of the waste at the location where it is generated), off-site processing at some regional hazardous waste facility, and a combination of on-site pretreatment and off-site treatment and disposal. This study examined the process economics and other considerations associated with these alternatives for a number of common waste streams that were regarded as strongly hazardous, and concluded that most should be processed at NDS (Arthur D. Little, Inc., 1973). Meanwhile, in Program for the Management of Hazardous Wastes, Battelle N.W. Laboratories (1974) estimated the quantities of hazardous waste generated in the U.S.A. and made a detailed examination of the feasibility of a system of NDS, including conceptual design, etc.

The results of this series of studies were integrated into the Report to Congress: Disposal of Hazardous Wastes (U.S. Environmental Protection Agency, 1974b). This report concluded that for the most part hazardous wastes were disposed of using low cost methods that did not provide adequate environmental protection. The technology to adequately manage most hazardous wastes was found to be available, but adequate management is often costly. Hence the waste generators frequently had an economic incentive for inadequate management.

The Report to Congress: Disposal of Hazardous Wastes determined that about 9 million tonnes (10 million short tons) of non-radioactive hazardous wastes were being generated annually in the U.S.A., increasing at 5 to 10 percent per year. About 90 percent of these wastes were in liquid form, the remainder being solids, sludges and slurries,[9] while 60 percent of the wastes were organic materials. Virtually all these wastes were industrial process wastes, and practically all of them were toxic (U.S. Environmental Protection Agency, 1974b:3,4).

Subsequently, the EPA commissioned detailed studies on the fourteen industries[10] that were believed to contribute the bulk of all hazardous process wastes (Abrams, Guinan and Derkics, 1976; Arthur D. Little, Inc., 1976; Battelle-Columbus Laboratories, 1976; Foster D. Snell, Inc., 1976a; Gruber and Ghassemi, 1975; Jacobs Engineering Co., Inc., 1976; McCandless, et al., 1975; Leonard, et al., 1975; SCS Engineers, Inc., 1976; Shaver, et al, 1975; Swain, 1976; Wapora, Inc., 1976a, 1976b, 1976c). Each of these

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(9) Emissions of hazardous materials to the air were not considered in these studies as such emissions were already controlled under Section 112 of the Clean Air Act as amended in 1970.

(10) In this dissertation, the term "industry" is used to denote an industrial category (e.g., the enterprises within an SIC), and not an individual firm.

studies characterized the structure of the industry, estimated the total process wastes generated (both at the time of the study and in the future), identified the portion of the waste which was considered to be potentially hazardous, determined the disposal methods currently in use, and estimated direct control costs for various levels of treatment and disposal technology. The results of these studies, which are summarized in Table 3, showed that these industries generated nearly 29 million tonnes (32 million short tons) of hazardous waste in 1974. This is expected to increase to 38 million tonnes (42 million short tons) by 1983, largely because of residues from additional air and water pollution controls. A pervasive problem with all hazardous waste research has been that of defining a hazardous waste. In each of the fourteen industry studies, the contractor chose the definition employed, which was not necessarily consistent with that used for the Report to Congress: Disposal of Hazardous Wastes.(11)

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(11) The estimates in the Report to Congress: Disposal of Hazardous Wastes of 9 million tonnes (10 million short tons) of wastes considered potentially hazardous were generated by Battelle N.W. Laboratories (1974) using the Battelle N.W. decision model (U.S. Environmental Protection Agency, 1974b). However, the problem of determining how much hazardous waste is generated is not restricted to the choice of criteria. In addition, waste stream magnitudes and concentrations of constituents are uncertain or subject

TABLE 3. POTENTIALLY HAZARDOUS WASTE IN THE U.S.A.

Industry	Amount (Million tonnes per year) 1974 Dry	1974 Wet	1983 Dry	1983 Wet
1. Batteries	0.005	0.010	0.105	0.209
2. Inorganic chemicals	2.000	3.400	2.800	4.800
3. Organic chemicals, pesticides and explosives	2.150	6.860	3.800	12.666
4. Electroplating	0.909	5.276	1.751	5.260
5. Paint and allied products	0.075	0.096	0.105	0.145
6. Petroleum refining	0.625	1.757	0.811	1.888
7. Pharmaceuticals	0.062	0.065	0.104	0.108
8. Primary metals smelting and refining	4.454	8.335	5.536	10.418
9. Textile dyeing and finishing	0.048	1.770	0.179	0.716
10. Leather tanning	0.045	0.146	0.068	0.214
11. Special machinery	0.102	0.163	0.157	0.209
12. Electronic components	0.026	0.036	0.050	0.108
13. Rubber and plastics	0.205	0.785	0.299	1.204
14. Waste oil re-refining	0.057	0.057	0.144	0.144
Totals	10.763	28.755	15.909	38.089

Source: U.S. Environmental Protection Agency, 1977b:14.

For some industries, additional studies have been completed on alternative control technologies that might be employed, and on the economic effects (e.g., changes in product prices and plant closings) of possible hazardous waste management regulations (e.g., Versar, Inc., 1977; and Williams, et al., 1976). Another study examined the structure and capacity of the independent hazardous waste management industry. In 1975, this was found to consist of about 95 firms operating 110 facilities. Annual capacity was determined to be about 7.3 million tonnes (wet basis) but only about half that capacity was being used (Foster D. Snell, 1976b; see also, Farb and Ward, 1975). Comparison of these data with those for total generation of hazardous wastes (Table 3) supports the EPA's finding that most industries dispose of their hazardous waste locally to the land, and that only a small proportion of this waste is handled in a manner that the EPA regards as environmentally adequate. (U.S. Environmental Protection Agency, 1977b:15)

Other federal research has included the collection and analysis of hazardous waste "incidents" data (an "incident" being where significant environmental degradation or damage

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to variation, and the toxicity and genetic effects of the components may be ill defined -- especially in the presence of other components.

to health or life has occurred) and numerous supporting studies on hazardous waste treatment and disposal technologies. This reasearch is discussed in Appendices A and B.

Public input to hazardous waste management decision-making was solicited via four public meetings on hazardous waste management held in December 1975 (Corson, 1976; U.S. Environmental Protection Agency, 1976c; Edelman, et al., 1976), and by meetings held early in 1977 in each of the ten EPA regions on implementation of the 1976 Resource Recovery and Conservation Act (U.S. Environmental Protection Agency, 1977d). One early study attempted to gauge the public's likely attitudes towards the NDS concept (Lackey, Jacobs and Stewart, 1973) and is discussed later.

Other Research

The EPA has encouraged the states to conduct hazardous waste generation and disposal surveys as a preliminary stage towards formulating hazardous waste management plans. Various EPA publications directed towards these ends are available (Porter, 1975, 1976; U.S. Environmental Protection Agency, 1977b). Although a number of statewide and some regional and local surveys have been initiated, several have met with only limited success due to poor response from the generating firms.[12] This difficulty has been compounded by the absence of an accepted and easily applied definition of hazardous waste. On the other hand, California has obtained excellent responses using a carefully designed and strongly followed up survey technique on a county basis (Sanders, 1977).

General Findings on Previous Hazardous Waste Research

After reviewing the numerous individual studies, the author has formed the following general impressions about previous hazardous waste research.

(i) It has emphasized process wastes (as opposed to post-consumer or post-industrial wastes) and has not to any significant extent considered hazardous emissions to the atmosphere.

(ii) It has emphasized toxic and radioactive wastes (as opposed to, say, flammable wastes).

(iii) It has been demonstrated that precise and comprehensive definition of hazardous waste is difficult, and subject to disagreement among authorities.

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(12) This statement is based on discussions between the author and a variety of persons involved with hazardous waste management.

(iv) It has had a technological emphasis and has not to any great extent attempted to consider public attitudes to waste management alternatives.

(v) It has been oriented towards "end-of-pipe" solutions, and much of it was predisposed towards the national disposal site concept.

(vi) It has largely been conducted on an industry-by-industry, waste-by-waste basis, and has shown that virtually every industry has a number of unique features with respect to hazardous waste management.

(vii) It has made evaluations largely in terms of direct control and disposal process economics and has generally not evaluated any indirect costs (such as environmental costs) or social impacts, nor has it considered the implications of differing attitudes towards risk-taking.

(viii) It has adopted "let the polluter pay" as its philosophy of equity.

(ix) The studies have used generalized analysis and have tended to specify what their authors regard as the "best" solution, rather than dealing with specific problems and displaying the pros and cons of alternative solutions.

This summary of the features of previous work on hazardous wastes is not intended to imply any criticism of that work, but is presented in order to identify gaps in society's knowledge and some pitfalls to be avoided. Again, it must be emphasized that these are general conclusions, to which there may be certain exceptions.

Thus, to date, economic analysis has not addressed the problem of selecting socially optimal hazardous waste management policies, except in an extremely general way (Talley and Albrecht, 1974). No significant attempt has been made to apply the techniques of cost-benefit or risk-benefit analysis to hazardous waste management, and research has not examined ways in which public attitudes could be factored into the selection of policies.[13] This research represents a first step towards rectifying these omissions.

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(13) This statement should not be construed as saying that hazardous waste management decision-making has been insensitive to public attitudes. What has not been examined are the ways in which hazardous waste management decision-making can systematically take account of public attitudes.

CHAPTER 2

ECONOMIC AND SOCIAL ASPECTS OF HAZARDOUS WASTE MANAGEMENT

Cost-Benefit And Risk-Benefit Analysis For Environmental Problems

Established Applications

Techniques of cost-benefit and risk-benefit analysis[1] are well developed, and have already been applied to several classes of environmental problems. For example, cost-benefit

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(1) In cost-benefit analysis, all the costs of a proposed action, including social and environmental costs, are summed and compared with the benefits arising from the action. Since costs and especially benefits can involve effects (such as environmental changes) for which there is no established marketplace, values for effects must frequently be imputed from other indicators. (This is discussed with reference to hazardous wastes in Appendix C.) The distinction between cost-benefit and risk-benefit analyses is not clear-cut. The term risk-benefit analysis is often applied to a category of cost-benefit analysis in which risks to life and health are an important component of the costs (National Academy of Engineering, 1972:3,4). It would not be applied to an analysis in which the risks are purely economic (e.g., where there is construction cost uncertainty or where there is doubt about the magnitude of the project benefits). Some authors dealing with risks to life retain the term cost-benefit analysis (National Academy of Sciences, 1977), while others use the term cost-risk-benefit analysis to suggest that the costs include both conventional costs and risk-related ones (U.S. Atomic Energy Commission, 1974).

analysis has been applied to air and water pollution control programs (Peskin and Seskin, 1975), while risk-benefit (or cost-risk-benefit) analysis has been used to compare alternative means of generating electric power (Barrager, Judd and North, 1976).

Cost-benefit analysis is usually used to determine whether or not a project or an activity should be undertaken, which requires that the total benefits conferred should exceed the total costs involved. At the same time, cost-benefit analysis frequently involves determining the optimum scale of activity, i.e., the project scope at which the net benefit (total benefits less total costs) is maximized. Analysis of this type could be appropriate to deciding whether or not to create a park or to preserve a natural environment as a wilderness area.

Where one is conducting a pollution control analysis, the analyst's terms of reference do not usually permit questioning the desirability of the economic activity that generates the pollutant. In many cases this activity is already in existence. Hence analysis considers only costs associated with pollution, and the conventional economic approach to pollution control becomes that of determining the optimum level of pollution, and devising a policy that results in that level. Conceptually (but not in practice) this is straightforward, and involves controlling the discharge of the pollutant to the level which minimizes the total cost, i.e., Q1 in Figure 3. In this case it is implicitly assumed that overall, the benefits of the activity outweigh all the costs.

Risk-benefit (or cost-risk-benefit) analysis can examine whether or not an activity that involves risk should be undertaken or permitted. It could, for example, be used to decide whether or not a particular toxic substance should be used in a given application (Provenzano, 1973). This involves comparing the benefits of such use with the risks incurred. In some risk-benefit analyses, however, the net benefit of the activity is also <u>assumed</u> to be positive, and the analysis is used to compare alternative ways of achieving the objective. For example, in assessing alternative means of generating electric power the expected numbers of accidents in mining and transportation, etc. have been estimated and have been expressed as a cost (U.S. Atomic Energy Commission, 1974). The effects of air pollution (e.g., sulphur dioxide) on health and property could also be included in the same way, although in practice there are major difficulties involved in predicting the effect of airborne pollution on human health (Sagan, 1972; Goldstein, 1975). The probability and results of accidents could also be estimated,

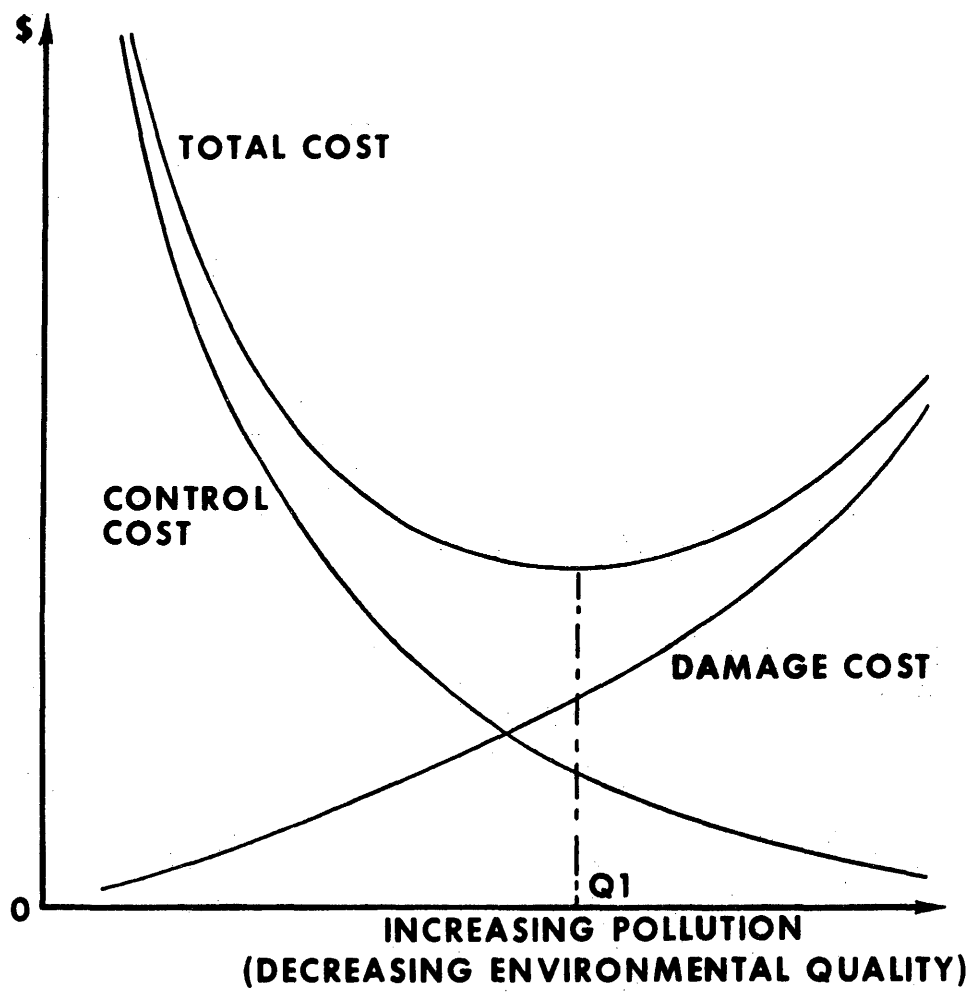

FIGURE 3: Conventional Economic Approach to Pollution Control

as in the "Rasmussen report" on major accidents in nuclear power plants (Rasmussen, 1975).

Most risk-benefit assessments use <u>expected values</u> to describe the risks. By assigning probabilities and economic values to the risks, an expected value of total damage or cost can be obtained, and the least cost means of achieving a specified objective can thereby be determined. Alternatively, the expected value approach can allow the optimum level of exposure to risk [e.g., radiation exposure from mammography (National Academy of Sciences, 1977)] to be determined in a manner that is analogous to Figure 3. This is comparatively simple where large numbers of individuals are exposed to risks that are statistically well defined, but the approach does not allow for a decision-maker's risk aversion, which could be particularly important where there are low probability risks with major consequences (e.g., nuclear power plant disasters).(2)

Tihansky and Kibby (1974) make a conceptual extension of the expected value approach by introducing confidence intervals and comment that a risk-averse decision-maker might base his decisions on values that are displaced from

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(2) The concept of specifying a decision-maker's utility function so as to build in a degree of risk aversion has been proposed (see Appendix D).

the means. For example, if asked to approve the manufacture of a toxic substance, he might choose the upper decile for damage costs and the lower decile for benefits. Of course, the difficulty with this approach is to determine all the necessary data.

While the basic approach in cost-benefit and risk-benefit analyses is to express all effects in terms of a common measuring rod (the dollar), studies rarely succeed in placing dollar values on <u>all</u> the environmental effects. Some authors have endeavored to make up for omissions by lising predictable impacts, such as annual quantities of effluents and wastes requiring disposal. The difficulties that may be encountered in attempting to perform a comprehensive cost-benefit or risk-benefit analysis are discussed by Fischhoff (1977) in an excellent critique of the techniques.

Application to Hazardous Waste Management

From an analytical viewpoint, there are significant differences between the types of pollutants and risks discussed above, and those associated with most hazardous waste problems. The conventional economic approach to pollution control (Figure 3) arrives at a least cost solution by changing the control measures used so that the quantity of pollutant released to the environment varies.

This approach assumes a single pollutant (or index of pollution, such as BOD) as the independent variable (the abscissa in Figure 3). Except where one is dealing with control measures like waste treatment for a single industry, hazardous waste management techniques (such as landfilling) usually accept many different wastes, possibly having different hazardous attributes. Hence, in many cases a variable representing the magnitude of a pollution threat would be difficult to generate. In the absence of a suitable index, analysis would have to be undertaken on a waste-by-waste basis and would need to consider interactions between wastes. This would require numerous data that would rarely be available, and the problem would be complicated by the variability in composition of many hazardous wastes.

Further difficulties arise with the damage function. It may not be desirable to use an expected value or similar measure of damage. There are two arguments against use of an expected value; that of risk aversion has already been mentioned, the second is that the public's perception of a risk may be more important than the true probability and magnitude. These issues will be discussed later in this dissertation.

However, consider what would be involved if one wished to make a hazardous waste risk-benefit analysis of the type described above for alternative means of generating electric power (Barrager, Judd and North, 1976; U.S. Atomic Energy Commission, 1974). Most electric power generation uses a limited number of comparatively uniform technologies (e.g., coal, oil, gas and certain nuclear fuel cycles). Likewise, the fuel extraction technologies are of limited diversity, and most have been established for a sufficient length of time to provide adequate data on risks such as occupational injuries, and some data on potential environmental damages such as acid mine drainage. The comparatively good data availability, the uniformity of the technologies and the magnitude of the resources that might be committed to those technologies can combine to warrant expenditure of considerable effort to make comparative risk-benefit analyses.(3)

In contrast to the electric power situation, hazardous wastes are highly diverse, and while some of the treatment and disposal technologies are comparatively uniform, the environmental conditions associated with disposal techniques (such as precipitation, soil and aquifer properties) are very variable. Hence, the threats that hazardous wastes pose to man and the environment can vary considerably with the circumstances. It will frequently be difficult to

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(3) For example, the Rasmussen study of accident risks in two types of nuclear power plants cost some $4 million (Rasmussen, 1975).

predict the probability of their occurrence, while it may also be hard to project the damage if a threat does materialize. This diversity implies that even if feasible, to comprehensively and accurately characterize the threats that might arise from hazardous waste management alternatives would often take considerable resources.

While detailed analysis (such as is used in conventional cost-benefit and risk-benefit analyses) may be possible and justified for some hazardous waste problems, there will be many for which it is not. This may occur because the necessary data cannot realistically be generated, or because the effort that would be required would be out of proportion to the scope of the problem (as measured by the worst case damage potential, or the cost of achieving a high level of control). What is needed is a methodology for evaluating hazardous waste management alternatives that recognizes the principles of cost-risk-benefit analysis, but which is simple to apply and does not require extensive data. This research attempts to provide a suitable methodology. A key component of the approach proposed is the identification of "threats" and the use of "threat scenarios" to describe the possible adverse consequences of hazardous waste management techniques.

Threats That May Arise From Hazardous Wastes

In the analysis of hazardous waste management alternatives, the damage or risk component can be regarded as a series of different threats of adverse events that may arise from the use of various control techniques. The term "threat" is used because, in most cases, there is some probability (not necessarily known) of the specified event occurring. It may occur soon, later or never, and if the threat does materialize the magnitude of the effect may also be uncertain. For example, there is a threat that a lagoon containing hazardous waste may overflow due to exceptional rainfall. The timing and the size of the spill (and hence its effects) cannot be forecast, although in this case they could quite readily be expressed in probabilistic terms.

Identification of Threats

A threat is always present, but for the threat to materialize, i.e., for the adverse event to actually occur, some sort of "initiating event" is required. Many initiating events are well defined specific incidents such as an industrial accident or an unlikely environmental occurrence (e.g., an earthquake) that can trigger a threat mechanism. However, a threat may also arise from inadequate design or poor practice, such as the operation of a landfill in such a way as to provide no environmental protection from hazardous leachates. A broad (as opposed to detailed) list of initiating events is given in Table 4(a).

Table 4(b) lists "threat mechanisms" which define the nature of the threat itself. Threat mechanisms may be sequential or hierarchical; for example, fire could lead to explosion, or vice versa.

The end results of a threat are termed "outcomes," and Table 4(c) provides a broad listing of these. A threat may not always carry through to result in an observable or measurable adverse outcome, such as poisoning of some life forms. However, even where there is no outcome of this type, there may well be a loss of some potential options. For example, a toxic leachate could contaminate an aquifer that is used as a drinking water source. In this case, the outcome would probably be poisoning and alternate water supplies would be needed. If, however, the aquifer (or at least the part that was contaminated) were not used for any sort of water supply, no poisoning would result, but the option of using the aquifer as a freshwater source would be lost unless decontamination were possible. Similarly, an area of barren ground could be contaminated by a spill, causing no destruction of life, but precluding various future uses.

By combining initiating events, threat mechanisms and outcomes, a series of possible threats can be developed.

TABLE 4. ENVIRONMENTAL THREATS IN HAZARDOUS WASTE MANAGEMENT

(a) Initiating events

Geologic event (e.g., earthquake, erosion, change in aquifer, meteorite impact)
Climatic event (e.g., unusual storm, flood, lightning, etc.)
In-plant accident
Transport accident
Sabotage
Operational failure or error (man caused)
Inadequate design or poor practice (including corrosion)

(b) Threat mechanisms

Spillage
Overflow
Containment failure
Leaching
Unintentional or unwanted mixing
Unintentional or unwanted contact
Fire
Explosion
Ground movement or shock waves
Unintentional or unwanted emissions (to air)
Odor
Vector
Bioconcentration

(c) Outcomes

Destruction of life (man, fauna, flora)
Destruction of real property
Poisoning
Modification of an ecosystem (by changing balance of species)
Olfactory insult

Loss of option(s)

For example, inadequate landfill design results in a leachate containment failure, which causes contamination of groundwater (by mixing) which leads to livestock poisoning. Numerous such threats could be identified, depending on the degree of comprehensiveness required. Thus in the example above, the leachate damage could lead to unspecified poisoning, to chronic or acute poisoning of flora, fauna, man, etc.

Figure 4 presents a morphological map that demonstrates in a general way how a threat evolves from some initiating event to some physical outcome.(4) In Figure 4 the threats mapped do not extend beyond initial outcomes; thus subsequent outcomes such as bioconcentration and spread of poisoning via

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(4) Morphological analysis is commonly used in technological forecasting, and is described by Ayres (1969:72) as a technique for ". . . identifying, indexing, counting and parameterizing the collection of all possible devices to achieve a specified functional capability." Of course, in the context of hazardous waste management, one is interested in identifying mechanisms that can lead to environmental degradation rather than identifying devices that achieve a specified capability, but the concept is similar.

The results of a morphological analysis may conveniently be presented in the form of a morphological map. Thus, this map may be used to display the components that can be involved in either event tree or fault tree analysis. Event trees are used to identify the various possible outcomes that may stem from a given initiating event, whereas fault trees start with an outcome and work back to find the ways in which it can be generated (Fischhoff, 1977). An attraction of the morphological map is that threats can be followed in either direction.

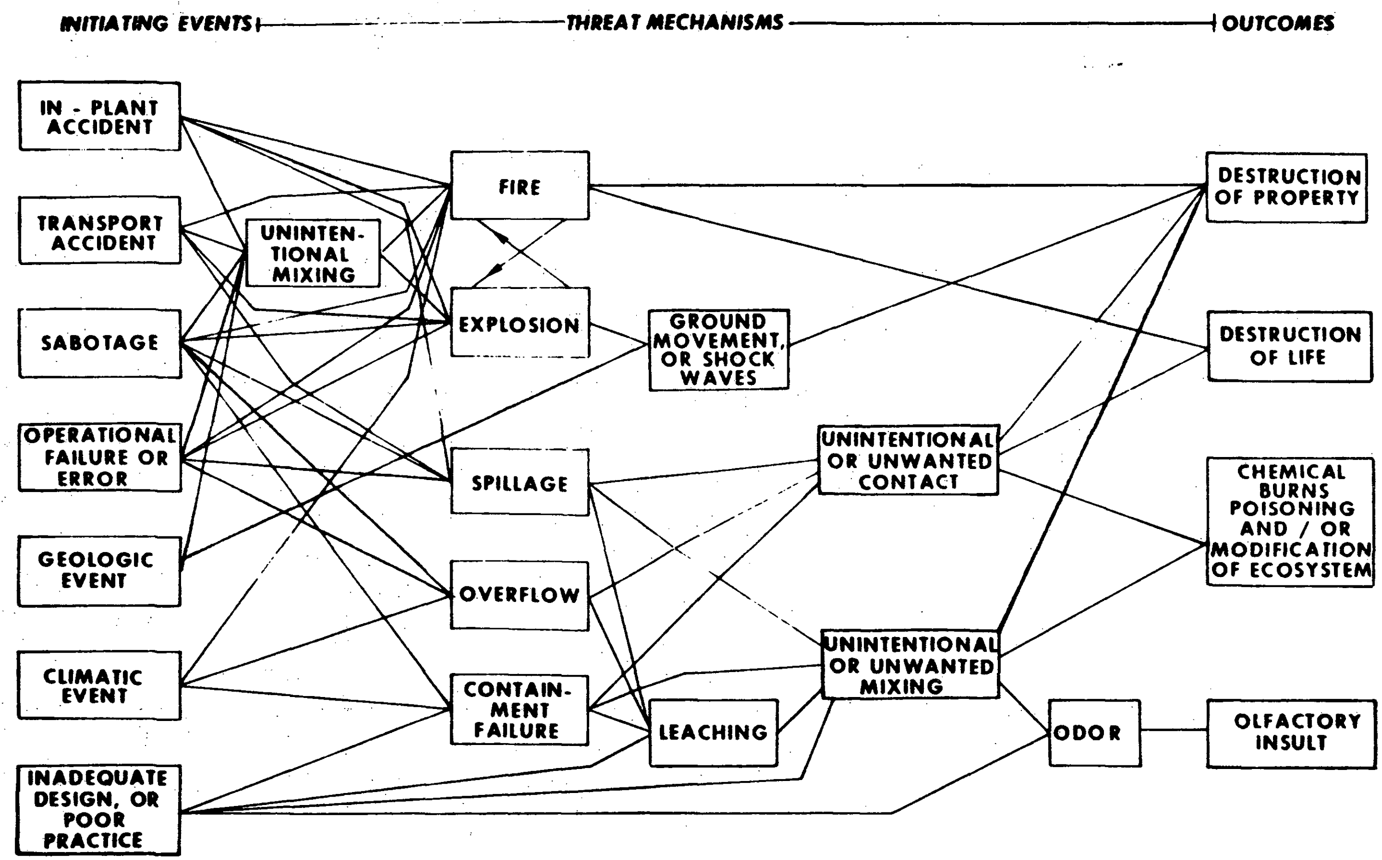

FIGURE 4: Morphological Map of Environmental Threats

vector or the food chain are not included. Although the map presented in Figure 4 is not fully detailed, it can be seen that there are numerous ways in which threats could develop. Thus, for practical purposes it will be necessary to limit the number of threats that are considered. (See Chapter 3.)

Common Threats in Hazardous Waste Management

Table 5 identifies some of the more important categories of threat that may occur in hazardous waste management, and indicates the waste management techniques which are likely to pose these threats. The techniques of potential interest include both those that provide good environmental protection and those that are generally regarded as unacceptable but which may nevertheless be employed (such as illicit dumping). Each of these threat mechanisms is discussed in Appendix B, which also includes some data on the probabilities of initiating events.

Economic And Social Effects Of Hazardous Waste Management Techniques

Classification of Effects

Use of various hazardous waste management techniques results in economic and social effects, i.e., the effects that these techniques have on man. The effects may occur either as a direct result of the waste management techniques

TABLE 5. MAJOR THREATS IN HAZARDOUS WASTE MANAGEMENT

	Threat Category	Techniques to Which Threat May Apply
1.	In-plant accident (spill, fire, explosion) leading to acute poisoning, destruction of property, etc.	All
2.	Systematic in-plant exposure, resulting in chronic poisoning of workers.	All
3.	Waste handling accident (spill, fire, explosion) during waste collection or disposal operations, leading to acute poisoning, destruction of property, etc.	All
4.	Transportation accident, leading to acute poisoning, destruction of property, water pollution, etc.	Wherever waste is transported from site of generation.
5.	Failure of treatment process, resulting in waste that retains hazardous properties or acquires new hazardous attributes	Any treatment process.
6.	Groundwater contamination via leachate.	Lagooning, land application, landfilling, mine disposal, possibly engineered storage.
7.	Surface or groundwater contamination by failure of containment.	Lagooning, landfilling, mine disposal, engineered storage.
8.	Surface water contamination via run-off or indirectly from seepage of polluted groundwater.	Lagooning, land application, landfilling.
9.	Modification of marine ecosystem by presence of waste.	Ocean dumping.
10.	Direct groundwater contamination by presence of waste.	Deep well injection.

used, or they may occur via environmental impacts. For hazardous wastes, many environmental impacts will take the form of threats as opposed to readily predictable impacts.

Analysis of waste management problems usually identifies two major categories of economic and social effects; control costs and damages. This is consistent with the cost-benefit approach to pollution control discussed earlier. While real benefits (as opposed to damages averted) may sometime arise from the use of waste management techniques (as with resource recovery) these can be accounted for by credits against control costs.

However, the author has elected not to use the term "damage costs" but to replace this term by "environmental costs" and "social impacts." There are two reasons behind this decision. First, the term "damage costs" does not take account of differing viewpoints. If, for example, a waste management scheme involves the construction of a dam on a river, moving water recreationists (e.g., kayakers) will perceive this as a damaging effect, but still water recreationists (e.g., water-skiers) will perceive a benefit. Secondly, although most authorities agree that it is conceptually possible to attribute a dollar value of any effect,[5] the

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(5) Where no market exists for the effects, valuation can theoretically be accomplished by using some sort of "willingness-to-pay" questionnaire (see Appendix C).

practical difficulties can be formidable, rendering the approach of dubious utility (Organisation for Economic Co-operation and Development, 1974). Hence there may be effects that are more appropriately described, rather than given a dollar value.

In this dissertation, the term "environmental costs" is used to describe the direct results of the environmental threats described hitherto, translated as far as practicable into economic terms. "Social impacts" is used to describe all remaining effects including those that are essentially psychological. Thus, in general environmental costs arise from the threat of physical environmental degradation leading to some specific potential economic loss. Social impacts on the other hand need not involve any physical damage, are more likely to need to consider differing viewpoints, and will more frequently defy quantification in dollar terms.[6] This terminology was chosen for convenience and may not coincide with those used by other sources. Further, in some cases allocation to an

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(6) It might be claimed that the environmental costs are "direct costs" while the social impacts are "indirect costs." However, because in reality there is rarely a sharp dichotomy between these categories, authors vary in the way in which they divide impacts (or costs) into "direct" and "indirect," and also in the terminology that they use to describe them. (Mäler and Wyzga, 1976:45)

environmental cost or a social impact may be arbitrary. Nevertheless, maintaining this division should help to ensure that all possible effects are considered.

Exclusion of Secondary Effects

This study does not, in general, address "secondary effects," which in the economic context are multiplier-type effects that reflect the fact that one person's expenditures constitute another's income. Secondary benefits are usually disregarded in cost-benefit and cost-effectivenss analysis on the basis that under conditions of full employment of resources, the resources used in secondary activities would be employed elsewhere in equivalently productive activities (Herfindahl and Kneese, 1974:248). Clearly, this argument is not always valid. Regional economists who are faced with a contracting economy and immobile factors of production (or conversely with a boom-town situation and shortages) may be vitally interested in economic multiplier effects; and such effects could be important in some hazardous waste management decisions. However, the author supports the view expressed by Maass that only where "secondary effects" (such as income redistribution) are made a part of project objectives (and thereby cease to be "secondary"), should they be included in evaluations (Maass, 1966). Hence, in this analysis the costs considered will be restricted to those conventionally used in assessing economic efficiency, except that environmental externalities (or "spillovers") will, of course, be included.

Types of Control Costs

Control costs associated with any approach to hazardous waste management may include the following:

(i) Generator's costs, i.e., those incurred by the firm that generates or may generate the hazardous waste. These include the costs of treatment, transport and disposal of the waste, which may be performed by the firm itself or by its contractors. They also include the generator's relevant administrative, legal and research and development costs.

(ii) Administrative costs, i.e., administrative and enforcement costs incurred by governments or by any other body that "oversees" or monitors hazardous waste management.

(iii) Social control costs, i.e., costs that reflect the differences between the dollar costs actually incurred by the waste generator for various services, and the true cost to society of these services. Such costs might arise, for example, where a government provides a waste disposal facility free or at a subsidized charge.

(These costs do not include an accounting of external environmental costs, which are covered elsewhere.)

In general, all control costs can quite readily be expressed in dollars, although for some there can be problems in deciding upon a method of valuation. They are discussed in more detail in Appendix C.

Types of Environmental Costs and Social Impacts

Several sources provide broad discussions of the evaluation of environmental damage including both environmental costs and social impacts as defined in this study (Mäler and Wyzga, 1976; Organisation for Economic Co-Operation and Development, 1974; Saunders, 1976; Bishop and Cicchetti, 1975). In general, empirical studies that involve pervasive pollutants (air pollution and radiation) appear to be the most advanced, possibly because the sources and receptors are comparatively readily identified. As far as the author is aware, there have been no studies that have addressed the empirical valuation of damages associated with hazardous waste *per se* in a cost-benefit or risk-benefit framework.(7) Talley and Albrecht (1974) have made a preliminary

(7) Moll, et al., made an empirical risk-benefit analysis of alternative standards for environmental sources of cadmium and asbestos (Moll, et al., 1975). However, although this study refers to these pollutants as "hazardous wastes," it was primarily concerned with damage to human life via air transport mechanisms, and the sources include atmospheric releases of cadmium and asbestos in normal use

analysis of the economics of hazardous waste control in which the emphasis was theoretical; while at the other end of the scale, individual waste-related damage incidents have been investigated (see Appendix B). However, while a systematic analysis of the various environmental and social impacts of hazardous waste control techniques has not been made, the types of damage that may occur and many of the mechanisms are common to other aspects of environmental and cost-benefit analyses. Hence method of valuation may be derived from these sources.

The environmental costs and social impacts that most frequently arise from the use of hazardous waste management techniques can conveniently be divided into five categories for valuation purposes:

(i) destruction of or damage to man-made structures;

(ii) damage to human life and health;

(iii) (a) destruction of, or damage to animals, vegetation and land ecosystems,

(b) fish and other aquatic life kills in surface waters (including the impacts of ocean dumping);

(e.g., asbestos releases from brake linings and airborne cadmium emissions from smelters). Hence Moll, et al.'s study did not deal with hazardous wastes as defined herein.

(iv) changes in property values; and

(v) aesthetic factors and option value.

The first three categories (which mostly lead to "environmental costs") relate to the physical impacts that can arise from the threat mechanisms. An additional physical impact, the modification of climate, can arise from many sources (Saunders, 1976:11,31), but is unlikely to be significant in hazardous waste management.

Changes in property values may reflect actual damages (usually noise or air pollution) or they may be essentially psychological in origin, reflecting aesthetic factors. Thus changes in property values can constitute environmental costs and/or social impacts, as defined herein.

The final category is intended to cover all remaining social impacts, i.e., those that do not involve direct economic costs. It includes the aesthetic value of the environment, the "existence value" that stems from the knowledge that something exists or is being conserved, and option values associated with risk aversion and uncertainty.

Note that a single environmental impact can give rise to more than one of the above categories of effect. For example, persistent pollution of a river could cause fish kills, changes in adjacent property values and a reduction in the aesthetic appeal of the river to bystanders. Thus, the distinctions drawn above among the five categories of effects stem largely from the methods that can be used for valuation. These methods are described in Appendix C.

The Parties-At-Interest In Hazardous Waste Management

The Concept of Parties-At-Interest

In analyzing the effects of using a hazardous waste management technique or an approach to hazardous waste control, the viewpoint of man is of ultimate concern; i.e., what effects does the use of a given approach or technique have on mankind? As has been shown, these effects can range from those that are direct and straightforward, such as dollar costs actually incurred in waste disposal, to those that are highly indirect, as for example the value that many individuals place on the preservation of a natural undisturbed ecosystem, which causes them to associate a cost with the modification of that system by the introduction of waste materials. Correspondingly, the distribution of these effects can vary from those that affect a single firm to those that impinge upon the general public.

This research is oriented towards the needs of decision-makers who may have multiple criteria, including social and political goals, for the acceptability of a hazardous waste management plan. Hence, in this study recognition of different viewpoints, and a means of taking account of social interactions, is desirable. This can be achieved by grouping individuals into "parties-at-interest." Each party-at-interest constitutes a class or group of individuals or enterprises that can reasonably be expected to have a common interest and viewpoint on the outcome of any particular plan or policy alternative.[8]

For manageability, the parties-at-interest must be limited to those that are quite strongly affected by one or more of the alternatives being evaluated. Clearly the grouping of numerous individual viewpoints and attitudes into a limited number of parties-at-interest constitutes something of a blunt instrument. However, it does permit the sociological aspects of alternative plans or policies to be considered, and by being able to observe the distribution of effects among different parties-at-interest, it provides a useful foundation for considering equity.

Identification of Parties-At-Interest in Hazardous Waste Management

The parties-at-interest in hazardous waste management may be determined from the effects that would or might arise

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(8) The concept of identifying parties-at-interest and examining policy alternatives from the viewpoint of each party-at-interest was first proposed by Gilmore, et al. (1971). Other workers have also identified similarly

from the use of the various control techniques. These effects fall into two general categories: effects (such as control costs) that arise directly from the use of a hazardous waste management technique, and effects that arise via environmental impacts. Note that an environmental impact need not actually occur in order to be real from the viewpoint of the analysis. Both very unlikely "threats" and completely imaginary effects may be of importance. For example, residents near to a proposed landfill may fear that their property values would be depressed by the proximity of the landfill. Even if this fear ultimately proves to be incorrect, it is a real fear to the residents who will, therefore, respond to it in some way, and hence it is an effect to be considered.

Some economic effects, and hence parties-at-interest, arise indirectly. For example, in considering the effects of using different hazardous waste management techniques within a given industry, all the firms that use a particular hazardous waste generating process could constitute one party-at-interest; firms using another process that does not generate a hazardous waste could constitute a different party-at-interest. In this case, the effect would be via

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affected groups involved in decisions, which in some cases have been called "the actors" (see Royston and Perkowski, 1975).

changes in the competitive situation within the industry reflecting different hazardous waste disposal costs to the firms, leading to changes in production costs.

The parties-at-interest in a given hazardous waste management situation may be deduced by examining the effects of every technique that might be used to manage the wastes (including no change from present practice). Political officials and administrators in environmentally-oriented government agencies are also included as they will respectively wish to minimize dissension among their constituencies, and facilitate effective administration.

Examination of the approaches that can be used to place a value on the effects (Appendix C) may be helpful in identifying parties-at-interest. Gilmore, et al. list four groups of parties-at-interest, as follows:

- Parties, internal to the affected industry: e.g., owners, stockholders, management, employees and their unions.

- Suppliers and customers of an affected industry: e.g., vendors of materials and of services including financing, insurance and advertising, intermediate and final consumers. A more comprehensive listing may be available from an input-output analysis.

- Government: e.g., at different levels, and in different roles. Includes legislator, executor, adjudicator, taxer, regulator, and keeper of economic stability, social welfare, and national security.

- Affected bystander: e.g., resources, wildlife, recreation potential, those concerned with aesthetic effects, and those secondarily involved such as investors, employees, residents, and other property owners (or residents). (Gilmore, et al., 1971:92)

Note that Gilmore, et al., include parties-at-interest associated with secondary economic effects ("suppliers and customers of an affected industry. . ."). As already indicated, the methodology proposed in this dissertation follows the commonly accepted approach of not evaluating secondary effects. However, in cases where secondary economic effects are particularly significant, these could lead to some important parties-at-interest. Considering these parties-at-interest might enhance understanding of the sociology of the situation,(9) even if the associated secondary economic effects are not directly included in any cost-benefit calculations.

Costs and Parties-At-Interest for Hazardous Waste Management Techniques

Table 6 summarizes the more important environmental threats, costs (and impacts), and parties-at-interest associated with each technique. In specific situations, additional

(9) In a parallel situation involving a water resource planning methodology, Milliken, et al., (1977) introduced the agriculture-dependent sector of the economy as a party-at-interest because of the large multiplier effects associated with agriculture, but did not consider any other secondary economic effects.

TABLE 6. ENVIRONMENTAL THREATS, COSTS AND PARTIES-AT-INTEREST FOR HAZARDOUS WASTE CONTROL TECHNIQUES

TECHNIQUE	ENVIRONMENTAL THREATS	PARTIES-AT-INTEREST	MAJOR COSTS, ETC.	COMMENTS
All techniques	Surreptitious dumping or accidental discharge to land, sewer or waterway In-plant accidents involving fire, explosion Acute and chronic poisoning	Waste generators-management Waste generators-workers Competing firms using different process Waste disposal industry Local political officials Local environmental officials Water supply authorities Environmentalists	Capital and operating costs for waste disposal (internal costs to generator)	
All techniques involving off-site activities	Surreptitious dumping Accidental spillage (to land or water)	Waste transporters Residents along transport corridors	Transport cost	
The Threats, Parties-at-Interest and Costs Identified Below are in Addition to Those Listed Above				
Change in waste streams		Secondary materials industry		May facilitate resource recovery
Resource recovery		Secondary materials industry Virgin materials suppliers		Resource recovery may have adverse effect on energy usage

Table 6 continued...

(p.2 of 4)

TECHNIQUE	ENVIRONMENTAL THREATS	PARTIES-AT-INTEREST	MAJOR COSTS, ETC.	COMMENTS
Treatment to reduce hazard	Treatment may fail leaving waste still hazardous (most likely with biological treatment)	Fishermen (where effluent is discharged)	Additional capital and operating costs for necessary processes, less value of any resources recovered	
-physical				Increased energy usage likely
-chemical		Chemical suppliers		
-biological				
-thermal	Air pollution	Local residents/workers Local property owners		Possibility of energy recovery
-encapsulation				
Land application	Crop take-up of toxic elements Soil sterilization Leaching/run-off Odor	Farmers Local water supply users Residents/workers/ property owners adjacent to land Fishermen?	Aesthetics Poisoning via food chain Water contamination	Any nutrients, etc., present may enhance crop growth
Landfilling	Leaching/run-off Odor Vector?	Local water supply users Local residents/workers/ property owners Fishermen?	Water contamination Aesthetics	Need to consider opportunity cost of land
Mine Disposal	Leakage to groundwater	Holders of adjacent mineral rights	Groundwater contamination	Need to consider opportunity cost of mine

Table 6 continued... (p. 3 of 4)

TECHNIQUE	ENVIRONMENTAL THREATS	PARTIES-AT-INTEREST	MAJOR COSTS, ETC.	COMMENTS
Lagooning (for storage or evaporation)	Leaching Overflow Odor and air pollution	Residents/workers/ property owners adjacent to site Local water supply users Fowl hunters Farmers?	Water contamination Aesthetics	Need to consider opportunity cost of land
Deep Well Injection	Groundwater contamination Land movement and consequent property damage	Authorities concerned with resource usage Local residents/property owners Scientists	Groundwater contamination Property damage	There may be an opportunity cost to using the aquifer
Ocean dumping	Modification of marine ecosystem	Ocean fishermen Ocean recreationalists Coastal recreation-related industry Local residents/workers/ property owners Scientists Other nations, national politicians	Reduced or inedible fish catch Reduced tourist income Aesthetics Possible international political strife	
Engineered storage	Containment failure	Local residents Local water supply users?	Maintenance after disposal is completed Water contamination	Requires perpetual monitoring and maintenance

Table 6 continued...

(p.4 of 4)

TECHNIQUE	ENVIRONMENTAL THREATS	PARTIES-AT-INTEREST	MAJOR COSTS, ETC.	COMMENTS
Space disposal	Contamination of space Launch failure consequences	Scientists Other nations, national politicians	International political strife Unknown scientific costs	
Discharge to sewer	Waste may destroy biological treatment colonies Waste may cause sewage sludge to become hazardous "Slugs" of waste may overload system	Sewer authorities	Malfunction of sewage works and consequent damage	Not normally legitimate hazardous waste management techniques, but included because a treatment process may fail resulting in a hazardous effluent, or they may be used covertly
Discharge to waterway	Waste may destroy aquatic life	Fishermen Other water users Local recreation-related industry Residents/workers/ property owners adjacent to waterway Local water supply users? Scientists?	Aesthetics Reduced recreational opportunities	

threats, costs and parties-at-interest may be important. Table 6 includes disposal to the sewer and to surface waterways. While these would not normally be options legally available to the hazardous waste generator, they might be used illicitly or for wastes that have been treated to render them non-hazardous. Since it is possible that the treatment system could fail, these disposal possibilities may be of some concern.

Certain costs and parties-at-interest are present for every available technique; for example, the firms generating the waste will always have some disposal costs and their managers and workers will always be parties-at-interest. This does not imply that the costs, or the posture of the firm will be the same for each technique. Similarly, it can be assumed that local government and environmental agencies will be interested in every technique that might be used. The term "local," in this context, means having jurisdiction over the location at which the technique is employed, hence different local officials may be parties-at-interest to different techniques. Similar considerations apply every time the term "local" is used (e.g., local residents, local property owners, etc.). These parties-at-interest are the individuals that are close enough to the location of the technique under consideration to potentially be affected by it.

The potential for fresh water contamination occurs with many of the techniques, giving rise to associated costs. Where water contamination costs are listed in Table 6, these costs can include the contamination of water supplies (from surface or groundwater sources) for human or agricultural use, and the pollution of other surface waters. The cost involved in the first case can include installing replacement sources of drinking and agricultural water, corrosion and materials damage costs (to pipes and appliances), foregoing the use of water or continuing to use the contaminated water and accepting lower crop yields and values (for agricultural irrigation) and aesthetic costs.[10] The costs associated with the pollution of surface sources not used for water supply can include fish kills, devalued recreational opportunities, environmental aesthetic costs and loss of future options.

Clean-up or mitigation costs could be involved where there is any form of contamination. These costs can be particularly expensive for groundwater sources which cannot feasibly be treated after withdrawal. In this event normal procedure is to counterpump wells drilled to intersect the

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(10) Persons who use their own well water may consider it aesthetically more satisfying than piped water, and hence suffer an aesthetic cost if they are forced to obtain water from public systems.

plume of contaminated water, and then dispose of this water; a procedure that is not always entirely successful (U.S. Environmental Protection Agency, 1977c:164; Miller, 1974).

The Socioeconomic Interaction Process

The Interaction Model

This section presents a simple model, or way of looking at the interactions between the technical (i.e., physical) aspects and the economic and social aspects of hazardous waste management. The purpose of the model is to enhance understanding of the relationships between hazardous waste management policy, what physically happens to the wastes and the effects that this has on society. The model is a conceptual one, and is not intended as the direct basis for any calculations.

The model is illustrated in Figure 5. It is divided into three sections, or levels. These are the policy level, the technical level and the socioeconomic level. The policy level is concerned with the philosophy of how hazardous wastes are to be managed. Decisions at the policy level are largely responsible for determining what goes on at the technical level, which deals with what physically happens to the wastes and to the environment. In turn, actions at the technical level have effects at the socioeconomic level, i.e., on

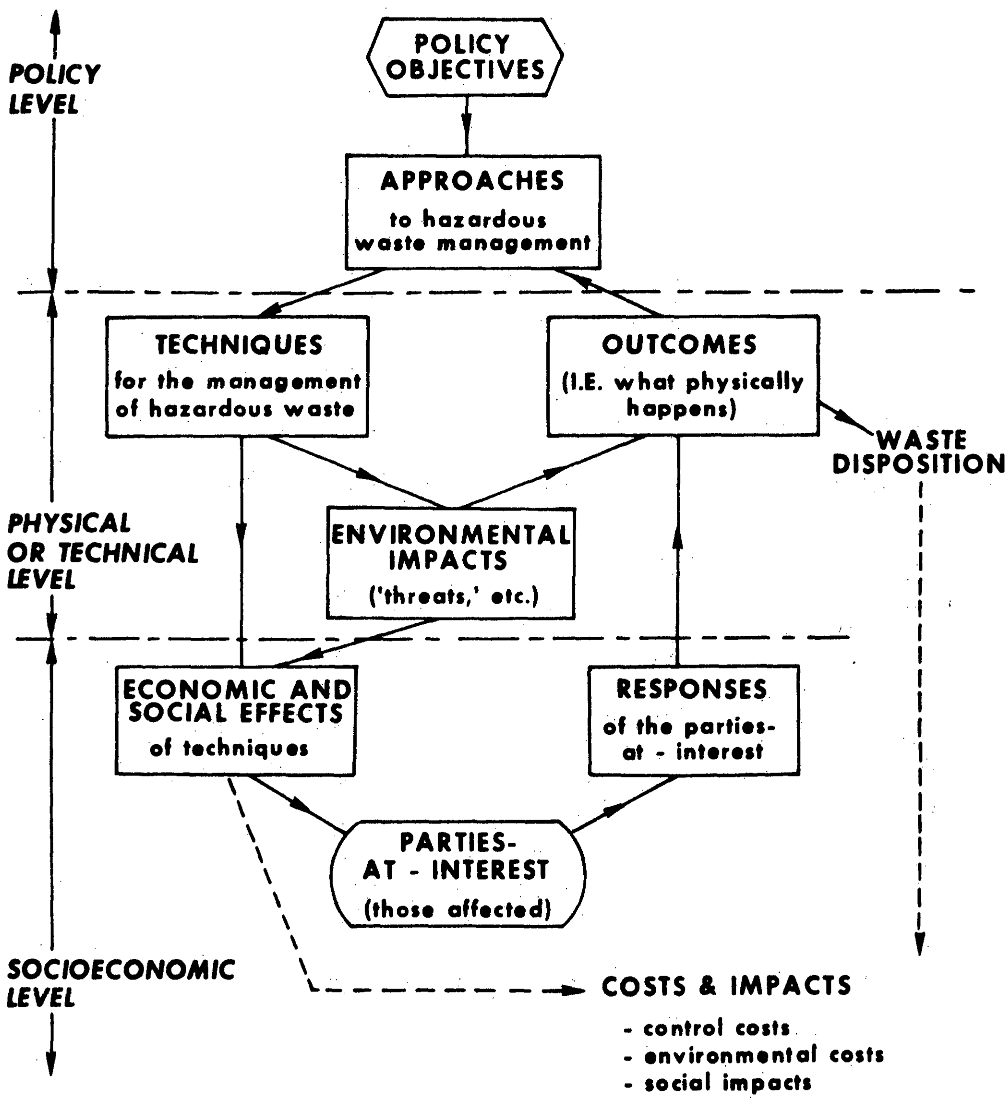

FIGURE 5: Interaction Model for Hazardous Waste Management

society. There is feedback from the socioeconomic level to the policy level via the technical level.

The elements in the model and the linkages between the elements are briefly described below. Most of these elements are discussed in more detail elsewhere.

Policy Objectives

Policy objectives, dealing with normative issues, are considered to be an exogenous input to the model (see Chapter 3).

Approaches to Hazardous Waste Management

The approaches to hazardous waste management represent strategies for the control of hazardous waste that are consistent with the policy objectives. Approaches may favor the use of certain techniques (see Chapter 3).

Techniques for the Control of Hazardous Waste

Techniques are the physical methods (e.g., treatment, landfilling) that may be used to manage or control hazardous waste (see Chapter 1 and Appendix A). They may include environmentally unacceptable techniques, such as surreptitious dumping. The use of a given technique results directly in control costs (one of the economic and social effects); and also causes or has the potential to cause environmental impacts.

Environmental Impacts

Environmental impacts are the physical effects, or potential effects, that could arise from the use of various hazardous waste management techniques. They occur largely in the form of "threats." (Threats were discussed early in this Chapter, and in Appendix B.) In addition, "pervasive effects" that relate to resource use may be of interest. Thus, although the economic aspects of energy or materials consumption attributable to the use of a technique are accounted for via the control costs (including any credits for resource recovery), these topics may be of specific interest, calling for individual treatment. The same argument applies to land use, which is another aspect of resource use. Note that if the emphasis is on conservation of resources, some "base case" will be needed for comparison.

Economic and Social Effects of the Techniques

The economic and social effects are the effects that the techniques have on man. These effects give rise to costs and impacts (i.e., control costs, environmental costs and social impacts, discussed earlier in this Chapter). In addition, man may have a special interest in certain aspects of resource use, discussed above.

The Parties-At-Interest

The economic and social effects will affect different groups of individuals or enterprises in different ways.

Each group that is relatively homogeneous in terms of its interests and attitudes and in the way that it is affected by the economic and social effects of the techniques constitutes a party-at-interest. (Parties-at-interest were discussed earlier in Chapter 2.)

Responses of the Parties-At-Interest

The various parties-at-interest will respond to the economic and social effects in ways that will be determined by their interests and attitudes. Responses could include opposing or supporting a scheme or policy, choosing a waste disposal technique, changing business activities, moving to another location to avoid an adverse effect, etc. (Responses are discussed later in this chapter.)

Outcomes

The outcomes represent what physically happens in terms of hazardous waste management, allowing for all the interactions and linkages that exist in practice. Thus prediction of outcomes involves determining what is likely to happen to the various hazardous wastes, i.e., how much will be disposed of by each technique and the extent to which waste generation will change as the result of using any particular approach to hazardous waste management. The outcomes also include the environmental effects that occur or are threatened.

There is feedback from the outcomes to the approaches to hazardous waste management. When a decision-maker predicts or observes the outcomes that result from a given approach to hazardous waste management, he may wish to modify that approach to change the outcomes and the associated economic costs and social impacts. (Outcomes and the complete interaction process are discussed in Chapter 3.)

Attitudes Towards Hazardous Wastes and Their Management

To be able to predict responses of the parties-at-interest, and hence to determine likely outcomes of approaches to hazardous waste management, it would be desirable to know something about the attitudes that individuals have towards hazardous wastes and the environment.

Only one study has specifically addressed public attitudes towards hazardous waste management facilities. This extensive study surveyed both a random sample and selected influential respondents in ten U.S. counties that were considered feasible locations for national disposal sites (NDS) (Lackey, Jacobs and Stewart, 1973). The study reported generally favorable attitudes towards both the NDS concept, and towards location of such a site in all counties surveyed; these favorable attitudes appeared to relate to the beliefs that an NDS would conserve material resources and result in a strong local economy (i.e., provide employment) (Lackey, Jacobs and Stewart, 1973:48). However, during the testing of the questionnaire it was found that the term "disposal" had negative connotations for the respondents, and accordingly NDS were described as "regional processing facilities" in the survey instrument (Lackey, Jacobs and Stewart, 1973: 12). This situation does raise the question as to whether or not the respondents really understood what they were being asked. If not, the attitudes reported by Lackey, Jacobs and Stewart might change when the issue becomes clearer.(11)

It was initially hoped that a study of attitudes towards nuclear power (and nuclear wastes) and towards hazardous-waste-generating industries (such as the chemical industry) would provide useful information on attitudes to hazardous wastes. The intention was to use the chemical industry as a proxy for a hazardous waste management facility; and to draw parallels between nuclear power, with its radioactive waste disposal problem, and non-radioactive hazardous waste disposal. Other than for nuclear power, no appropriate material on attitudes towards waste-generating industries was found.

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(11) If the issues are not understood by the public their responses are unlikely to be valid. As one authority said--"it is almost meaningless to study either attitudes toward hazardous wastes or willingness-to-pay for hazardous waste control, without making certain that the public really understands what is involved. . . attitudes, etc., are meaningless if the public is not well informed about the attitude object." (Dunlap, 1977)

While there have been many attitudinal studies relating to nuclear power (several of which have included the question of nuclear wastes) it was concluded that attitudes towards nuclear power would be of very limited value in predicting attitudes towards non-radioactive hazardous wastes, and their management. This is because several studies have suggested that the public associates the possible discharge of radioactivity from nuclear power plants and wastes with the effect of nuclear weapons (Pahner, 1976; Louis Harris and Associates, Inc., 1976; Rappeport and Labaw, 1975; Slovic and Fischhoff, n.d.:21). While hazardous wastes comprising obsolete chemical warfare and ordnance materials could to some extent pose an analogous type of threat, in general reactions to nuclear facilities are far too extreme to be appropriate for non-nuclear hazardous wastes. However, there is one finding about nuclear power plants that may be applicable to some hazardous waste management facilities. That is, that familiarity can evidently breed acceptance; those living near to a nuclear reactor perceived it as safer than those living further away (Maderthaner, et al., 1976).

As a result of the paucity of data that could provide specific guidance on attitudes towards hazardous wastes, a broad survey of research on attitudes to the environment was undertaken. This survey provided some general guidance on the attitudes and priorities of the general public and some special interest groups (i.e., parties-at-interest) towards pollution problems (Taylor and Avitable, forthcoming). Based on these findings, the EPA-sponsored meetings on hazardous waste management (see Chapter 1) and the material discussed above, Table 7 presents some generalizations about the likely attitudes and behavior of various parties-at-interest.

Responses of the Parties-At-Interest[12]

The responses of the parties-at-interest are very closely related to the economic and social effects that arise directly or indirectly from the use of the various hazardous waste control techniques. Although human behavior is not always predictable, it may be possible and useful to identify likely responses of the parties-at-interest to the various economic and social effects that they experience.

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(12) Unless indicated otherwise, the views expressed in this subsection are those of the author. They are based on the same sources as Table 7, supplemented by insights gained from the author's background of working with firms in the manufacturing industries and from his experiences in relation to hazardous waste management during the course of this research (largely in the northwestern U.S.A.).

TABLE 7. GENERAL ASSUMPTIONS ABOUT THE ATTITUDES AND BEHAVIOR OF THE PARTIES-AT-INTEREST

1. Firms desire to minimize their internal costs, including management costs.

2. Wastes are a "nuisance" to manufacturing firms which, in most cases, will not devote much effort to their disposal, unless this represents a significant cost to them, or if there is a significant risk of public opposition to the firm or its products because of its waste disposal practices.

3. In selecting a waste disposal technique, firms will tend to favor those in which they can dispose of the responsibility for the waste along with the waste.

4. Large firms are the most likely to be environmentally responsible, as they have high public visibility. Smaller ones are more variable in their concern for the environment.

5. Workers are concerned with their own physical safety and with security of employment. Often, however, the latter outweighs the former in determining their actions.

6. Local government and environmental officials prefer to adopt policies that minimize the risk of adverse incidents (i.e., they are strongly risk-averse).

7. Wastes are politically negative, local politicians prefer them to go elsewhere.

8. Residents are concerned with property values. They fear that nearby waste processing or disposal sites will depress property values.

9. Residents are generally uneasy about wastes. They often object strenuously to wastes from another jurisdiction, especially another state.

10. Residents have some interest in local employment, tax base, etc.; but the strength of this interest tends to depend on the employment history in the area. Local politicians and businessmen often have strong interests in these areas.

(p.1 of 2)

Table 7 continued... (p.2 of 2)

11. Environmentalists wish to minimize all environmental risks and tend to resist change, with only limited concern about costs.

12. Environmentalists exhibit high "existence values" and may claim that no compensation would be great enough to justify some adverse environmental impacts.

13. The public has become cautious about new technologies, especially those that they do not understand. They are more accepting of established technologies (hence, the "chemical industry" is less threatening than nuclear power). Public credulity towards scientific expertise is declining.

14. In some cases, those close to a facility that is perceived to be hazardous are less concerned about it than those that are somewhat further away.

15. The public favors conservation and recycling. Most, but not all, accept the need to dispose of some wastes. However, few individuals are prepared to go to great lengths to promote their ideals.

Responses to Positive Effects

Many of the impacts that would be regarded as positive (i.e., beneficial) by the parties-at-interest are comparatively weak and are unlikely to elicit an active response. For example, assume that it is proposed that one class of firm be required to use a costly process to dispose of its hazardous waste (a strong negative impact on these generators). Competing firms that use a different process which does not generate hazardous waste will perceive a mild positive impact (since the competitive situation will be changed in their favor). However, these competing firms are likely to be passive in taking advantage of this situation, and probably would not publicly support the proposal (in part for fear that "they might be next"). On the other hand, the hazardous waste generators are likely to protest the proposal (on the grounds that it will weaken their competitive position) and to exert whatever pressure they can to get it modified.(13)

Perhaps the only category of positive impact that is likely to trigger a strong response is that of an impact on

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(13) This type of behavior has recently been demonstrated in the U.S. steel industry. Several plants have had difficulty in meeting air and water effluent standards, and have asked that variances be permitted on the grounds of economic hardship. On the other hand, firms whose plants have had little difficulty in meeting these standards have remained

an environmentalist. Environmentalists tend to support actions that they perceive as positive by interaction at public meetings and through the political process.

Responses to Changes in Generator's Costs

Any change in generator's costs (for hazardous waste disposal) must either be absorbed by the firm or reflected in product prices, or both. If the change were an increase, internal absorption would reduce the firm's earnings and weaken its position in the capital market to the ultimate detriment of the shareholders; while an increase in product price would reduce unit sales to an extent that would depend on the price elasticity of demand.(14) If the long-run elasticity were known and the firm were assumed to be a profit maximizer, it would theoretically be possible to determine the extent to which the firm could pass an increase in costs on to its customers. Some manufacturing firms (primarily those that make non-differentiated products) have little control over the prices that they receive for their

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comparatively quiet on the subject. [Some background data on environmental problems in the steel industry is provided by Cannon (1974)].

(14) The long-run elasticity is the most relevant as the changes being considered are essentially permanent changes in the firm's cost structure and hence in its prices. This elasticity will in turn depend on the competitive situation, e.g., if the product has no close substitutes and can only be made by a process that generates hazardous waste (so that all the manufacturers face similar cost changes), demand

products; but even where this is not the case, pricing decisions are not always made on the basis of maximizing profit (Kotler, 1967; Backman, 1965). Indeed, some marketing authorities claim that manufacturing costs are one of the last factors considered when selecting a consumer product price. (Oxenfeldt, 1960.) Hence, prediction of a firm's response to a change in costs may not be an easy matter.

Fortunately, it appears that the costs of adequate hazarduous waste management are often a small proportion (e.g., of the order of one percent) of the value of shipments (U.S. Environmental Protection Agency, 1974b:30) and hence in many cases it may be possible to neglect the effect, even though small changes probably have an effect on pricing in the long run. Where changes in hazardous waste management costs could represent a significant proportion of the product price, an examination of the pricing structure of the relevant industry would be desirable to establish likely behavior.

Response to Negative Impacts

The category of impact that appears to be the most likely to evoke an active response is that of a negative impact via an environmental threat. Responses are likely to include local opposition to the siting and operation of

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will be inelastic. However, it the product has close subsitutes or is also made by processes that do not generate hazardous waste, demand will be elastic.

most hazardous waste management facilities,[15] but avoidance actions (e.g., moving to another house) are only likely when the threats become realities. Nizard and Tournon (1974) have developed a simple model (presented in Figure 6) that predicts the circumstances under which an individual will tolerate pollution, and those under which he will be predisposed to respond again it.

Environmentalists usually respond vigorously to perceived threats, and are likely to be joined by other groups strongly affected by threats (e.g., fishermen where there is a threat to surface water quality). In addition to political actions, these parties-at-interest may use the judicial process to delay or halt projects.[16] Responses of local administrative officials, etc., are likely to be

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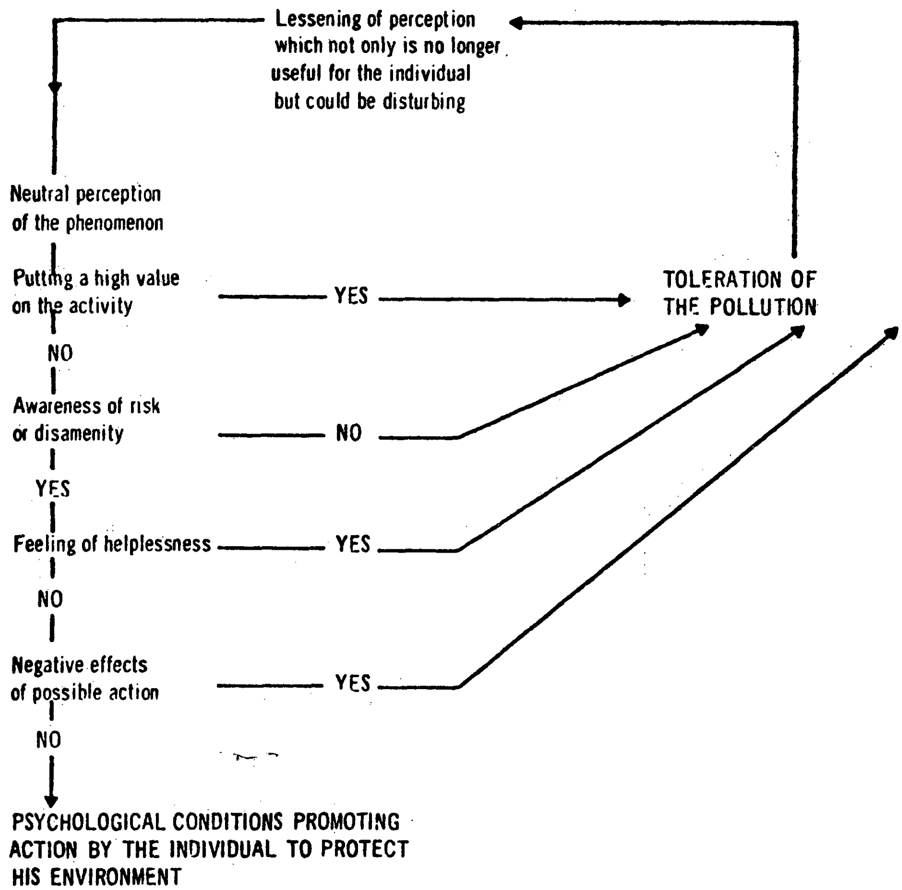
(15) There is strong evidence that local residents, etc., frequently object to chemical landfills. There is evidence to extend this to lagoons and to some hazardous waste storage facilities. (See Appendix C.) Under some circumstances resource recovery facilities could benefit from the positive connotations associated with the concept of resource recovery, but this could easily be degraded by negative experiences. Alternatively, a resource recovery operation might merely be regarded as a regular manufacturing plant. For example, one such operation claims that nearby workers and residents "see us as just another chemical plant" (West, 1977).

(16) As noted by Hardin (1974:180,181), environmental organizations such as the Audubon Society and the Sierra Club can put their views before administrators and lawmakers or go to the courts, but cannot directly enter the political process for fear of jeopardizing their tax-exempt status.



SOURCE: Nizard and Tournon, 1974:308.

FIGURE 6: Model for Pollution Toleration

more subdued and could include such tactics as "negation by delay." There have, however, been a number of moves by political officials to prevent the disposal of wastes within their jurisdictions, and even to prevent their movement across them.

Again, when and if the threats materialize, fishermen, tourists and the like will avoid polluted areas, while even if there is no official pronouncement on the matter, the public may reduce their consumption of suspect fish and game [for example, some pollutants, such as phenols and certain heavy metals, give fish a bad taste or smell (Cannon, 1974:95-106)].

CHAPTER 3

GENERAL METHODOLOGY FOR ANALYSIS

This section outlines a methodology that may be used by a decision-maker to evaluate the effects of alternative approaches to managing hazardous wastes.

Introduction

The primary objective of the methodology is to provide a "framework" for the analysis of hazardous waste problems that is based on economics and that is cognizant of social factors. The methodology is intended to assist a decision-maker to systematically examine various alternative approaches to controlling hazardous waste; to determine the nature, and as far as possible, the magnitude of the various effects that can occur, and thereby to make informed and balanced hazardous waste management decisions.

The methodology is referred to as a "framework for analysis" because it provides structure and method for analysis, but it does not attempt to determine an "optimum solution." Choice between alternatives remains the prerogative of the decision-maker, who can make his own "trade-offs" and introduce whatever degree of risk aversion that he favors. Indeed, the concept of an "optimum solution" (in the mathematical sense) is of limited value in hazardous waste decision-making; since where there are both economic and social considerations, decisions are normative, i.e., they involve value judgments. Such judgments are necessary because the various impacts fall upon different parties-at-interest, thereby introducing questions of equity. Also, there is the question of risk; different persons will have various attitudes towards risk-taking, and hence will require different benefits to offset a given risk. While an optimum solution could be determined if rules for decision-making were specified, in this methodology the decision-maker is encouraged to develop his own criteria on a case-by-case basis. Another feature of this approach is that although it is possible to place dollar values on changes in environmental features, the available techniques and data do not generally permit these valuations to be made with much confidence, and hence once again judgments are likely to be necessary.

Thus, situations of the types encountered in hazardous waste management call for a systematic analysis of the various possibilities in such a way as to provide a decision-maker with information about the trade-offs between the various alternatives. The decision-maker can then use his own norms, or norms that he believes are representative of agency policy, to select an approach that satisfies whatever policy objectives may exist.

This methodology attempts to provide a decision-maker with the information that is needed to make normative decision of the type outlined above. It was developed with an orientation towards decision-making for the management of hazardous industrial wastes on a regional or local basis. However, it could quite readily be adapted to apply to special categories of hazardous waste, or to the waste management of a specific industry, possibly on a national basis. It is not appropriate to determining whether or not a particular substance should be manufactured or to what extent it should be used (e.g., the use of PCB's) and this type of problem has been addressed by other studies (e.g., Kennedy, et al., 1976; National Academy of Sciences, 1977; Moll, et al., 1975). The distinction is that the cost- or risk-benefit studies mentioned above examine the "cradle to grave" costs and benefits of using a particular material, whereas this study essentially addresses only the problem of dealing with hazardous wastes once those wastes have been created.

Theoretical Considerations

There are some concepts from economic theory that, although difficult to apply in practice or subject to debate, provide useful insights for hazardous waste management decision-makers, and for this reason are discussed here. These are Pareto optimality and market failures, and the treatment of intertemporal effects.

Pareto Optimality and Market Failures

The Pareto Criteria

The concept of "Pareto optimality" constitutes the apogee of planning goals in welfare economics.[1] Although it is unrealistic to expect a real economic system to be Pareto optimal, the concept is worth examining as it provides useful guidance for decision-making.

The basis of Pareto optimality is that a situation is optimal (or "efficient") when no one can be made better off without at least one person being made worse off. Herfindahl and Kneese (1974:40-54) provide a useful discussion of Pareto optimality, and show that it implies the following:

(1) Efficiency in production. It is impossible in an optimum to increase the production of one good without decreasing the production of at least one other good.

(2) Efficiency in distribution. It is impossible in an optimum to redistribute the goods among the consumers, so that one consumer is better off while no other consumer is worse off.

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(1) Welfare economics has been described as ". . . the theory of how and by what criteria economists and policy-makers make or ought to make their choices between alternative policies and between good and bad institutions" (Arrow and Scitovsky, 1969:1). Consequently, hazardous waste decision-making by public officials falls within its purview.

(3) Allocation of resources in accordance with consumer preferences.
(Herfindahl and Kneese, 1974:41-42)

It can be shown that there is no unique Pareto optimum, as an optimum depends on the initial conditions (Herfindahl and Kneese, 1974:41). Since arrival at an optimum may be too much to expect in practice, projects can be examined for Pareto improvements, which occur if some economic change makes one or more persons better off without making any worse off (Mishan, 1971a:311).

Because of the difficulties inherent in arriving at a Pareto optimum or making a Pareto improvement within a real economic system, the concepts of a potential Pareto optimum and a potential Pareto improvement are often substituted as planning goals or tools. A situation is said to be potentially Pareto optimum[(2)] if it could be transformed to Pareto optimality merely by making economic transfers between individuals, i.e., that ". . . that gainers be able to more than compensate losers" (Mishan, 1971a:316). The acceptability, or otherwise, of any given distribution of costs, benefits, income, etc., becomes the subject of some other criteria of welfare. Inevitably, these criteria are normative, and distributional questions are considered as "equity" in this methodology.

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(2) This is also known as the Kaldor-Hicks criterion (see Haveman and Weisbrod, 1975:41).

The Problem of Market Failures

It can be shown that perfect competition and its associated marginal cost pricing leads to Pareto optimal conditions. However, there may be circumstances in which major divergences from this situation occur, and these are termed "market failures." The failure that comes readily to mind is that of monopoly, as it is well known that where a monopoly exists it is in the monopolist's interest to price goods at a level that is higher than the marginal cost of production. Thus in attempting to arrive at an optimal solution, it would be necessary to replace market prices by those based on marginal costs.

A particularly difficult problem arises where the monopoly is a "natural monopoly," i.e., where long-run average costs decrease with increased output. In this case, the monopoly could not use marginal cost pricing unless it were given a subsidy, as the marginal cost would be below the average cost, and the monopoly would be incapable of recovering all its costs. This situation occurs where there are economies of scale over the entire range of output that is of potential interest. Many public services, such as sewage disposal and electricity supply can be natural monopolies, and monopoly situations (both natural and otherwise) could well arise with some techniques for hazardous waste disposal.

For example, high temperature incineration facilities suitable for hazardous waste might fall in this category, as they are comparatively capital intensive, and unless there were particularly large volumes of waste generated in one location, a high temperature incinerator would be likely to establish a monopoly within a zone of influence determined by transport costs.

Landfills constitute a rather interesting situation, because to some extent their operation resembles the mining of a mineral deposit. Because of the finite capacity of a landfill the variable costs should include an element of "depletion" to allow for the consumption of a resource.(3) Even so, there seems no reason why marginal costs should rise with the volume of waste handled for most chemical landfills, with the result that both their pricing and behavior are likely to reflect elements of monopoly. Since fixed operating costs (e.g., licensing, environmental monitoring

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(3) It follows from this analogy that if the landfill is analyzed as an isolated entity (i.e., not subject to replacement when full) that the optimum economic efficiency can be achieved by operating at the lowest average total unit cost, and not where the marginal cost is equal to the marginal revenue (and equal to price for perfect competition) (Gray, 1914). In practice, the time value of money shifts this optimum towards a higher rate, but still one that is lower than that given by the criterion of marginal cost equal to marginal revenue (Carlisle, 1954).

and security) can be comparatively high, the marginal and average costs could differ significantly.

The second important area of market failure is where prices do not reflect "externalities." Free use of environmental resources, such as the pollution assimilation capabilities of a river, provides a classic example of an externality (or "spillover effect" as it is sometimes called). If the waste generator does not pay for the use of the environment (which is a cost to society, since some individuals are damaged by a degraded environment) his production costs (known as his "internal costs") will be lower than the true costs, and consequently he will produce more of the good than is societally efficient (i.e., Pareto optimal). Further, under these circumstances there is no incentive for efficient use of the environment: since it is free to the generator, he will theoretically use whatever quantity it takes to minimize his unit production cost. (For a detailed analysis see Barnett and Morse, 1963:101-125.) Since the environment generally has a limited restorative or treatment capacity, this can lead to a "commons situation" (Hardin, 1968) in which such capacity is overloaded because no individual user has sufficient incentive to reduce use.

A key part of the methodology described in this report is to identify and, if possible, evaluate such externalities.

Further, some approaches to hazardous waste management may involve the use of incentive means, such as user charges and effluent fees, that "internalize" these externalities. However, the question that is pertinent here is what adjustments, if any, should be made to data where there are uncompensated market failures? There is some debate about the extent to which "shadow prices" should be used in cost-benefit analysis, where such prices are non-market prices, e.g., prices based on marginal costs and benefits that fully reflect externalities (McKean, 1968). The differences between shadow and market prices will affect quantities of products and wastes produced (Freeman, Haveman and Kneese, 1973:72-76). While shadow prices may be necessary to evaluate Pareto optimal conditions, the problem is that once one adjustment is made to one price, then output, consumption of other products, other prices, etc., will also change. In short, something of a chain reaction will be set off. Unfortunately, if there is a departure from one of the Pareto optimal conditions, it can be shown that a "second best" optimum situation can be achieved only by departing from all other optimum conditions (Lipsey and Lancaster, 1956), and it may be a complex task to find such an optimum (Herfindahl and Kneese, 1974:54; Mishan, 1971a:91).

The analyst or decision-maker has two interests when he identifies a second best situation. First, what should he do if he has control over pricing, and second how should he conduct his evaluations if he does not have that control? The pragmatic answer to the first question is that where he can control prices (through some policy means) it is probably more efficient to move towards marginal cost pricing, even though this is not employed in other sectors of the economy (see Price, 1977:31-42; Bohm, 1973). In the second case, it is the author's view(4) that the analyst should be cautious about substituting shadow prices for market prices in evaluations, unless the market failure is clearly a major one.(5) Of course, external costs (such as environmental costs) should be included in the evaluation, which will partly correct the deviations from optimal conditions; while the analyst can also seek strategies that endeavor to eliminate market failures.

Ultimately, however, one should not lose sight of the fact that most analyses involve making changes from an

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(4) The literature provides some support for this viewpoint (See McKean, 1968).

(5) One purely practical reason for not using shadow prices in an evaluation is that a project is more likely to be accepted by the various parties concerned if the analysis is straightforward and readily comprehensible.

existing (non-optimal) situation. Provided that the new situation represents a potential Pareto improvement, society has gained and hence the analyst need not be too inhibited by the second best theorem (Mishan, 1971a:96). (For more detailed treatments of these topics, see Mishan, 1971a, b; Scitovsky, 1951; Arrow and Scitovsky, 1969; Price, 1977; Bohm, 1973; Chase, 1968.)

Intertemporal Considerations

It is very widely accepted that the discounted cash flow (DCF) approach is an appropriate technique for evaluating the economics of business projects where income and expenditures do not coincide in time. The approach is based on the concept that future income is "less valuable" than present income, and correspondingly that future costs are less onerous than current costs, since in the intervening period the capital could be invested in some other way. Thus the "discount rate" chosen for any evaluation should be related to the opportunity cost of capital.(6) (For further information on this topic, see Taylor, 1964; Merrett and Sykes, 1963; Stermole, 1974.)

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(6) This argument does not presuppose the existence of inflation, and is therefore applicable to costs and revenues expressed in constant dollars. In the event that under conditions of inflation costs were expressed in current dollars, the discount rate would need to be increased (see Merrett and Sykes, 1963:213, et seq.)

The same basic concept can be applied to cost-benefit or cost-effectiveness studies of public investments; however, in this case some difficulties can arise over the choice of an appropriate discount rate. There are two major aspects to these difficulties; (i) the question of the use of a "social" discount rate, and (ii) whether or not the discount rate should be raised to reflect risk.(7)

The "Social" Discount Rate

If for the moment one disregards the question of risk and considers risk-free projects, there are two principal opposing views on the use of a "social" discount rate that is lower than the business rate (after paying corporate income tax). On the other hand it is argued that the private market decisions generally favor the short term and do not make sufficient provision for the future, leading to a rate of consumption that is too high (Krutilla and Fisher, 1975:62). Hence, a lower or "social" discount rate is proposed in order to adjust private preferences for consumption versus investment or conservation (as expressed in the private discount rate) to a time preference that is deemed appropriate for society as a whole. (Marglin, 1963.) Another argument that arrives at the same conclusion is that

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(7) In the literature that addresses the capital market, the term "risk" is used to denote any uncertainty.

because of positive externalities, capital put to public use often has a higher social rate of return than the same capital put to private use. Hence, it is claimed that a lower discount rate is needed to stimulate social projects[8] (U.S. Congress, Senate, 1974:49; Musgrave and Musgrave, 1976:174). Clearly, the extent of any externalities depends on where the boundary for evaluation of the project is drawn. However, as Arrow and Kurz (1970:2,3) point out, the benefits of (say) cleaner water may be spread so wide that it would be impracticable to devise a way of charging for these benefits, and correspondingly it would probably be difficult to value the benefits.

On the other hand it is argued that the correct discount rate is the opportunity cost of capital based on the returns when the project resources are put to alternative uses. Thus it is claimed that to use a low "social" rate of discount on public projects will divert capital from the private sector to the public sector, leading to a distribution of investment that is not optimally efficient (Musgrave and

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(8) The requirement for a lower discount rate to stimulate social projects (as opposed to private projects) stems from the long time scale over which some social projects operate (e.g., water resource developments), and the pattern of expenditures and benefits (which are equivalent to income). This pattern usually involves heavy expenditures in the early years of the project, while the benefits are usually small in the early years but continue for a long time.

Musgrave, 1976: 172-177). The need for shadow prices and other devices associated with "second best" is avoided by the use of a market rate (Musgrave and Musgrave, 1976:172-180).[9]

Adjustment of the Discount Rate for Risk

In assessing business projects, it is a common practice to raise the discount rate (or the minimum acceptable internal rate of return) as one method by which to allow for uncertainty associated with the project.[10] Correspondingly, it is assumed that an investor will demand a higher rate of return (expressed as an expected value) from a "risky" project than from a "safe" one. Thus investment criteria will reflect investors' risk aversion by including a risk premium in the discount rate.

Similar arguments can be applied to public projects, and some authors hold that public projects should be assessed in exactly the same way as private projects, in order to avoid the capital diversion effect already mentioned. The

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(9) Decision-making under second best conditions, i.e., where the social and private business discount rates diverge, has been addressed by several authors. (See Mishan, 1971a; Eckstein, 1958; and Herfindahl and Kneese, (1974:204, et seq.).

(10) Uncertainty can arise from numerous factors such as the magnitudes of the expenditures and revenues, and the timing and duration of the phases of the project as well as the possibility of "catastrophic" events (such as a major uninsured accident).

alternative contention is that public investment criteria should not include a risk premium. Several arguments can lead to this position, including the claims that the private capital markets are so imperfect that they give no useful information about individuals' risk preferences, and that many of the risks in the private sector (such as "moral risks") do not exist in the public sector (Arrow and Lind, 1970). However, there are three major arguments for the "risk free" approach. First, that governments invest in a great number of diverse projects which enables them to pool risks to a far greater extent than the individual investor (i.e., the government acts as its own insurer). Second, that a government distributes the risk associated with any one project over such a wide range of individuals that the total cost of risk-bearing is insignificant. Third, that the state is more than a mere collection of individuals and has an existence and interests apart from its individual members, and that government policy therefore need not reflect the risk aversion of individual preferences (Arrow and Lind, 1970).

More extensive discussions of both these difficulties and of some possible solution may be found in Herfindahl and Kneese (1974:204-221) and in Krutilla and Fisher (1975:61-75). However, when all the arguments are analyzed, most observers would probably draw the conclusion that the "correct" (or better, most appropriate) solution to the social rate of discount question will depend on the nature of the project involved, and that while arguments for using a risk free discount rate may predominate, there can be circumstances where a risk premium is appropriate for public projects. To a large extent, these answers will depend on the degree of competition with the private sector; for example, evaluation of the "perpetual care" costs of storing long-lived wastes might use a low "social" discount rate, while evaluation of a project to install an incinerator as an alternative to landfill might use a "risky" commercial rate, as this has the nature of a normal business decision.

The Optimum Timing of Projects

There is a substantial body of literature that deals with the optimum timing of projects. For example, it can be shown that the time profile of the stream of benefits or income can be such that net present value is maximized by delaying project inception(11) (e.g., Herfindahl and Kneese, 1975:202-204). This situation could apply to some pollution "clean up" projects (in which case, the benefits are damages averted) where the major investment is an initial indivisible

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(11) This can occur when the annual benefits from the project increase abruptly or rapidly during the project life.

lump sum (as for effluent treatment plant) and where the benefits increase rapidly with time (as where the quantity of effluent treated or its potential for environmental damage increases after the earliest time by which the treatment plant can be completed).

Another situation in which delay can be beneficial is where there is uncertainty about magnitude of future benefits, and where delay permits additional data to be obtained. This benefit of reducing uncertainty can be regarded as an option value (see Appendix C), and could be particularly significant in hazardous waste management where the irreversible impacts of the use of a particular technique are not well defined. In this event it could be of advantage to society to delay taking an essentially irreversible action (such as deep well injection of a waste) until further research and analysis of the impacts of this action could be completed. During the intervening period it would be necessary to use a management technique (such as engineered storage) that had a low potential for adverse impact (both in terms of low expected impact and limited uncertainty about the impacts) but which was more costly or which was unsuitable as a long term solution for some other reason (such as limited capacity).

Intergenerational Effects

So far, the discussion has been appropriate to actions and projects with a time span of a decade or two, since they revolve around decisions from the viewpoint of the present generation. However, where a longer time span is involved we should also consider the viewpoint of future generations. This would be particularly appropriate to any projects that result in irreversible changes--and any project that involves modification of the natural environment, the use or disposition of non-renewable resources or even construction is a candidate for this category.[(12)]

Two of the arguments already presented for a low discount rate are particularly appropriate when intergenerational effects are considered, although they are also valid from the viewpoint of a single generation. These are (i) the view that society is more than a collection of individuals and hence does not have to be risk-averse, and more importantly, (ii) the view that market decisions stress present consumption to the detriment of conservation.[(13)] While the

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(12) See Chapter 1, footnote 2.

(13) Page (1977:145-207) provides, in the context of resource conservation, an excellent and extensive discussion of the implications of the various approaches to the choice of a discount rate.

latter argument can be applied directly (in assessing the benefits of resource recovery), the general view that one generation should not unduly mortgage another's activities in return for immediate benefits is applicable to the management of any "non-treatable" waste.

Krutilla and Fisher (1975:65-69) have analyzed some intergenerational problems and conclude that where there is less than perfect altruism the overall optimum use of a limited resource will not be achieved,[14] due to the generations' inabilities to bargain with each other. Of particular interest is the case where an option demand (see Appendix C) increases with time, and a project that is justified (using the potention Pareto criterion) at $t=0$, may cease to be justified when evaluated at $t=t_1$ ($t_1 > 0$) as a result of the increasing benefits of maintaining the <u>status quo</u>. Further, the magnitude of the benefits (viewed from $t=t_1$, or later) of not undertaking the project could be sufficient to permit the compensation of early beneficiaries of the project and still satisfy the potential Pareto criterion. Thus, where an irreversible action is contemplated some

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(14) What will happen is that each generation will optimize the use of resources from its own viewpoint, and each succeeding generation will wish to revise the plan to provide it with maximum benefits.

additional test of efficiency is required if society is to aspire to altruism.(15)

Objections to Discounting

In the above discussion, the concept of discounting was not itself an issue, although Krutilla and Fisher (1975:65-67) show (in the context of the consumption of a fixed resource stock) that to achieve altruism the discount rate must be uniform between generations. However, several authors (concerned with empirical cost-benefit analysis) have questioned the concept of discounting(16) on the grounds that it unreasonably penalizes future generations, or even the later welfare of the present generation. The problem is that with any conventional rate of discount, even a "social rate," the future is so heavily discounted after a few decades that distant events can be disregarded in virtually every case. This is no great problem for a conventional project (such as the construction of an incinerator) where technological obsolescence is expected to limit the project's useful life to two or three decades; but it can present difficulties where human life or the environment are involved.

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(15) This test, attributed to Scitovsky, is discussed in Krutilla and Fisher (1975:29, 68). Anderson (1977) also provides a useful discussion (from the viewpoint of resource conservation) of intergenerational effects with more emphasis on distributional considerations.

(16) For example, in their development of methodology for cost-benefit analysis of pesticide use, Epp, et al. (1977), suggest the use of a zero discount rate, although they do not justify this proposal.

This issue has been pointed up by a National Academy of Sciences committee as follows:

> There have been long-standing debates as to the appropriateness of applying a discount rate to effects on future generations, since any positive rate of discount will directly discriminate in favor of choices that involve bad impacts on later generations but not on earlier ones. Again by way of example, if the discount rate were 5 percent, 100 cases of toxic poisoning 75 years from now would be equivalent to about 3 cases today; or 1 case today would be valued the same as 1,730 cases occurring in 200 years, or the same as the current world population (more than 3 billion cases) in 450 years. Clearly, intergenerational effects of these magnitudes are ethically unacceptable; yet they might be made to appear acceptable if the traditional social rate of discount concept were used to discount future costs to compare with present benefits. Some other method of ethically weighting intergenerational incidence of effects must be devised.
> (National Academy of Sciences, 1975:177)

The committee also concluded that "There is as yet no generally accepted method for weighting the intergenerational incidence of benefits and costs" (National Academy of Sciences, 1975:43).

Another National Academy of Sciences (1977:63) committee also indicated that it had problems with discounting with respect to the valuation of lives exposed to radiation, and proposed that:

> Weighting factors should be applied to those terms which may be undervalued by market place economics. Typically, these are likely to include the terms which have a component which involves people not able to take part in the decision-making process.

> The values of the weighting factors have to be established by society in general, whether through the political process, public survey, or other means. (National Academy of Sciences, 1977:69-70)

Sociologists have, however, developed some alternatives to the utility approach inherent in discounting. Thus, if the present generation desires to minimize the regret of future generations as to the present generation's choices, then the appropriate social rate of discount is zero, i.e., all generations are valued equally over a finite planning horizon (Schulze, 1974). Rawls (1971) argues that society should focus attention on maximizing the welfare of the poorest individual. This approach has been developed by Solow (1974) and by Phelps and Riley (1978), but their arguments concentrate on the consumption of non-renewable resources, and, although interesting, cannot be applied directly to hazardous waste management problems (see also Page, 1977:200 *et seq*.).

Application to Hazardous Waste Management

This author has considerable sympathy with those who question the use of discounting in empirical studies involving intergenerational effects. On the other hand, in a mixed economy the complete abandonment of the discounting concept could result in some dubious "second best" analysis, as discounting is implicit in virtually all business decisions. This is clearly not a topic upon which wide agreement will readily be reached, yet some solution must be adopted in order to proceed with any numerate analysis. The author will therefore offer some pragmatic suggestions and arguments that could be appropriate to the particular characteristics of "non-treatable" hazardous wastes. Note that many decisions relating to "treatable" wastes are reversible (assuming that costs sunk in physical facilities are disregarded) and only involve a conventional time scale, as opposed to an intergenerational one. Hence, in these cases the only problem is the choice between a social and a market discount rate.

Where intergenerational effects are possible (i.e., effects that stem from environmental threats), two approaches could be employed: (i) do not discount the effects of threats or (ii) do not further discount the effects of any threats that occur after one generation. In the second approach the intention is that all costs and impacts that occur during a normal (single generation) project life are discounted in the usual way, but that no effect is <u>further</u> discounted if it occurs past this time. These approaches have the added practical attraction that they eliminate or reduce the problems associated with deciding upon the time at which a threat is assumed to materialize. It is difficult to predict the time at which a threat that arises from hazardous waste disposal (as opposed to treatment, etc.) might become a reality. It is true that, for example, given sufficient precipitation and geohydrologic data, the emergence and movement of a leachate from some form of land disposal could be predicted. In practice, however, adequate data are not likely to be available--and the greatest threats may come from unanticipated sources such as unrecognized interconnection between two aquifers. Effects may be cumulative, and may not become apparent until some (probably ill-defined) threshold level is passed. Where the threat relates to an irregular or random process (such as an uncommon natural event) the timing cannot be predicted, although of course it might be possible to derive an expected value. Hence, use of the methodology is simplified if threat timing does not affect the results.

While neither of the two approaches suggested above can be rigorously justified (unless one accepts the minimum regret criterion mentioned earlier), arguments in their favor can be put forward. First, little is known about man's future uses of the environment, and especially those to which it may be put after two or three decades (i.e., one generation later). Society may need to employ some resources that are currently unused and little valued. For example, when might we need to extract either freshwater or minerals from a saline aquifer? When may we need and be ready to farm the ocean? When may we need to use the land where a landfill is presently located? An allowance for the unknowns can be made by placing some form of option value on them, and it is not unreasonable to suggest that its value increases with time. This increase would stem from the increasing relative scarcity of the fixed supply of environmental resources in comparison to man's growing real wealth. Thus, the further into the future that one looks, the higher are likely to be the opportunity costs associated with irreversible decisions. Put another way, the materialization of a threat (such as contamination of an aquifer) may prove to be increasingly costly as one moves further into the future.

The increasing opportunity cost hypothesized above could be regarded as balancing the discounting effect, leading to an argument for not discounting when the impacts of these threats are expressed in today's values. The drawback to this argument is that there is no particular reason why the discount rate should become zero, i.e., that the two effects should exactly balance. The "correct" rate (i.e., that which would be determined with hindsight, when viewed from the future) might turn out to be a low positive rate, zero or even a negative discount rate (i.e., a growth rate). But this information is not available, and a zero rate has the attraction of simplicity.

The concept of discounting over a "normal" project life, but thereafter holding the discount factor constant (i.e. not continuing to discount) has an even stronger pragmatic attraction. The lives of many industrial projects are limited by technological obsolescence, either directly via the process technology used, or indirectly through changes in the marketplace. Consequently, industrial project lives are often taken as one and a half, two or at the most three decades.(17) Technologies pass through a succession of phases as they move from basic research or concept development to commercial use. Technologies that are likely to be used in the next decade or so will generally be well advanced along this progression and, hence, comparatively easy to identify. In contrast, some of the technologies that will be important after (say) three decades may not yet be conceived, or may be in the very early stages of development, making technological predictions over this time scale most uncertain (Taylor, 1978).

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(17) Of course, it is also true that at the high rates of discount commonly used to evaluate industrial projects, the contribution to net present value made by any cash flow beyond this point is often very limited. This reduces the importance of accurately predicting the technological life of a project.

Thus, it can be argued that current valuations of resources will probably reflect their utility over the next decade or so with reasonable accuracy, but that beyond this period uncertainty becomes so great that some resources could be seriously undervalued. (Correspondingly, some resources currently in use may by that time be of little value.) Discounting during the first generation (say 25 or 30 years, which is about the same duration as a normal project life) but not continuing to discount environmental effects thereafter, is equivalent to postulating an impact or opportunity cost that starts to rise when the period of high uncertainty at the end of the conventional project life is reached. A major attraction of the approach, however, is that it simulates the normal industrial decision-making procedures (which in most cases do not consider times beyond one generation), yet it does not overly discount the very distant future.

These two alternative approaches will lead to present values of intergenerational environmental threats that differ by up to one order of magnitude.(18) Since estimates of the magnitudes (and, if used, probabilities) of environmental threats are likely only to be "order of magnitude" estimates,

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(18) For example, by ratios of 3.4:1, 5.4:1 and 10.8:1 for discount rates of 5, 7 and 10 percent respectively over a period of 25 years.

the difference need not be of great concern. Note however, that it is only possible to use lump-sum valuations of threats (e.g., a one-shot clean up cost, replacement cost, etc.) if the period of evaluation is infinite. Any annual cost continuing for an infinite period (such as maintenance cost for "perpetual care") will have an infinite present value if it is not continuously discounted. Thus, where no lump sum equivalent can be found to replace a continuing cost, the planning horizon must be limited or conventional discounting must be employed.

Use Of Threat Scenarios

The most difficult part of any economic analysis of pollution control problems is almost invariably that of determining damages. According to Fisher and Peterson (1976), there are four stages in the assessment of damages from conventional pollution sources, as shown in the upper part of Figure 7. Starting with a specified emission or waste discharge, the ambient conditions and the physical effects must be determined before the dollar damage costs can be estimated.(19) To extend Fisher and Peterson's model to

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(19) As already noted, there is some disagreement about the effectiveness of attributing dollar values to all the effects that may arise from an environmentally oriented project. The terminology in the upper part of Figure 7

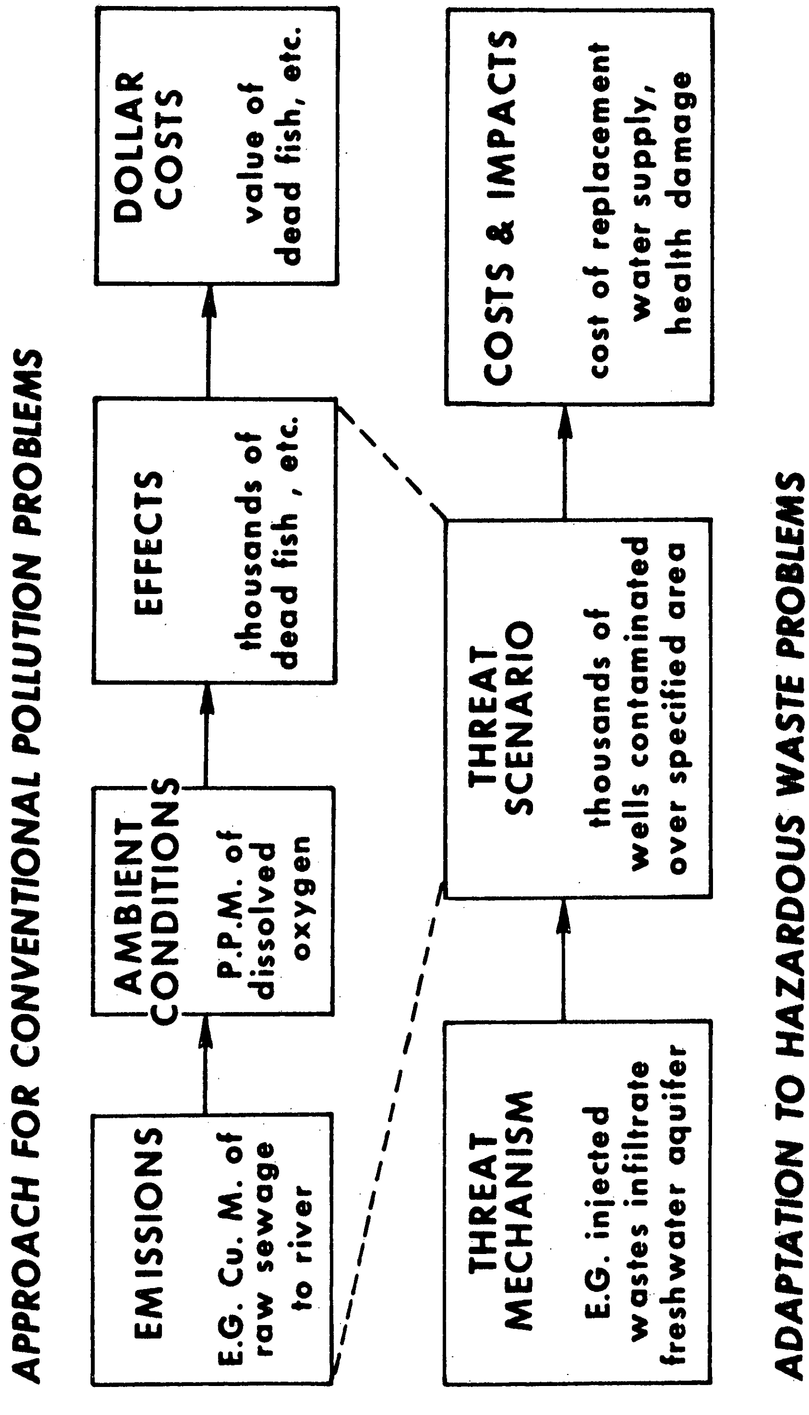

FIGURE 7: Damages Associated with Hazardous Waste Management

hazardous wastes it is necessary to add one preliminary stage: identification of the possible threat mechanisms. This stage is necessary because the nature of most hazardous waste management problems is that the techniques used present a variety of threats of adverse environmental impacts, whereas conventional pollution control analysis usually centers on the effects of a known waste stream discharged to a specified environment.

In principle, it is possible to model environmental impacts and hence arrive at dollar values for the damages attributable to the use of any technique, using willingness-to-pay where necessary. In practice, however, this can be a far from simple procedure and could require considerable resources. For each technique, it might be necessary to consider several threat mechanisms, while each mechanism could probably cause impacts with a variety of magnitudes (e.g., depending on ambient conditions). Waste stream variability could further compound the number of cases to be considered in the physical modeling. Hence, assuming adequate data were available, the dollar damages would ideally be expressed, not as a point estimate, but as a probability distribution

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is that used by Fisher and Peterson (1976:20-21), but these authors acknowledge that in practice there will be effects which will defy economic quantification.

of costs. The ways in which these costs would fall upon the various parties-at-interest could also vary from situation to situation. Furthermore, as is shown in Appendix D, the way in which individuals perceive a risk or threat may be more important in determining their responses than the actual magnitudes and dollar sums associated with that threat.

Its sheer complexity, and the fact that the "probabilistic approach" outlined above fails to recognize perceptions of threats[20] are reasons why this approach may not be an appropriate tool for many hazardous waste decisions. However, in most circumstances the coup de grace is delivered by the non-availability of many of the necessary data, together with the "fuzziness" of those that are available. To generate the missing data and refine those that are available could be a major task, requiring a level of effort that is simply not available, or that is beyond that justified either by the nature of the decision to be made, or by the crudeness of the available techniques for modeling and valuing effects. Even where this "probabilistic approach"

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(20) This could be partly overcome by modeling the physical effects and then asking the parties-at-interest how they would respond to these threats. However, this would not overcome the difficulty (so apparent with nuclear power) that the public may not trust the "experts'" assessments of threats.

is conscientiously followed through in detail, there are numerous possible sources of error and bias (Slovic and Fischhoff, n.d.).

As already explained, an objective of this research was to develop an analytical methodology that does not involve detailed analysis and which does not require extensive data. A central concept of the proposed methodology is to replace the first three stages of the conventional damage model ("emissions," "ambient conditions" and "effects" in Fisher and Peterson's terminology) by a "threat scenario," as illustrated in the lower part of Figure 7. The scenario describes what might typically happen as the result of any specified threat becoming a reality. Where appropriate, more than one scenario could be used to cover different threat mechanisms, or different outcomes arising from a given mechanism.

Judgment will be necessary to limit the number of scenarios that are considered. As shown in Chapter 2, there are usually numerous possible threats. The analyst should pick those that appear to be comparatively likely, those that, as far as is known, could have particularly disastrous consequences, and those with which the general public or certain parties-at-interest are especially concerned. In practice (as illustrated in Chapter 4), reducing the number of scenarios to manageable proportions may not be as difficult as it appears at first sight, since in a given situation there may be consensus on the threats that are significant.

While merely qualitative descriptions of threats would be useful, where possible typical quantitative data would be suggested, reflecting judgments based on the results of modeling studies, actual experience with that type of threat, or worst case assumptions. Where site-specific modeling of threats is not feasible, the analyst may be able to adapt some of the available analyses or case studies of hazardous waste incidents to meet his needs. (See Appendix B.)

A major difficulty with the use of "typical" threats taken from actual experience elsewhere will be to choose a magnitude or scope for the impact that is appropriate to the types and quantities of wastes concerned and to the local circumstances (e.g., geohydrologic conditions). However, simple worst case assumptions could be useful to place limits on some impacts. For example, in evaluating the effect of landfill leaching, the assumption could be made that after many years a steady state is achieved in which the leachate contains the same quantities of non-degradable toxic elements as enter the landfill and that this leachate enters the local river system without attenuation. Knowing the streamflow, the average concentration of toxic elements in the river could be calculated and its effect on aquatic life predicted. Another approach to the same problem would be to assume that any leachate was normally highly attenuated (e.g., by ion exchange) before it left the vicinity of the landfill, but to estimate a clean-up cost represented by the cost of installing and pumping a sufficient number of interceptor wells to contain the leachate should it become necessary.

While admittedly simplistic, the threat scenario approach overcomes or avoids many of the difficulties associated with the more detailed "probabilistic approach." It can accommodate whatever data are available, but perhaps its most attractive feature is that it recognizes the sociological dimensions of a decision situation. Threat scenarios can be constructed to reflect or include actual public perceptions and concerns. The attitudes and behavior of parties-at-interest can be predicted and decisions can take these factors into account. In many respects, the absence of accurate qualitative data need not be of undue concern, as one is largely interested in individuals' reactions to the threats from hazardous waste management alternatives, and in many cases these are likely to reflect what has happened in the past, even if the circumstances are different.(21)

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(21) This statement reflects the view of the author, but behavioral research has provided some support for this position. For example, individuals tend to rely on recent experience when making judgments on probabilities, and on the

Thus, the mere identification of threats is an important part of the methodology, even if the magnitudes of their impacts and the probabilities of their occurrence are ill defined.

Prerequisite Information For Analysis

(Obtaining prerequisite information is the first phase in applying the methodology.)

Before the analytical framework can be applied to a hazardous waste management situation, there are some prerequisite steps that must be taken to provide the exogenous inputs that are necessary before analysis can commence. These steps are as follows:

(1) Define the scope of the study, in terms of both the type of waste and the geographic area to be considered.

(2) Inventory the existing hazardous waste situation including both generation and disposal.

(3) Determine how the hazardous wastes are currently controlled within the study area.

(4) Ascertain policy objectives for hazardous waste control.

These steps are discussed in turn below.

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maximum (expected) magnitude of an event such as a flood. See Slovic, Kunreuther and White, 1974; Slovic, Fischhoff and Lichtenstein, 1976; and Slovic and Fischhoff, n.d.

Define the Scope of the Study

The first prerequisite step is to decide on the scope of the study. The geographic scope will usually be dictated by the terms of reference of the study, and is likely to correspond to a political division or unit, such as a state or a planning region. If any choice is possible, it is desirable that the area chosen be geographically isolated, as otherwise wastes crossing the study area boundaries could complicate matters. For example, where two separate political units share a major metropolitan area, there could be difficulties if the two units adopted significantly different hazardous waste management policies, possibly leading to waste transfers between the units that would be unlikely to promote overall economic efficiency.

Two aspects of the scope of the study in terms of waste type need to be considered. These are: the source-related categories of waste, and within these categories, the definitions chosen for a hazardous waste.

Although this study is oriented towards industrial (process) wastes, the general methodology could be adapted to cover a wide range of potentially hazardous wastes. Since these wastes will tend to have different characteristics (largely in terms of type of generator and frequency of generation, also varying exposures to hazard) they may ideally require different management policies. For example, it is unlikely that exactly the same approach towards waste management would be ideal for (say) large recurrent quantities of industrial process wastes, occasional stale laboratory chemicals and pesticide containers. Because of these differences, it may be desirable to limit the scope of any study to insure that the wastes considered exhibit some degree of homogeneity, or to consider different approaches for different wastes. Further, the agency conducting the study might not have, or might not wish to exercise, control over certain categories of wastes (e.g., Department of Defense wastes). Alternatively, some categories of wastes might already be adequately controlled (this could arise with radioactive wastes) and therefore, additional study would be unnecessary. Hence, some limitation of the scope of the study will probably be necessary. The major source-related categories of potentially hazardous wastes were listed in Chapter 1.

Within the source-related categories, there remains the problem of deciding which wastes are hazardous, and which, in this context, are not. Various definitions that have been proposed for "hazardous waste" were discussed in Chapter 1, where it was shown that there is at present no universally accepted definition of a hazardous waste, and even if there was, due to data deficiencies there would be difficulties in applying it in practice.

Where a definition is not mandated, it is likely that the results of the study itself might provide some input for the definition. In this case, it would be practical to start off with a broad working definition, and refine this as the study data were analyzed. However, at the beginning of the study it might be worth eliminating certain marginally hazardous wastes from consideration if it would be impractical to regulate them in the same way as the other hazardous wastes.[22]

Of course, in addition to studies that cover all hazardous wastes, studies can be conducted on the wastes of a single industry (e.g., pesticide manufacture) or on the disposal of a particular waste (e.g., PCB's) or wastes containing a particular element (e.g., mercury). For single industry studies, the industry can be defined by its SIC

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(22) Waste oil (other than perhaps that from the oil refining and rerefining industries) would be a good example of such a waste. The use of oils in the engineering industries is so widespread that it would be difficult to control the disposal of small quantities of waste oil in the same way as (say) a heavy metal waste, and in view of the comparatively limited threat that waste oil poses to the environment it is often omitted from hazardous waste studies (Stradley, Dawson and Cone, 1975:18-19).

number (Statistical Policy Division, Executive Office of the President, 1974). This approach works well for some industries (e.g., the "basic" process industries, such as copper smelting), but care must be exercised when dealing with diverse industries (such as electronics) which can appear under many different SIC numbers.

For studies that deal with a particular waste or element, the main problem will be to define the concentration or quantity that qualifies as hazardous. For example, even in the absence of industrial sources, sewage sludge usually contains low concentrations of some heavy metals which originate from plumbing fixtures (Ross, 1977). However, while sewage sludge is not without its disposal problems, this sludge would not usually be regarded as a hazardous waste. The solution to this type of problem is to establish cut-off concentrations and/or quantities.

Inventory the Existing Hazardous Waste Situation

Before any economic analysis can be performed, it is necessary to obtain a general picture of the existing hazardous waste situation within the study area. The information required will depend upon the precise objectives of the study, but in most cases it would be appropriate to obtain data as follows:

Source of waste (SIC category and location)

Type of waste

Annual quantity

Current disposition of waste

The EPA has published a guide to conducting hazardous waste surveys (Porter, 1975), but a more detailed appreciation of what might be involved could be obtained by reviewing one of the state or industry surveys (depending on the orientation of the study).

The critical aspect of any hazardous waste survey lies in the way in which the assessment of waste generation is approached. There are three principal approaches that can be used, as follows:

(i) attempt to inventory all hazardous waste sources;

(ii) sample hazardous waste sources and extrapolate to estimate the study area total on the basis of industrial employment, physical output or value added within SIC categories;

(iii) use waste generation factors (e.g., tonnes/year per employee for a given SIC category) obtained from national studies, and study area employment, physical output or value added by SIC category to estimate the study area total.

Clearly, the first method is the most accurate, but hitherto has rarely been used due to the high cost. To date it has been only feasible where there were a limited number of firms involved, as in some state/regional and some industry studies.[23] In the future, under Section 3002 of PL 94-580, data should be available for all generators of such wastes as are deemed hazardous under Section 3001 of that law. However, data would not be available for wastes that were not deemed hazardous under the above law, and hence studies that addressed other wastes would still need to collect data.

Note that even with a general study at, say, the state level, it would be virtually impossible to inventory <u>every</u> organization that might occasionally have small quantities of hazardous wastes, as opposed to the major regular generators.

The second approach (multiplying up from a sample) has been by far the most frequently used to date.[24] A common

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(23) For example, this approach was adopted for some sectors in the hazardous waste practice study of the non-ferrous smelting industries (Leonard, et al., 1975) and was attempted in by Battelle N.W. Laboratories in their study of hazardous waste management in EPA Region X (Stradley, Dawson and Cone, 1975).

(24) For example, this approach was used in a study of hazardous wastes in Massachusetts (Fennelly, et al., 1976) and in the study of hazardous waste management in the pharmaceutical industry (Arthur D. Little, Inc., 1976).

method is to attempt to obtain data from all the major generators, and then assume that the smaller ones produce the same proportion of waste per unit of physical output (appropriate for process industries producing a single major output), per employee or (less commonly) per value added dollar. The disadvantage to this method is that it implies that the process technology in the smaller firms is similar to that in the large firms. Since small firms are rarely "carbon copies" of large firms, this assumption can lead to significant error. A further drawback to this method is that, unless there are additional independent data, the disposition of wastes from the smaller firms will be unknown.

The third approach (use of waste generation factors) is inexpensive but is liable to be of questionable accuracy, as, in addition to the deficiencies noted above, it does not take account of regional differences in technology or (for the "per employee" and "value added" versions) of differences in labor productivity, etc.(25)

A fourth approach which is something of a hybrid between the third approach (waste generation factors) and the first two, is that of the development of a series of "model plants."

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(25) For example, a hazardous waste generation study for the Twin Cities area, Minnesota used this approach in part (Barr Engineering Co., 1973).

These plants can be of differing sizes and can use different processes, and any particular industry structure can be simulated by specifying an appropriate mix of model plants.[26]

While collecting data on the quantities and types of wastes generated in the study area, it is also convenient to collect data on existing disposition. However, to some extent, an independent check on wastes within the study area can be made by obtaining data on wastes being sent for various forms of disposal (e.g., landfilling at licensed sites) and resource recovery. What these data will not reveal is the extent of uncontrolled waste disposal or storage at a manufacturer's site, so this approach cannot be substituted for some sort of study of waste generation. However, waste disposal data can provide a supplementary source of information about hazardous waste generation (e.g., by identifying firms that have hazardous waste in unexpected industry categories) and can permit checks on some firms' quantity estimates.

Many waste surveys also include estimates of future waste generation. This can be particularly significant when new air and water pollution controls are expected to lead to

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(26) For example, largely due to the paucity of survey data, this approach was adopted in the study of hazardous waste management in the electroplating and metal finishing industries (Battelle-Columbus Laboratories, 1976).

additional wastes for disposal (e.g., sludges) or where process technology is undergoing change. Estimates of the solid wastes expected to be generated as a result of the Federal Water Pollution Control Act Amendments of 1972, the Marine Protection, Research and Sanctuaries Act of 1972, and the Clean Air Act of 1970 are available (Stone, et al., 1974). However, the waste disposal options (and costs) may interact with the quantities of wastes that are generated, so predictions of future waste generation needs to be considered later in the analysis.

Determine How Hazardous Wastes Currently Are Controlled

The existing situation or "*status quo*" (of hazardous waste generation and disposition) makes a useful "base case" against which to measure changes that might result from various alternative approaches. Hence, it is also necessary to determine how hazardous wastes in the study area are controlled.

In addition to explicit controls (such as mandating that for ultimate disposal certain wastes must go to a chemical landfill or other approved facility), there may be indirect controls which must be identified. For example, regular landfills in the study area might be prohibited or restricted in accepting "industrial wastes." Even if these restrictions were not scrupulously adhered to (as is likely to be the case in practice), the effect would be to divert most hazardous waste into alternative forms of disposal, or to land disposal within another jurisdiction that does not have such restrictions. It is therefore necessary to examine rules and regulations, licensing requirements and practices to seek out indirect ways in which hazardous wastes are controlled. The (Federal) Clean Air Act Amendments of 1970 (PL 91-604) and the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) are ubiquitous examples of such indirect controls, which, although not specifically directed towards hazardous waste (other than Section 112 of PL 91-604), nevertheless have a major impact on hazardous waste management. Several other federal laws can have generally minor impacts (see Chapter 1), and in addition there will be many state (and sometimes local) laws and ordinances that also exert indirect influence. An important feature of much of this legislation is that it is not the actual statutes, but the administrative proscriptions and decisions that are important (Haskell and Price, 1973:264). Hence to establish how hazardous wastes are controlled under the status quo, it is important to examine these administrative decisions and their enforcement.

Ascertain Policy Objectives

The final prerequisite is to ascertain the policy objectives that will govern the approach to hazardous waste control that is adopted. Policy objectives generally deal with normative issues, and it is not infrequent that optimization of a given approach or choice between approaches will require trade-offs between achievement of different objectives. Economic efficiency in the allocation of resources (i.e., striving towards a potential Pareto optimum) is usually assumed without question (Haveman and Weisbrod, 1975:38; Planning Branch, Treasury Board Secretariat, 1976:9), even though it may not be achievable in practice. Other policy objectives might cover the following topics:

(1) What is regarded as equitable and to what extent can departures from an equitable situation be tolerated?

(2) Preferences for the use of taxation and economic incentives as policy tools.

(3) The extent to which policies should reflect risk aversion.

(4) The degree to which government should proscribe and regulate, as opposed to relying on market forces backed up by the judicial process for determining liability questions.

(5) The degree of autonomy permitted to relevant individual jurisdictions, agencies, etc.

Some policy objectives may not be specifically laid down, but will constitute a tradition of that agency, or will reflect the mores of that society.

Where policy objectives (including implied objectives) are not sufficiently detailed or complete, it is probably best to apply the methodology to the evaluation of various alternative approaches that might be considered, and then highlight policy implications along with other information required for decision-making. It may also be found that it is not possible to devise approaches that satisfy all policy objectives. For example, it may not be feasible to achieve perfect economic efficiency due to uncorrectable market failures, or there may be trade-offs between the efficiency and equity that can be attained. In this case, the most expeditious procedure would be to consider a variety of approaches that look as though they may come reasonably close to meeting objectives. When the outcomes of using these approaches have been determined, any shortfalls with respect to objectives can be identified and brought to decision-makers' attention.

The Analytical Framework

(Applying the analytical framework is the second phase in the use of the methodology.)

The steps involved in applying the analytical framework are as follows:

(1) Develop alternative approaches for hazardous waste management.

For each approach under consideration:

(2) Allocate wastes to techniques.

(3) Develop threat scenarios, list other impacts.

(4) Determine economic and social effects.

(5) Determine impacts on the parties-at-interest.

(6) Project responses of the parties-at-interest.

(7) Predict physical outcomes.

(8) Enumerate costs and impacts.

(9) Reiterate steps 2 through 8 as required.

Each step is discussed below. As these steps closely follow the interaction model (Figure 5) which was discussed in Chapter 2, there is some overlap with that discussion. However, in Chapter 2 the orientation was behavioral, while that which follows is intended to provide practical guidance.

Development of Alternative Approaches to Hazardous Waste Management (Step 1)

Each "approach" represents an alternative general philosophy or actual strategy for managing hazardous waste that is broadly consistent with the policy objectives. For example, one approach could be to require all hazardous waste to either be detoxified or to be disposed of in a chemical landfill. Another example could be an incentive approach to encourage disposal at chemical landfills by subsidizing their operation.

Different definitions of hazardous waste and detoxification, or different levels of subsidy would be considered as falling within one approach. Thus an approach is a general strategy, rather than a detailed plan.

In the author's terminology approaches may be either positive or negative, "specific" or "influencing." A positive approach directs actions towards a solution or form of management, while a negative approach directs action away from something. In the case of "specific" approaches, requirements are spelled out; thus a specific positive approach would mandate something, such as the use of a particular pollution control technology. Conversely a specific negative approach would ban something, such as the use of a particular means of waste disposal. On the other hand, "influencing" approaches attempt to encourage or discourage something (e.g., by using economic incentives) as opposed to mandating something. This distinction is important when the linkage between approaches to hazardous waste management and techniques for the control of hazardous waste is examined.

In most situations, it will be appropriate to include the status quo as a "base case," even though it may prove difficult to define the approach that it represents. The principal advantage of using a base case is that the effects and outcomes of the various approaches can be expressed as changes with respect to this case, and it is often easier to determine changes in some parameter, as opposed to calculating absolute values.[27] The *status quo* is often a good starting point as people are familiar with it and are largely concerned with changes from the existing situation. However, in some circumstances, a base case other than the *status quo* might be appropriate. This could occur when some major new development (such as a change in the law, a major new waste-generating plant, or a new disposal facility) is already underway. In these situations the base case would need to reflect such developments.

Allocation of Wastes to Techniques (Step 2)

As a preliminary action it is necessary to determine which waste management techniques should be considered (see Appendix A). Techniques can be ruled out for a variety of reasons, including local infeasibility (e.g., lagooning for evaporation in wet climates), technical infeasibility (e.g., biological treatment when there are no biodegradable wastes), conflict with policy or objectives (e.g., the use of ocean

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(27) For example, it can be very difficult to determine the total magnitude of the consumers' surplus, whereas the size of a small change can often be estimated with comparative ease. Aesthetic and existence values must be evaluated in terms of changes (see Appendix C).

dumping), and excessive cost (e.g., space disposal for most wastes). Clearly, one has to be careful about eliminating disposal techniques on economic grounds before economic analysis has been conducted. However, there may be some situations in which one technique has a very high control cost and appears to provide no environmental advantages over a technique that has a much lower control cost. If the parties-at-interest are similar for both, then it would be reasonable to eliminate the high control cost technique.

The next action is to try to predict which techniques will be used to control what wastes. Each approach will have a different influence on the techniques that are used. In the case of a specific positive approach the linkage will be direct, i.e., the technique(s) will be mandated. However, in all other cases, including those which represent combinations of the types of approach, the linkage is indirect. For an "influencing" approach the dispositions of wastes are steered towards or away from certain control techniques, but all feasible techniques are still theoretically available. In the case of a specific negative approach, the available options are reduced by the elimination of one or more techniques, but other factors determine which techniques are used for what wastes. These factors are the normal economic forces in which a firm generally minimizes its own (internal) costs, tempered by the desire to minimize managerial effort (which is really a cost to the firm). This is equivalent to minimizing generator's cost (see Appendix C), and will cause firms to favor the use of certain disposal techniques. However, the techniques that are actually used will be influenced by the actions of the various parties-at-interest, and the firms' desires to avoid risk. Because outcomes have yet to be evaluated, at this stage in the evaluation process only a tentative allocation of wastes to techniques can be made.

A difficulty arises when waste stream changes and treatment techniques (as opposed to disposal techniques) are being considered. For the common regional situation where a wide variety of wastes are produced by many generators, it will not be feasible to examine changes that may occur on the generators' sites. Changes in the opportunities for and costs of disposal techniques could cause generators to change waste streams and treatment methods. In this event some broad assumptions about such changes will have to be made, or such changes disregarded (as already noted, waste disposal costs are usually only a small portion of product value, which suggests that on-site operations may not be very sensitive to off-site disposal costs). However, where there are major regional industries, producing substantial quantities of reasonably homogeneous wastes (e.g., petroleum refining in Texas), further investigation would clearly be warranted.

Development of Threat Scenarios, etc. (Step 3)

The identification and description of threats has been discussed in Chapter 2 and in Appendix B, while the philosophy of using "threat scenarios" was expounded earlier in this chapter. To proceed with the analysis, it is necessary to identify one or more threats for each technique being considered. In many cases it will be possible to establish that, for a given technique, one threat is of far greater import than all others. In this event, this threat scenario should be developed as fully as possible, while other less significant threats could merely be identified. However, an attractive feature of the methodology is that it provides a flexible framework for analysis that can readily accommodate inputs from a variety of sources. Waste management personnel, for example, may generate the threat scenarios that they consider to be the most relevant to a given situation. If, however, it becomes apparent that the public is largely concerned with some other threat, an appropriate scenario can be added without disrupting or contradicting the previous work.

The quantitative data used to describe threat scenarios should probably be kept simple, e.g., by using means, modes and possibly ranges, rather than probability distributions of effects. More detailed data may be appropriate when the waste management alternatives have been narrowed down to two or three options.

Environmental impacts of hazardous waste management techniques other than those that arise via threats can also be listed. These impacts are all related to resource use, i.e., energy consumption, materials and land use. While this aspect of the environmental impacts is accounted for via the cost mechanisms (e.g., the control cost for land disposal includes the cost of the land and energy used), there are many who consider that the market prices for some resources (e.g., energy) may not reflect their true values. Hence there is frequently additional interest in resource use, and for this reason identification of these data is helpful.

Determination of Economic and Social Effects (Step 4)

This process, which leads to the evaluation of some of the costs and impacts (see Figure 5) was discussed in Chapter 2. Effects should be evaluated for each of the techniques involved in any approach being considered.

Determination of the Impacts on the Parties-at-Interest (Step 5)

Determination of the economic and social effects leads directly to determination of the parties-at-interest. Table 7 provides some generalizations about attitudes and behavior of the parties-at-interest (see Chapter 2). These data can be used to examine the nature and degree of impact that a waste management technique may have on a party-at-interest.

While predicting individual responses of the parties-at-interest (the next step) may be important, a general analysis of the impacts of the use of the various techniques on the parties-at-interest can be a powerful tool when it comes to comparing the effects of the use of different techniques, and hence, alternative approaches. Table 8 presents a matrix of the parties-at-interest for each major technique, and suggests the nature of the effect that use of the technique has on each party-at-interest. This is a generalized matrix, not applied to any specific situation where the effects could differ from those indicated in Table 8, and in which there could be additional parties-at-interest.

It may be useful to examine a few of the entries in Table 8 to understand how the author's judgments about the nature of the effects were made. Consider, for example, a

TABLE 8. MATRIX OF EFFECTS ON THE PARTIES-AT-INTEREST

Party-At-Interest

Key: Nature of effect

- ++ Very favorable
- + Generally favorable
- +- Mixed, or depends on circumstances
- - Generally adverse
- -- Very adverse
- (blank) Not significant

Hazardous Waste Management Technique	Waste generators-management	Waste generators-workers	Competing firms (different process)	Waste disposal industry	Waste transporters	Secondary materials industry	Local political officials	Local environmental officials	Local residents and workers	Local property owners	Water supply authorities	Local water supply users	Fishermen	Recreation (freshwater and ocean)	Environmental related industry	Environmentalists	Scientists	Other Parties-at-Interest
Change in waste stream	+-	+-	+-	+-	+-	+	+	+			+-				+			
Resource recovery	+-	+-	+-	-	+-	++	+	+			+				++		-	Virgin material suppliers
Treatment - physical	+-	+	+-	+-	+-	+	+	+			+-		+-		+			
- chemical	+-	+	+-	+-	+-	+	+	+			+-		+-		+		+	Chemical suppliers
- biological	-	+-	+-	-	-	-	+-	+-			-		-		+-			
- thermal	+-	+-	+	-	-	-	+-	+-	-	-	+				+-			
- encapsulation	-	+	+	+	++	-	+	++			+				++			
Land application	+	+	+-	+-	+	-	-	+-	-	-	-	-	-		-		+-	Farmers
Landfill - secure	+-	+	++	++	++	-	+	+	-		+	+-			+			
- ordinary	+	+-	-	+	+-	-	-	-	--	-	-	-	-		-			
Mine disposal	-	+	++	++	++	+-	++	++			+				++		-	Adjacent mineral interests
Lagooning	+-	+-	-	-	--	-	-	-	--	-	-	-	-		--		-	Fowl hunters, farmers
Deep well injection	+	+	-	+-	+-	--	-	--		-	-	-			-	-		
Ocean dumping	+	+	-	++	+	-	-	--	-	-	+		--	-	--	--	-	Other nations, politicians
Engineered storage	-	+	+	+	-	+-	+-	+-	-		+	+-			+-			
Space disposal	--	+	+	+-	+	-	-	-			++				--	-	-	Other nations, politicians
Discharge to sewer	+	+	-	--	--	-	-	-			-				-		--	Sewer authorities
Discharge to waterway	++	+	--	--	--	-	--	--	-	-	--	-	--	-	--	-	--	Other water recreationists

technique involving chemical treatment to reduce hazard potential. Management of the firm generating the waste will have mixed views about the technique (+-), as it is likely to be comparatively costly, but treatment should reduce the risk of an adverse incident.[28] The firm's workers are likely to favor treatment (+) because it probably makes their job safer. The effect on the waste disposal and transport industries will depend on the process streams following treatment (+-): they may have safer waste to dispose of (+), or there may be no waste requiring off-site disposal (-). Local officials are likely to favor chemical treatment due to the reduced risk of an environmental incident (+), but water supply authorities might be concerned over the possible discharge of an undesirable effluent to a river that constitutes part of a water supply (-). While water supply authorities and environmentalists are likely to have definite views on most technques, the perception of threats and benefits from chemical treatment may be remote to most local residents (no entry in Table 8). Thermal treatment, on the other hand, which could cause the deterioration of local air

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(28) Where a "reference level" was necessary to determine the nature of the impact, each technique has been compared with temporary storage at the generator's site. Although not an acceptable long-term solution, this situation represents a common starting point. In other situations, the status quo or a base case could be used as a reference level.

quality, might be viewed negatively by many residents and property owners (-), while a technique such as lagooning could pose a discernible threat to local water supply users (-).

In identifying and evaluating impacts in Table 8, each party-at-interest is assumed to represent only one viewpoint. Any individual could fall into more than one category of party-at-interest; for example, one individual could be a local resident, property owner, worker and environmentalist. In Table 8, the attitudes of the parties-at-interest are "pure"; for example, business management is assumed to adopt only those attitudes listed under firms' behavior in Table 7. In the event that the chief executive of a firm happened to be a strong environmentalist, that particular firm would probably exhibit some "mixed" behavior. However, this is not allowed for in Table 8, where the impacts on "waste generators-management" and "environmentalists" are maintained separate.

To apply the parties-at-interest matrix to a specific situation, it might sometimes be more appropriate to conduct the analysis in terms of approaches (which could encompass more than one technique), than techniques.

Projection of Responses of the Parties-at-Interest (Step 6)

Attitudes which predispose the parties-at-interest to certain responses were discussed in Chapter 2, along with some likely responses.

Responses include a variety of actions, ranging from raising the price of a product to cover increased hazardous waste management costs, to public protest about potential adverse effects. Individual responses can, to an extent, be predicted from a knowledge of the situation and the parties-at-interest. In evaluating approaches, it is useful to note possible responses even if these are not certain. Some responses are in the nature of threats, for example, requirement of costly disposal techniques increases the threat of illicit disposal (dumping) of wastes.

Prediction of Physical Outcomes (Step 7)

The physical outcomes include the waste dispositions, and some of the responses of the parties-at-interest such as householders moving to avoid threats or actual pollution, or fishermen avoiding depleted fisheries. Waste dispositions (including the non-disposal options such as process change and resource recovery) are largely determined by the initial allocation of wastes to techniques, described under step 2. If there were no socioeconomic interaction (or policy level feedback), simple cost minimization should determine the ways in which the firms choose to distribute their wastes among the available techniques. However, the responses of the parties-at-interest may also affect the outcomes. For example, some parties-at-interest might oppose the use of certain techniques, and their actions might thereby render them unavailable to the waste generators, or cause them to become less attractive than others due to this opposition. For these reasons waste dispositions other than those based on direct generator's cost minimization may be chosen.

At this stage, it is also appropriate to consider how the quantities of wastes will change in the future. Although data on the price elasticity of demand of industrial waste disposal services are rare, it can be expected that the quantities generated will exhibit some response to price, as increased disposal costs will encourage in-plant treatment, volume reduction and resource recovery. The availability of local resource recovery facilities (e.g., solvent redistillation equipment) should also encourage the latter. Known plans for new plants or expansions of existing ones can be factored in at this stage, but it should be remembered that these will probably use state-of-the-art technology, in some cases replacing less advanced systems. Hence, even if economic activity in the study area is expected to grow, the quantities of wastes requiring disposal may not increase at the same rate.[29]

Environmental threats can also be listed as outcomes. Of course, only those that materialize constitute actual physical outcomes, but it does not seem appropriate to segregate definite (though ill-defined) outcomes such as those of ocean dumping from those that are probabilistic in nature--such as lagoon overflow. All are possible outcomes, while few, if any, are clearly defined.

Enumeration of Costs and Impacts (Step 8)

Once the waste dispositions are determined, it is possible to list all the costs associated with that approach to hazardous waste management. These include the generator's costs which are associated directly with the disposition of the wastes, and the other costs of control, i.e., the administrative and social control costs.

In addition to these costs, there may be some definite environmental costs or social impacts that can be specified,

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(29) These comments are supported by a situation observed in Oregon. For many industrial sectors the quantities of hazardous wastes requiring disposal declined between surveys conducted in 1972 (State of Oregon, 1974) and 1974 (Stradley, Dawson and Cone, 1975). This has been attributed to process changes and increased resource recovery (Dawson, 1977).

such as changes in property values and noise insult to residents along a road leading to a landfill. It will be recalled (see Chapter 2) that the dividing line between environmental costs and social impacts is not a firm one, but is based largely on the feasibility of quantifying costs.

Many of the environmental costs and social impacts stemming from an approach to hazardous waste management will be associated with threats. These should be listed as part of each threat scenario, which should also include an estimate of the probability of the threat occurring--if a reasonable estimate can be made.

While all costs should be specified in constant dollars (i.e., without allowing for future inflation), they should also be discounted by whatever rate or approach is chosen (as discussed earlier in this chapter). Where threats are concerned, this will normally involve choosing a time at which the threat is assumed to materialize. Where a process such as leaching is involved it may be possible to use engineering judgment to decide, say, the earliest likely time; where events are completely random the analyst will be forced to use some arbitrary assumption such as halfway through the planning period, or at the end of one generation. If the recommended approach of not discounting beyond one generation is employed, threat materialization at the end of one generation is in many respects an attractive choice, since thereafter the actual time of materialization will not affect the discounted values.

Reiteration of Procedure (Step 9)

Once the above procedure has been carried out, and the physical outcomes, costs and impacts associated with any approach are predicted, there is feedback to the policy level. An analyst can examine the results for each approach, can test them against the policy objectives and can modify the approaches to improve the results. In this way he can suboptimize within a given approach, by making one or more iterations of the evaluation procedure. For example, the analyst could change the number and location of landfills in order to arrive at a least cost land disposal solution, or he could change the levels of taxes or subsidies to enhance effectiveness or correct the equity of a situation. Once this suboptimization is reasonably complete, then the decision-maker is in a position to compare the results of different approaches.

Aids To Decision-Making

(Decision-making is the third phase in applying the methodology.)

Arraying the Alternatives

Once the framework, described above, has been applied to each approach being considered, the decision-maker must choose among approaches (or develop new ones). Cost-benefit and risk-benefit analysis usually seek to reduce all effects to dollar terms and then choose the alternative that has the greatest net present value. A simple refinement would be only to choose among those alternatives that also passed certain other tests, such as equity and government cost criteria. Although the methodology presented here draws strongly on the techniques of cost- and risk-benefit analysis, it is the author's view that reducing all data to dollar terms suppresses too much information for environmental planning.

There has been a variety of approaches proposed for systematizing the decision-making process where there are complex considerations such as multiple objectives. Some tend towards the use of a utility-based approach, often in conjunction with event trees to cope with alternative outcomes (e.g., Bell, Keeney and Raiffa, 1977; Wendt and Vlek, 1975; Fishburn, 1964; and Schlaifer, 1967). This does, however, involve selecting a utility function which then essentially represents part of the policy objectives of the agency or decision-maker concerned.

The use of simple scales (both ordinal and cardinal) for achievement with respect to a number of objectives, and of ranking systems that combine such scales is commonly used in marketing and in corporate planning and could be useful here. Sewell (1973) discusses a variety of evaluation techniques that have been used for resource-oriented problems.

The approach proposed here is to use a "balance sheet" format in which costs, threats, etc., and their effects on the parties-at-interest, together with the latters' possible responses and the physical outcomes, are set out for each approach. The decision-maker is then in a position to select his own trade-offs between the approaches. Provided that maintaining the *status quo* is used as a base case, then one can be certain that whatever approach is chosen will represent an improvement (at least by the decision-maker's measuring rod). This is equivalent to requiring a project assessed by traditional cost-benefit techniques to have a benefit/cost ratio greater than unity.

Appropriate ways of handling and displaying the data will depend on the situation being considered; a simple example is used in the next chapter. A more comprehensive illustration of this approach to decision-making (including ways of analyzing trade-off decisions) is presented in Milliken, et al. (1977), who analyzed the conflicting issues involved in a water supply situation.

Dominant Approaches

There may be some situations in which one approach can be eliminated from further consideration by comparison with another. Consider, for example, two projects A and B that are designed to achieve the same objective (e.g., disposal of wastes). If the net monetary control costs of A exceed those of B and the environmental costs of A clearly exceed those of B (even though the environmental costs are not quantified), then approach B is said to dominate approach A, as A is higher on both types of cost. Hence, assuming that the only factors that enter into the comparison of the two projects are the control costs and the environmental costs, the approach A can be discarded. Analysis for dominance can be a useful way of eliminating approaches without needing to fully evaluate some of the costs (Fisher and Peterson, 1976:9-10).

Risk Aversion

The handling of risk in decision-making is discussed in Appendix D. Practically everybody, i.e., firms, the public, decision-makers, politicians, etc., is risk-averse to a lesser or greater degree. The decision-maker needs to reflect an appropriate degree of risk aversion in his choice among alternatives. In making this choice he will generally have to trade-off added costs against reduced probabilities of environmental threats materializing. The added costs will usually be known with comparative certainty, whereas the threats may be quite ill-defined. A complicating aspect of this decision situation is that known costs may be borne by one party-at-interest, while the risks may fall on another.

A decision-maker should remember that if individuals <u>feel</u> threatened (even if the threat does not materialize) then their welfare is reduced, i.e., feeling threatened is a cost. On the other hand it is probably not reasonable--even if feasible--to achieve a situation that is virtually risk-free, since it is likely that in many cases the marginal cost of risk reduction increases as the level of risk is reduced (Tihansky and Kibby, 1974).

Equity

Equity is a normative facet of economics. For example, one viewpoint on equity is that potential beneficiaries should pay to obtain that benefit. Another approach is that "clean-up" costs should be borne directly only by those who cause the environmental degradation. Yet another aspect is that it is considered by some to be unreasonable to drastically alter competitive conditions by, say, banning (or rendering highly costly) a particular industrial process unless there are exceptionally powerful arguments in favor of this course of action. It will be seen that these three viewpoints on equity could easily be in conflict, calling for a judgment on whether or not specific approaches lead to outcomes that are acceptable as regards equity.

The identification of the parties-at-interest is particularly useful in this respect, as it is comparatively easy to compare the effects of alternative approaches on each of the parties-at-interest. By examining the way in which costs and impacts fall on different parties-at-interest, the decision-maker can evaluate the acceptability of the results. He can also devise strategies to render a given approach equitable by finding ways to shift some of the costs and impacts from one party-at-interest to another, For example, examination of the alternatives for the disposal of a particular waste might lead to the conclusion that economic efficiency would be achieved by discharging this waste to a landfill, but that this could render the water in a limited number of wells unsafe to drink. To make this solution equitable, the waste generator could be made to pay for the cost of installing and operating an alternative water supply, possibly together with an additional payment to compensate the well owners for a loss of aesthetic value caused by changing from their well water to the alternative supply.

Summary of the Methodology

For the reader's convenience, the complete procedure involved in defining the scope of the study, applying the analytical framework and deciding between alternatives is summarized in Table 9.

TABLE 9. SUMMARY OF METHODOLOGY

PHASE I OBTAIN PREREQUISITE INFORMATION

1. Define scope of study.
   - geographic area
   - types of wastes
2. Inventory existing waste situation.
3. Determine how wastes are currently controlled.
4. Ascertain policy objectives.

PHASE II APPLY ANALYTICAL FRAMEWORK

1. Develop alternative approaches for hazardous waste management. (Consider _status quo_ as a base case.)

For each approach under consideration:

2. Allocate wastes to techniques.
3. Develop threat scenarios, list other impacts (resource use).
4. Determine economic and social effects.
5. Determine impacts on the parties-at-interest.
6. Project responses of the parties-at-interest.
7. Predict physical outcomes, including future wastes.
8. Enumerate costs and impacts (discount as appropriate).

Reiterate steps 2 to 8 until each approach has been suboptimized. Design new approaches if appropriate.

PHASE III DECISION-MAKING

1. Array alternatives.
2. Eliminate subservient approaches.
3. Check approaches against policy objectives (e.g., for equity).
4. Examine trade-offs between known costs and threats.
5. Select an approach, using an appropriate level of risk aversion.

CHAPTER 4

DEMONSTRATION OF THE METHODOLOGY

Introduction

This chapter provides a simple example of the use of the methodology described in Chapter 3. The example considers only a single waste stream, and hence much of Phase I of the methodology (Prerequisite Information for Analysis) is inapplicable, as this is oriented towards complete studies of hazardous waste management within a specified area. The example concentrates on applying the analytical framework (Phase II) and on illustrating the decision-making process (Phase III). While the example is hypothetical, the data used are intended to be representative of a situation that might be encountered in the western U.S.A.

The Problem

An agency responsible for hazardous waste management receives an application from a firm that wishes to dispose of a hazardous waste by deep well injection. The agency has no policy or regulations that specifically ban the use of deep well injection, but any technique used for hazardous waste disposal requires agency approval.

The waste will come from a new process which is assumed to have a 20-year technological life. The process will generate 250,000 cu.m. per year of an aqueous waste containing 50 parts per million of non-degradable toxic elements (e.g., heavy metals). The firm proposes to dispose of this waste by injecting it into a saline aquifer some 600 meters below their premises. They estimate that this will cost them $50,000 per year (including capital charges) over the 20-year life span.

The next step is to investigate the technically feasible alternatives. These are found to be as follows:

(i) The waste stream can be reduced to 25,000 cu.m. per year with a corresponding increase in the concentration of toxic elements, at a cost of $20,000 per year to the firm.

(ii) The waste stream can be treated to provide an effluent that is acceptable to the municipal sewer. Treatment results in 250 cu.m. per year of a toxic sludge. The cost of treatment plus effluent charges would be $115,000 per year.

(iii) There are two landfills that could accept either the liquid waste [from (i), above] or the sludge [from (ii)]

The "local landfill" is a public sanitary landfill located immediately adjacent to a river 50 km. from the generating firm. Rainfall in this region is much greater than either open pan evaporation or potential evapotranspiration. This landfill charges $3.00 per cu.m. for any waste.

The "secure landfill" is a chemical landfill located in a dry zone (rainfall is much less than evaporation or evapotranspiration), 360 km. from the generating firm. The gate fee is $30.00 per cu.m. for the sludge and $20.00 per cu.m. for the liquid.

Transportation to either landfill would be by truck, at a cost for either sludge or liquid of $7.00 per cu.m. to the local landfill, and $22.00 per cu.m. to the secure landfill.

(iv) Other techniques for dealing with the waste (such as resource recovery or ocean dumping) are not feasible.

Hence, there are five technically feasible disposal plans, as follows:

(A) Deep well injection on the firm's premises.

(B) Sludge sent to the local landfill.

(C) Concentrated liquid waste sent to the local landfill.

(D) Sludge sent to the secure landfill.

(E) Concentrated liquid waste sent to the secure landfill.

Threat Scenarios

The next step is to develop likely threat scenarios, at least one for each disposal plan. In-plant accidents under any plan are expected to have approximately similar impacts, and hence do not have to be evaluated. The following scenarios represent the major threats identified.

Threat Scenario I: Water Contamination From Deep Well Injection (Applies only to Disposal Plan A)

Drinking water is obtained from numerous wells that penetrate a shallow aquifer in the vicinity of the generating firm. This aquifer may become contaminated as a result of some unanticipated interconnection with the deep saline aquifer. The probability of this cannot be determined. If contamination occurs, corrective action could be taken by providing temporary water supplies to the local residents, and by drilling several additional wells into the saline aquifer and counterpumping to reverse the migration of the waste. The total cost of this clean-up operation, including some hospitalization costs, is estimated to be some \$2,400,000; which would be considerably less costly than providing a permanent new water supply to the local residents.

Threat Scenario II: Leaching From the Local Landfill (Applies only to Disposal Plans B and C)

If the concentrated liquid waste were discharged to the local landfill, it can be assumed that the entire waste would quickly infiltrate the river, due to the wet conditions and absence of leachate barriers at the landfill. If the sludge were deposited at this landfill an appreciable proportion of the toxic elements would probably be retained, especially in the earlier years, but the above assumption could be used as the worst case. Either sludge or liquid waste contributes 12.5 tonnes of toxic elements per year. The river has a mean flow of 200 cu.m. per second implying a toxic element concentration of two parts per billion (ppb) if the waste were uniformly diluted. However, local concentrations are expected to be higher.

The river supports an important salmon fishery, and experts value a typical year's fishing at $800,000, excluding indirect effects such as tourist dollars brought into the region by the fishery. The experts expect the onset of high fish mortality to occur at toxic elements somewhere between 20 and 100 ppb, but are reluctant to say what impact two ppb would have on the salmon due to effect variability with duration of exposure, alkalinity and the presence of other elements. They point out, however, that there is some evidence that fish avoid sub-lethal concentrations of toxic elements; hence the waste could conceivably ruin the fishery by discouraging the salmon from returning to spawn. (Chapman and Lorz, 1977.)

Threat Scenario III: Transport Accidents
(Applicable to Threat Scenarios B through E)

Statistics indicate that 50 accidents involving waste spills can be expected per billion kilometers traveled by truck in the region. The clean-up cost associated with a typical accident is estimated to be $10,000. Serious injuries and deaths directly attributable to the properties of the waste are expected to be negligible.

Threat Scenario IV: Flash Flood at the Secure Landfill
(Applicable only to Threat Scenarios D and E)

The most likely threat from the secure landfill is contaminated run-off from a flash flood. Such a flood is expected to occur less than once per hundred years and damage along the flood path directly attributable to the toxic elements is expected to be minimal. Leaching problems are highly unlikely due to the dry climate and extreme depth to usable aqifers.

Analysis Of The Alternatives

Table 10 presents a comparison of the alternative plans. Only the generator's cost portions of control costs have

TABLE 10. COMPARISON OF ALTERNATIVE WASTE DISPOSAL PLANS

	PLAN				
	Deep Well Injection	Local Landfill		Secure Landfill	
	A	B	C	D	E
		Sludge	Liquid	Sludge	Liquid
CONTROL COSTS (dollars)					
Generator's annual costs					
-On-site operations	50,000	115,000	20,000	115,000	20,000
-Transport	-	1,750	175,000	5,500	550,000
-Gate fees	-	750	75,000	7,500	500,000
Total Annual Cost	50,000	117,500	270,000	128,000	1,070,000
Present value: 20 years' cost discounted at 10% per year	426,000	1,000,300	2,298,000	1,089,700	9,109,500
Other control costs					
-Administration and monitoring	← Not significantly different →				

(p. 1 of 2)

Table 10 continued... (p.2 of 2)

	PLAN A	PLAN B	PLAN D
ENVIRONMENTAL IMPACTS			
Resource use) In-plan accidents)	← Not significantly different →		
Major threat scenarios	I: Water supplies contaminated. Mitigation cost $2,400,000, plus cost of changing plan. Probability: not estimated.	II: Salmon fishery at risk. Direct value $800,000 per year. Indirect effects locally important. Probability: not estimated.	III: Transport accident. Clean-up cost $10,000. Probability: 1.4×10^{-4}/year.
	Note: There is some risk that the mitigation measures might be unsuccessful.	III: Transport accident. Clean-up cost $10,000. Probability: 2×10^{-5}/year.	IV: Contamination via flash flood. Damage potential minimal. Probability: $<10^{-2}$/year.
OTHER EFFECTS	Product prices would be slightly higher and/or generating firm's net income slightly lower with Plan B or D than with Plan A.		

been evaluated, as other costs are not expected to differ significantly between alternatives. The net present value of the control costs has been calculated by discounting at 10 percent per year, which is the rate recommended by the Office of Management & Budget for such calculations (Executive Office of the President, 1972).

As soon as the control costs are evaluated, it is possible to eliminate plans C and E because these plans are "dominated" by B and D respectively. Consider plan B versus plan C. The control costs for B are $117,500 per year versus $270,000 per year for C, and detailed evaluation is not necessary to show that the potential environmental damages from B are also less than from C. There is less possibility for release of toxic elements from the sludge (plan B) than from the concentrated liquid (plan C); while plan B requires less transportation than plan C, which should result in fewer accidents. Thus plan B is clearly preferable to plan C as both the quantified costs (the generator's costs) and the non-quantified costs (the environmental damage potential) are lower for plan B than plan C. Similar arguments apply to plan D versus plan E. This approach cannot, however, be used to compare plan A with any other plan, as the environmental threat from plan A is quite different to those from all other plans. This reduces the number of plans to be evaluated to three (A, B and D).

The next step is to examine the threats associated with each plan and to determine the nature of the effects of each plan on the parties-at-interest. The effects on the parties-at-interest are summarized in Table 11. The parties-at-interest most strongly affected in this example include the water supply authority, and to a lesser extent the water users near the plant, who would be concerned about the threat from deep well injection (Threat Scenario I). Fish experts would oppose plan B, although fishermen and related industry might perceive only a weak threat. Fishing interests might, however, have an unexpected ally. If plan A were prohibited, the generating firm itself could well prefer plan D over plan B. While the firm will strongly favor plan A because of its low cost, the annual cost of plan D is only $10,500 greater than plan B, and if the firm opted for B, it could receive adverse publicity if the fish threat (Scenario II) materialized. In contrast, the firm might enhance its reputation as a responsible environmental citizen if it sent its waste to the secure landfill under plan D. In this case a lot is at stake (an $800,000 per year fishery and the firm's image) for only a small net benefit ($10,500 per year in reduced

TABLE 11 PARTIES-AT-INTEREST ANALYSIS

The matrix characterizes the expected attitudes of the major parties-at-interest towards each plan.

Party-at-interest	PLAN A	PLAN B	PLAN D
Generating firm's management	++	--	-
Local water supply users	-		
Water supply authority	--	-	+
Fish experts	-	--	+
Fishermen, fish-related industry		-	
Environmentalists	--	-	+

Key: see Table 8.

costs). Although the probability of the fish threat materializing is unknown, the firm would not have to be very risk averse to prefer plan D to plan B. Returning to the parties-at-interest analysis, it will be noted that all parties perceive negative impacts for plan B, which confirms the general unattractiveness of this plan.

Decision-Making

If plan B is dropped from futher consideration, the choice is between plans A and D, and involves reduced control costs and greater damage potential if A is preferred to D. If plan A is selected, the present value of the control costs discounted over the 20-year project is $663,700 less than for plan D (i.e., $426,000 versus $1,089,700). On the other hand, plan A poses the threat of water contamination (Threat Scenario I) with its clean-up costs and the need to find an alternative disposal method if deep well injection does contaminate the water supply. The threats from transport accidents (Scenario III) and from flash floods at the secure landfill (Scenario IV) appear to be so minor that they can be neglected. Nevertheless it was important to recognize them, and demonstrate (or obtain consensus judgment) that they could be disregarded.

If plan A were adopted, and problems with the deep well scheme developed after (say) five years, the <u>additional</u> costs of taking the corrective action described under Threat Scenario I and switching to plan D for the next 15 years would have a present value of $1,895,000 when discounted at 10 percent per year. (Note that it was necessary to select a time at which the threat is assumed to materialize in order to be able to calculate a present value.) Thus, assuming that the mitigating measures prove successful and that the data above completely and accurately represent the choice, the economic question becomes: is it worth risking an unknown probability of future costs that have present value of $1,895,000, in order to save certain future costs that have a present value of $663,700? If the decision-maker disregards equity and is not risk averse, he will favor plan A when its expected value is lower than that of plan D. This will occur if the probability of water contamination (Threat Scenario I) is less than 35 percent (i.e., $663,700 ÷ $1,895,000).

A 35 percent probability that contamination will occur seems quite high. There is no known reason why contamination should occur, so on this basis a decision-maker who is not unduly risk averse would probably favor the deep well injection plan. However, he must consider some other factors before making a final judgment. First, there is a slight possibility that if water contamination occurs, the mitigating measure of drilling additional wells and counterpumping to reverse waste migration might be unsuccessful. In this event a new water supply would have to be piped in at a cost of tens of millions of dollars. Although this possibility is not formally analyzed, its existence will encourage the decision-maker to be risk averse.

Secondly, he should consider equity. If he favors plan A over plan D, the waste-generating firm will gain economically[1] but the local residents will be at risk. However, should the threat of contamination materialize, the water supply authority would be able to bring a suit for damages against the generating firm. Hence, although at first sight plan A is inequitable because benefits and risks accrue to different parties-at-interest, there is a mechanism that --at least in theory--is capable of redressing this inequity.

Finally, the decision-maker must consider the less tangible factors. Are the local residents and environmentalists highly disturbed about the waste injection proposal? If so, they will be subjected to psychological damages not

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(1) Benefits to the firm will ultimately be returned to society via lower prices or higher net income, so a decision-maker who takes the societal view will not necessarily oppose a plan that benefits a firm while putting the public at risk.

accounted for in the dollar costs discussed above. How important is the option value associated with not contaminating the saline aquifer? Are there any other factors that have not been considered? Public hearings could be used to gauge the strength of local feelings and concerns.

Even if a decision-maker does not consider the personal risk of making a choice that is later perceived to be a poor one, the issues are complex. Excessive risk aversion will reduce society's welfare just as excessive risk proneness will. Each decision-maker must formulate his own trade-offs between the various factors. However, it is hoped that by laying out the principal features involved in the alternatives as illustrated above, the decision-maker's task can be made easier. He must, however, still make the decision.

CHAPTER 5

RESEARCH FINDINGS

Summary Of Findings

It has been shown that the management of hazardous waste has certain features that from the economist's viewpoint differentiate it from that of common wastes or pollutants. A basic characteristic of hazardous wastes is that they pose far stronger threats to man or the environment than other wastes. Because of the strength of the threats, waste management techniques that may be acceptable for non-hazardous wastes, such as using the assimilative properties of the environment, are not suitable for hazardous wastes, and techniques that are intended to minimize the exposure of these wastes to the environment must generally be used. Consequently, when analyzing the potential damages from hazardous wastes, the economist or decision-maker is largely concerned with threats or risks (e.g., from the failure of waste management techniques) rather than with predictable environmental impacts.

Many hazardous wastes are non-degradable or persistent. This implies that environmental effects may be irreversible, and that it could be necessary to consider management techniques that provide for the "perpetual care" of these wastes.

Some hazardous wastes are biologically magnified or have cumulative effects on organisms. Waste stream compositions are subject to substantial variation, and when the wastes contain multiple components, antagonistic and synergistic effects can occur. Although most of these characteristics may also be found in non-hazardous wastes, they are particularly significant to the analysis of hazardous waste management, as they make it difficult to determine the precise nature of the threats that are posed by hazardous wastes.

The author asserts that because of the special characteristics of hazardous wastes, traditional approaches to the economic analysis of pollution control will often be inappropriate, and comprehensive cost-benefit or risk-benefit studies may be neither feasible nor warranted for many hazardous waste problems. Instead, the author proposes a methodology for the analysis of hazardous waste management alternatives that is comparatively simple to apply and which has modest data requirements. At the same time, the methodology encourages a decision-maker to examine the sociological aspects of a situation and to evaluate the effects of whatever degree of risk aversion that he favors.

Determining control costs for hazardous waste management presents no special problems; the major analytical difficulty lies in the uncertainties associated with damage functions. Conventional analysis of environmental damages starts by determining pollutant emissions, evaluates exposures and consequent effects on organisms, and then attempts to place a dollar value on these effects. Instead, a central feature of the methodology proposed in this dissertation is the use of environmental "threat scenarios." These could be derived from modeling studies, but they can also be based on previous experience, public fears or worst case assumptions. Some of the effects of these threat scenarios may readily be valued using well established techniques, but others may prove difficult to translate into dollar terms. However, the mere description of plausible threat scenarios is valuable because it helps to identify the "parties-at-interest," which are groups of individuals, firms, etc, that are affected in a common manner by some hazardous waste management alternative.

Identification of parties-at-interest is another key feature of the methodology, as it helps a decision-maker to recognize differing attitudes and viewpoints on hazardous waste management. It also encourages him to consider equity since it highlights the distribution of favorable and unfavorable effects. The methodology utilizes a simple conceptual model of the socioeconomic interaction process which focuses on the effects that hazardous waste management techniques will have on the parties-at-interest, and their responses to these effects. These responses will in turn influence the outcomes of the use of any particular approach to hazardous waste management. The author was able to include some broad indications of the likely attitudes and behavior of the parties-at-interest, derived from hazardous waste management practitioners and the attitudinal literature. A decision-maker should be able to supplement these data with his perceptions of any specific situation. The local viewpoint may be important because responses of the parties-at-interest to environmental threats will depend on their perceptions of those threats, irrespective of the true probabilities and magnitudes.

Because hazardous waste management decisions are normative, a decision-maker must usually make the final choice among alternatives, examining them against the agency's objectives and deciding on preferred trade-offs. However, some alternatives can be eliminated because they are dominated by others, i.e., where both quantifiable and nonquantifiable costs are higher for one alternative than another, and the nature and distribution of the costs is similar for both. Ultimately, the critical aspect of decision-making will usually be to decide on an appropriate degree of risk aversion. Research on risk evaluation, i.e., determination of the acceptability of risks to society, has provided some useful background information on the public's perceptions of risk. However, this research cannot at present provide the specific guidance that a decision-maker would need to choose between hazardous waste management alternatives. Deciding on an appropriate degree of risk aversion remains his most difficult problem.

This dissertation identifies the various techniques that may be used for hazardous waste management and analyzes the environmental threats and other effects that can arise from the use of each technique. It provides a general indication of the effect that each technique is likely to have on each party-at-interest. The study includes an extensive discussion of methods that may be employed to value environmental effects, but recommends against attempting to value all effects: some may better be described and taken subjectively into account by a decision-maker. This may occur where data or valuation techniques are inadequate, or where the nature of the effect depends strongly on the individual's viewpoint. The author also offers a pragmatic solution (and some justifications for its use) to the problem of intergenerational discounting.

It is believed that the research described here meets the needs of analysts and decision-makers for a simple methodology for analyzing a variety of hazardous waste management problems. The methodology is adaptable to specific situations, is firmly based on economic principles and recognizes the sociological factors involved. When necessary, it can be used with comparatively limited information, but it can accept more sophisticated data when these are available. Ultimately, however, it requires a human decision-maker to choose between screened alternatives.

Recommendations

The methodology has been demonstrated using a simple example. In practice it is capable of dealing with more complex situations and it should be tested and, if necessary, developed to fulfill a decision-maker's needs under more complex circumstances. In particular, two of the linkages in the socioeconomic interaction model require further attention. These are the linkages between a policy-maker's objectives and the approaches (i.e., strategies) that may be used to control hazardous wastes; and between the approaches and the physical techniques that are actually employed. The use of non-regulatory policy elements such as incentives, subsidies and penalties has been extensively analyzed in the literature, but their application to practical hazardous waste management situations needs further investigation.

Since the methodology presented here uses threat scenarios, the EPA's policy of documenting and analyzing hazardous waste incidents is useful and should be continued. In addition, it would be valuable if modelling studies (e.g., of leachate movement from landfills) included typical results for commonly encountered situations as a help to threat scenario generation. Research on risk evaluation, and in particular on the psychometric "expressed preference" method (see Appendix D) is promising, and should now be developed to provide more specific guidance for common environmental decisions.

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APPENDIX A

HAZARDOUS WASTE MANAGEMENT TECHNIQUES

This appendix describes the techniques (listed in Table 2 of the main text) that may be used for the control (including disposal) of hazardous wastes.

Techniques Involving Waste Stream Changes

Process Change

In process change, the industrial process that generates the waste is changed. Substitution of a different process will normally result in a different waste being generated; the new waste could be inherently less hazardous or non-hazardous, or could be generated in smaller quantities than before. An example of process change is the replacement of the mercury cell by a diaphragm cell for chlorine production; it appears that this change-over (all new capacity is expected to use diaphragm cells) has been caused entirely by the problems associated with wastes and emissions from the mercury cell (Saxon and Kramer, 1974:90,92).

It is not necessary to substitute a new process to change the waste streams; in some cases process modifications, such as changing the operating conditions or adding process steps (including pollution control devices) could cause the composition of the wastes to change, but also might simply change the volume or concentration of the waste stream (Saxon and Kramer, 1974:10-12).

Source Reduction

With source reduction the basic composition of a waste stream remains unchanged (except perhaps for concentration) but the quantity of the waste is reduced. This may be achieved by process modification (including the more efficient use of materials), by changes in the quality of the material inputs, or by improving procedures to reduce production spoilage, etc. (Saxon and Kramer, 1974:12-13; U.S. Environmental Protection Agency, 1976b).

Waste Separation

Waste separation involves segregating waste streams in order to isolate those wastes that are hazardous from those that are not, or to keep apart wastes with different hazardous properties. In the former case the objective is to reduce the quantity of hazardous waste to be handled. In the latter case, it is presupposed that the mixed waste is more difficult or costly to treat or dispose of than the same total volume of waste made up of several streams, each of which contains a lesser number of constituents. This supposition is not universally valid, as there could be an antagonistic reaction between two waste streams (such as neutralization), or the economies of scale could outweigh any added complexities of treating or disposing of mixed wastes.

Resource Recovery

In resource recovery the magnitude and composition of the waste stream is unchanged, but some of the materials or the energy content of the stream are recovered and put to beneficial use.

Materials Recovery

Recovery of materials is often carried out in conjunction with various treatment processes (U.S. Environmental Protection Agency, 1974:9), and does not necessarily achieve total recovery of all materials present in the waste stream. In many cases only the more valuable or readily isolated constituents are recovered.

Energy Recovery

As an alternative to materials recovery, where the waste stream has a significant calorific value, energy recovery may be practiced. This usually involves burning the waste in some type of incinerator that is equipped with a heat exchanger to enable the heat to be used beneficially.

Waste Treatment

There are numerous treatment processes that may be used to render wastes less harmful. Table A.1 lists some of the processes that have been identified as being appropriate to the treatment of hazardous wastes. Details of these, and of other treatment processes, are provided in Ottinger, et al. (1973: Vols. 3 and 4). Many treatment processes are specific to a limited range of waste types, and for this reason are not discussed here.

Treatment processes do not eliminate the waste stream, although by separating out harmless components from those that are hazardous, some processes may significantly reduce the quantities of hazardous wastes that ultimately require disposal. Volume reduction by the evaporation of water, or the precipitation of hazardous solids leaving a non-hazardous effluent, are examples of such treatments. Some wastes can be rendered non-hazardous by treatment (e.g., neutralization of sulphuric acid), whereas in other cases the treatment may be a preliminary step towards disposal (e.g., a change of chemical form to reduce the waste's mobility or toxicity). Encapsulation, described below, is invariably followed by a storage or disposal process.

TABLE A.1 CURRENTLY AVAILABLE HAZARDOUS WASTE TREATMENT AND DISPOSAL PROCESSES[1]

Process	Functions Performed[2]	Types of Waste[3]	Forms of Waste	Resource Recovery Capability
Physical treatment:				
Carbon sorption	VR, Se	1, 2, 4, 5	L, G	Yes
Dialysis	VR, Se	1, 2, 3, 4	L	Yes
Electrodialysis	VR, Se	1, 2, 3, 4, 6	L	Yes
Evaporation	VR, Se	1, 2, 5	L	Yes
Filtration	VR, Se	1, 2, 3, 4, 5	L, G	Yes
Flocculation/settling	VR, Se	1, 2, 3, 4, 5	L	Yes
Reverse osmosis	VR, Se	1, 2, 4, 6	L	Yes
Ammonia stripping	VR, Se	1, 2, 3, 4	L	Yes
Chemical treatment:				
Calcination	VR	1, 2, 5	L	
Ion exchange	VR, Se, De	1, 2, 3, 4, 5	L	Yes
Neutralization	De	1, 2, 3, 4	L	Yes
Oxidation	De	1, 2, 3, 4	L	
Precipitation	VR, Se	1, 2, 3, 4, 5	L	Yes
Reduction	De	1, 2	L	
Thermal treatment:				
Pyrolysis	VR, De	3, 4, 6	S, L, G	Yes
Incineration	De, Di	3, 5, 6, 7, 8	S, L, G	Yes
Detonation	Di	6, 8	S, L, G	No
Biological treatment:				
Activated sludges	De	3	L	No
Aerated lagoons	De	3	L	No
Waste stabilization ponds	De	3	L	No
Trickling filters	De	3	L	No
Soil application	De	3	L, S	No

[1]Adapted from: U.S. Environmental Protection Agency, 1974:9.

[2]Functions: VR, volume reduction; Se, separation; De, detoxification; and Di, disposal.

[3]Waste types: 1, inorganic chemical without heavy metals; 2, inorganic chemical with heavy metals; 3, organic chemical without heavy metals; 4, organic chemical with heavy metals; 5, radiological; 6, biological; 7, flammable; and 8, explosive.

[4]Waste forms for which process is feasible: S, solid; L, liquid; and G, gas.

Encapsulation

Where a waste is not readily amenable to a detoxification treatment, it may be desirable to immobilize it in some way so that control can more readily be maintained over it. Encapsulation is often used to prevent (or at least severely retard) leaching and consequent contamination of groundwater. The technique is commonly applied to low level radioactive wastes[(1)] (Ottinger, et al., 1973:131-134, 140-142, Vol. 4). Hazardous wastes may be encapsulated by mixing the waste with concrete, asphalt and various plastics[(2)] (such as polyethylene or polyurethane) (Fields and Lindsey, 1975:21-22). Often, for convenience, the waste and encapsulating medium are solidified in a steel drum, and it is sometimes possible to use off-specification resins as the encapsulating medium. The resulting mixture is typically 60 percent (by weight) of waste when mixed with a resin, but only 25 percent waste when encapsulated in cement (Ottinger, et al., 1973:140-142, Vol. 4).

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(1) In radioactive waste management, the term high-level is applied to wastes in which there is significant heat generation arising from radioactive decay; low-level wastes are those in which this effect is not significant.

It is interesting to note that Federal regulations require the conversion of commercial high-level liquid wastes to a stable solid form preparatory to "terminal storage" (Energy Resources Council, 1976:5).

(2) Encapsulation in glass has been proposed for high-level nuclear wastes (U.S. Energy Research and Development Administration, 1977).

One encapsulation technique, recently developed specifically for hazardous chemical wastes, agglomerates the waste in polybutadiene and then jackets the agglomerates in a thin layer of polyethylene. The attraction of this technique is that the waste can constitute 94 to 96 percent of the agglomerate, but nevertheless the process is still costly (Wiles and Lubowitz, 1976).

Incineration

There are three hazardous waste management techniques that fall on the borderline between treatment and disposal. These are incineration, land application and lagooning. Incineration is discussed immediately below, while land application and lagooning are discussed later.

Incineration has wide potential application to hazardous wastes. It is a controlled process that uses combustion to convert the waste to a less bulky, less toxic or less noxious material. The principal products of incineration are carbon dioxide, water and ash, but products of primary concern (due to their deleterious effects) are compounds containing sulphur, nitrogen and halogens. Where the combustion products from an incineration process contain undesirable compounds, secondary treatment such as after-burning, scrubbing or filtration is required to lower concentrations to acceptable levels for atmospheric release (Ottinger, et al., 1973:83, Vol. 3). Thus incineration largely converts the waste to a harmless gaseous form, usually leaving only comparatively small quantities of ash and scrubber sludge that require disposal.

There are many different types of incinerators that can be used on industrial wastes, and different types of incinerators can handle solid, liquid or gaseous wastes. Ottinger, et al. (1973: Vol. 3) and Powers (1976) provide detailed descriptions of the various types, while Scurlock, et al. (1975) specifically discuss incineration in hazardous waste management.

There are four technical characteristics that affect waste incineration (Ottiger, et al., 1973:84, Vol. 3). The first is combustibility, i.e., a measure of the ease with which a waste can be oxidized in a combustion environment. The next two are dwell or residence time in the combustor and the flame temperature. These parameters affect the degree of combustion. The fourth is the turbulence present in the reaction zone of the incinerator, which is required to insure sufficient mixing of the air and the waste fuel.

Since turbulence and dwell time are determined by the incinerator design, while for a given incinerator, flame temperature can be varied within certain limits, it follows that different incinerators will be more or less appropriate to the treatment of different wastes. While high temperature capability incinerators with long dwell times would usually be capable of adequately treating wastes that need only low temperatures and short dwell times, such incinerators are more costly to build and operate than low temperature incinerators. Hence economic as well as technical factors limit the appropriateness of a given incinerator design for treating different wastes.

Clearly it is a prerequisite of incineration that the total materials stream entering the incinerator has a high enough calorific value to achieve the desired dwell time and temperature; if the waste cannot fulfill this requirement it can be supplemented with a fuel. However, where the calorific value of the waste stream is itself sufficiently high, it is possible to recover energy from the waste via a heat exchanger and hence generate power, process steam or use the surplus energy in some other useful way.

Among the most attractive candidates for incineration are organic wastes (including many pesticides) which are hazardous due to the structure of the molecule (for example, "synthetic organics" such as PCB's), rather than those which are hazardous due to elements which make up the molecule (e.g., wastes containing heavy metals). Incineration may be attractive for the disposal of many ordnance wastes and for some inorganic wastes (Ottinger, et al., 1973: Vol. 1); Powers (1976:56-61) and Scurlock, et al. (1975) provide lists of materials that may be suitable for incineration, both largely based on Ottinger, et al.

A very specialized form of incineration is that of incineration at sea using purpose-designed ships. This is discussed under ocean dumping.

Storage And Disposal Techniques

Land Application

Land application involves spreading or spraying of wastes over large areas of land. This technique is often used for certain non-hazardous wastes such as waste water (Stewart, 1973; Pound, Crites and Griffes, 1975), sewage sludge, animal and food processing wastes and certain industrial wastes where the waste contains materials (nutrients or soil conditioners) that should enhance crop growth (Loehr, 1977; U.S. Environmental Protection Agency, 1977b: 245-293). Land application is sometimes used for some biodegradable hazardous wastes, primarily oil-related wastes[3] (Snyder, Rice and Skujins, 1976; Park, 1977; Lofty, 1977)

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(3) Waste petroleum oil has been regarded as hazardous by some authors and as non-hazardous by others. (See Jacobs Engineering Co., 1976.)

and the EPA is investigating its effectiveness for other industrial sludges (Schomaker, 1976:12). Naturally, land application should be used only where there is careful control of access to the land and of its future use, and it is inappropriate for any waste that contains appreciable quantities of non-biodegradable hazardous components.

Landfilling

The term landfilling will be used to denote any type of land burial of wastes close to the surface (as opposed to engineered storage, mine disposal and deep well injection). The technique is commonly used to dispose of many types of solid wastes and sludges, but is also used to dispose of liquids (which are poured onto the more solid components). There is an extensive body of literature on landfill disposal of hazardous wastes (e.g., Fields and Lindsey, 1975; Fuller, 1976; Ghassemi and Quinlivan, 1975), and on the physical effects that may arise from landfilling (e.g., Geyer, 1972; Fungaroli, 1971; Genetelli and Cirello, 1976; Hill and Zipp, 1974; Banerji, 1977; Garland and Mosher, 1975; Pavoni, Hagerty and Lee, 1972; Schultz, 1978). The material below is based on these and other sources.

Types of Landfills

Open Dumps: The least sophisticated form of land disposal is the "open dump." In such dumps, a waste is simply deposited on the ground and left. Clearly, the open dump is an inappropriate means for disposing of any hazardous waste; it would only be acceptable (aesthetics aside) for inert waste such as some demolition debris.

Sanitary Landfills: The sanitary landfill [e.g., California Class II landfill (California State Water Resources Control Board, 1976)] provides for some environmental protection from the wastes. In a sanitary landfill, the wastes are compacted to the smallest practicable volume and are covered, usually daily, with earth. These procedures minimize problems with blowing litter and with vector (animals and insects). Waste compaction and a cellular construction of the sanitary landfill also reduce the possibility of fire, and of its spread should one occur (U.S. Environmental Protection Agency, 1976a:109-117). Microbial decomposition of wastes results in the generation of gases (principally methane and carbon dioxide) which are generally regarded as a problem, but there have been some successful methane recovery projects (U.S. Environmental Protection Agency, 1976a:115-6).

The hydrologic conditions at a landfill are of great importance. Groundwater or infiltrating surface water moving through solid waste can produce leachate, a solution containing dissolved and finely suspended solid matter and microbial waste products. The composition of the leachate naturally depends on the waste composition and also on the physical, chemical and biological activities within the fill. Leaching can be minimized by landfill designs that restrict the ingress of surface water, but some authorities hold that generation of leachate is probably inevitable (Brunner and Keller, 1972).

Where annual precipitation is low in comparison with potential evapotranspiration, over the course of a year actual evapotranspiration may balance infiltration resulting in zero net percolation and hence negligible long run leachate production (Fenn, Hanley and DeGeare, 1975). This situation is characteristic of Southern California (Fenn, Hanley and DeGeare, 1975) where large quantities of liquid wastes are routinely injected into landfills only to "disappear" (Park, 1977). Nevertheless, even in arid areas where leachate production is expected to be negligible, a good landfill design will attempt to restrict the potential environmental damage that could be caused by a leachate. In areas with less favorable climates, e.g., Cincinnati, Ohio; Orlando, Florida, (Fenn, Hanley and DeGeare, 1975) where leachate production is inevitable (unless of course the surface or near surface of the landfill is rendered impervious), some means of isolating the leachate from groundwater is essential to provide complete environmental protection.

Chemical Landfill: The chemical landfill (e.g., California Class I landfill (California State Water Resources Control Board, 1976) is designed to accept industrial wastes that may include hazardous wastes. In a chemical landfill particular attention is paid to minimizing the potential for leachate contamination of water sources. Thus, a chemical landfill should be designed so that any surface water run-off is collected and treated, and that there is virtually no chance of leachate percolating into any aquifer.

Isolation of Landfill Contents From the Environment

There are three principal means available to minimize the probability that the leachate(4) can contaminate groundwater(5): geologic isolation; landfill liners and leachate collection systems.

Geologic Isolation: Geologic isolation involves selecting the landfill (or lagoon) site such that there is

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(4) In this dissertation the term leachate will be used to denote any aqueous-based liquid that may emanate from a landfill or lagoon (discussed later). Thus, the leachate may be generated either by the interaction of environmental water (precipitation, surface water or groundwater) with an essentially solid waste as described above, or it may be the aqueous component of a liquid or semi-liquid waste that is sufficiently mobile to be able to leave the landfill or lagoon.

(5) The primary concern is contamination of a potentially usable aquifer, rather than contamination of small lenses of "perched" groundwater which are not significant as potential water supply sources.

no natural hydrologic interconnection between the fill and aquifer. This condition may be fulfilled if the permeability of the soil or rock that separates the landfill from any aquifer is sufficiently low (i.e., essentially zero). This approach is favored by the California Class I landfill regulations, which specify geologic isolation for vertical water movement, but which permit liners to control lateral movement. A modification of this approach is found in arid areas, where natural leachate generation (i.e., that resulting from the infiltration of external sources of water) plus any liquid emanating from the waste, is expected to be slight. In this case, provided the vertical distance to groundwater is sufficiently large, there is less concern over the permeability of the intervening strata on the assumption that the total quantity of leachate generated will be insufficiently great to percolate down to the groundwater.

Many soils have the capacity to attenuate leachates that pass through them, or to render these leachates less hazardous (e.g., Roulier, 1977; Farquhar, 1977). This can be regarded as a form of treatment, but if the mechanism is that of ion exchange (as opposed to microbial action) the treatment capacity, although often very large, will not be unlimited, since there is no regeneration mechanism.

Landfill Liners: Liners usually comprise either a layer of impervious soil (such as clay), asphalt or a polymeric membrane (Haxo, Haxo and White, 1977; Geswein, 1975), and may be used to replace or supplement[6] geologic isolation to provide separation from groundwater. Some of these materials could also be used to cap a completed landfill to prevent the ingress of surface and near-surface waters. There is one important difference between complete geologic isolation and the use of a liner; due to the comparative thinness of a liner, in most cases it is probably only a matter of time (in the context of "perpetual care") before the leachate penetrates the liner.

Leachate Collection Systems: Where significant leachate production is expected, something must be done with the leachate. Leachate collection systems can be used to divert the leachate into treatment or holding tanks. Even if a collection system does not collect all the leachate, the quantity that is available to threaten aquifers is reduced, leading to a potentially more secure operation. Collection systems often comprise a porous medium (e.g., loam or

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(6) For example, a liner could be used to provide a seal over a faulted or fissured zone of an otherwise impervious stratum, or could be used to control the sideways movement of leachate where geologic isolation is effective in the vertical direction.

gravel) which permits the leachate to migrate into headers for collection and treatment. The porous medium is placed on top of a liner or other impervious layer (Fields and Lindsey, 1975). Of course, the collected leachate will usually constitute an additional hazardous waste that must be appropriately managed, e.g., by precipitating a sludge which is returned to some form of land disposal.

Mine Disposal

Disposal of hazardous wastes in underground mines has been proposed for both radioactive and non-radioactive wastes. The attraction of the approach lies in the high degree of environmental protection that can be provided by such storage due to the impermeability and geological stability of the candidate formations. The material of the greatest interest is salt formations (both bedded and domes), followed by gypsum and potash; but shale, limestone and granite formations have also been considered (Stone, et al., 1975). The most widely accepted concept is to place the solidified containerized wastes in disused room and pillar salt mines (Kown, et al., 1977). This means of disposal has substantially greater direct economic costs than landfilling, especially if it is necessary to construct a mine for this purpose, rather than to adapt an abandoned mine. Another feature of this approach is that provision can be made for future retrieval of the waste.

Lagooning

Lagooning involves placing liquid wastes in open ponds, and may incorporate some of the chemical or biological treatment processes listed in Table A.1, such as biological oxidation via aerated lagoons or oxidation ponds (Ottinger, et al., 1973:21-43, Vol. 4). Where the evaporation rate is sufficiently high,(7) lagooning really constitutes a treatment process for volume reduction, in other cases it is more appropriately regarded as a storage technique; in either case quantities of sludges and/or solids will ultimately require disposal.

Since the contents of a lagoon are at least in part liquid, protection of the groundwater below and adjacent to the lagoon is of particular significance. The techniques that can be used to achieve this have already been discussed under landfilling. It is also important to insure that the lagoon does not overflow and thereby contaminate surface waters, and that birds are protected by being discouraged from landing on the surface.

Deep Well Injection

Deep well injection involves disposing of liquid wastes by pumping them into "deep wells," whereby the wastes become

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(7) I.e., where open pan evaporation significantly exceeds precipitation.

contained within the interstices of the rock. This procedure has been used for decades to dispose of oil field brines, and is now an accepted means of disposal for such wastes (Reeder et al., 1977). Wapora has catalogued all the wells used for injection of industrial wastes (excluding oil field brines) in the U.S. (Wapora, Inc., 1974). Over half the wells have been constructed in Texas and Louisiana, and 68 percent serve SIC 28 and 29 (chemical and allied products and petroleum refining industries).

The term "deep well" may be something of a misnomer, as the concept merely involves disposing of the waste in formations that are below usable aquifers. Nevertheless, 90 percent of the 278 U.S. wells identified by Wapora, Inc. (1974) used for injecting industrial and municipal wastes, were over 305 meters deep.

Virtually all deep wells used for industrial waste disposal inject into sands, sandstones and carbonates (Wapora, Inc., 1974). Suitable strata almost invariably contain saline groundwater, and hence injected wastes will displace and/or mix with this groundwater. Because any solid matter will plug the host rock pores, it follows that only filtered liquids that are compatible with the host fluid (i.e., do not form precipitates) can be injected. Rock fracturing to increase permeability is feasible under certain circumstances

(Reeder, at al., 1977:60-63). There is an extensive body of literature on deep well waste injection (Rima, Chase and Meyers, 1971; Cook, 1972) and the topic has been well summarized by Warner and Orcutt (1973).

Ocean Dumping

Ocean dumping has been a common means of disposing of unwanted materials for centuries (Miller, 1973). Although the quantities involved have been dominated by dredge spoils, significant quantities of sewage sludge and industrial wastes were dumped in the 1960's, together with smaller quantities of construction and demolition debris, solid waste, explosives and radioactive wastes (Council on Environmental Quality, 1970).

It is the policy of the Marine Protection, Research and Sanctuaries Act of 1972, to strictly limit the ocean dumping of any material which would adversely affect the marine environment (U.S. Environmental Protection Agency, 1977a), and in recent years the quantities of industrial wastes that have been dumped off the U.S. coast have declined significantly.

There are three basic techniques for the disposal of wastes:

(i) bulk disposal of liquid or slurry/sludge wastes using specially constructed barges.

(ii) scuttling vessels filled with wastes (usually obsolete munitions).

(iii) the sinking at sea of containerized wastes (e.g., in 55-gallon drums) which are carried as deck cargo on merchant vessels.

Depending on the details of the techniques and the waste involved, the ocean may be used as a reacting or neutralizing medium, as a diluent, as a cushioning medium (for detonated explosives) or for "protective isolation" (Ottinger, et al., 1973:59,60, Vol. 3). In general, ocean dumping sites avoid estuarine locations, and while some of the barged disposal uses comparatively shallow water, containerized wastes and vessels are scuttled in the deep sea (Smith and Brown, 1971:3-24).

The type of waste strongly affects its physical disposition. Hazardous wastes that would float are clearly unacceptable for ocean disposal. Wastes that are considerably denser than seawater fall to the ocean floor and any dispersion that occurs will be via ocean bottom processes. Most aqueous-based wastes, on the other hand, have densities similar to seawater and can diffuse widely (Ocean Disposal Study Steering Committee, 1976:28). Clark, et al. (1971) review these physical diffusion processes and also discuss disposal economics.

A variety of data on the practice and impacts of ocean disposal may be found in the literature (Council on Environmental Quality, 1970; Ocean Disposal Study Steering Committee, 1976; Smith and Brown, 1971; Reed, 1975; Interstate Electronics Corporation, 1973).

Incinerator Ships

Incinerator ships can be considered as a special case of ocean dumping. While the objective of incineration is to thermally degrade the hazardous material, it is almost inevitable that a small proportion of the waste will escape degradation. Further, the products of degradation may themselves be hazardous and require some form of disposal. Thus, by conducting incineration at sea, the wastes emitted from the incinerator are widely dispersed, which may be more environmentally accepted than using similar incineration equipment on land. This technique has been in use in Europe since 1968 (Powers, 1976:131).

Incineration of U.S. organochlorine wastes has been conducted on a experimental basis in the Gulf of Mexico using the Dutch incinerator ship M/T Vulcanus. The incinerators achieved upwards of 99.9 percent oxidation of the wastes, and the resulting emissions (which included hydrogen chloride) were discharged to the atmosphere without scrubbing (Wastler, et al., 1975). Had a similar operation been performed on land, scrubbing would doubtless have been required to provide environmental protection from the hydrogen chloride (see, Maritime Administration, n.d.).

Engineered Storage

As already indicated, most forms of disposal amount to storage, as it is not possible to eliminate matter. However, the term engineered storage is usually reserved for the emplacement of wastes into man-made structures (as opposed to, say, burial in the ground).

This technique is largely advocated for high-level radioactive wastes and for other wastes for which no satisfactory alternative means of disposal exists. The intention is that the wastes are stored under very carefully controlled conditions until a safe means of disposal can be found; for this reason provision for easy retrieval must be an integral part of the design (U.S. Environmental Protection Agency, 1974:64).

Other Techniques

Disposal into space has been proposed for certain radioactive wastes (Battelle N.W. Laboratories, 1976: Ch. 26) and represents a unique concept. As far as the author is aware, it has not been proposed for non-nuclear wastes, doubtless because of its extremely high direct costs.[8]

All other techniques that have been proposed appear to constitute subcategories or special cases of those discussed above. For example, thermal treatment can be split into four principal subcategories, which are (in descending order of control maintained over the waste and its decomposition products): pyrolysis, incineration, open burning and detonation. At least some of these subcategories are capable of further division, as already illustrated for incineration. Even ice sheet disposal [proposed for some radioactive wastes (Battelle N.W. Laboratories, 1976:25.52-25.58)] can be regarded as a special case of land disposal, since many of its features and potential threats to the environment are similar to the more conventional forms of land disposal already discussed.

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(8) In excess of $2,000 per kilogram of waste, including containers (Battelle N.W. Laboratories, 1976:26.3).

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APPENDIX B

ENVIRONMENTAL THREATS ASSOCIATED WITH HAZARDOUS WASTE MANAGEMENT TECHNIQUES

This appendix discusses some of the more important threats to man and the environment associated with hazardous waste management techniques.

The Nature Of Hazardous Waste Threats

This section characterizes the threats, commencing with threats that are applicable to many techniques, followed by the threats that are more specific in nature. (The sequence followed is the same as in Table 5.) In some cases models or numerical data are available and can be used to provide estimates of the magnitude of the impacts, while in others only descriptive scenarios are feasible. [Ott (1976) provides much information on environmental modeling techniques.] Probabilities that threats will occur are largely discussed later in this appendix, and the economic implications of the threats are discussed in Appendix C.

In-plant Accidents and Other Events

Within the manufacturing plant that generates the waste a threat of some sort of accident or operational failure exists irrespective of the waste management technique employed, unless all hazardous wastes are eliminated. However, the probability of occurrence and potential consequences may change with different control techniques. In an assessment of hazardous waste management alternatives (as opposed, for example, to examining the total costs and benefits of using a particular substance or manufacturing a particular product), it is only differential effects between alternative approaches that are of interest. Thus, where a given waste (type, form and quantity) is generated and is shipped out of the plant without treatment for disposal or resource recovery, the probability and consequences of in-plant waste-related accidents should be constant. However, where the waste stream itself changes--arising from process change or in-plant resource recovery operations--the probability, nature and consequences of in-plant accidents may vary. Likewise, the probability of in-plant accidents may change if the waste is subjected to an on-site treatment process prior to disposal.

The location (on or off the manufacturing site) of final disposal need not affect the occurrences of in-plant accidents, as accidents and other events associated with on-site disposal can be regarded as disposal threats rather than in-plant accidents. However, wastes are often stored prior to disposal--sometimes for long periods while waiting for an appropriate disposal method to be developed--and accidents arising from such storage can conveniently be included with in-plant accidents.

While it is not difficult to generate scenarios for in-plant accidents associated with hazardous wastes, statistical data on such accidents are not generally available. The problem is that official industrial accident data [e.g., data on occupational illness and injury at manufacturing plants (U.S. Department of Labor, 1976)] do not usually differentiate between those involving wastes and those involving other materials.(1) Buckley and Weiner (1976) have collected numerous data from insurance loss records, newspaper reports and other sources that provide a useful indication of the causes and size distribution of hazardous material spills, but in many cases it is not known whether or not the material was a waste.

Possible in-plant accident scenarios that can directly affect man will largely be related to spills and emission of materials that can cause acute human poisoning by absorption through the skin or inhalation (Munn, 1975). Poor plant practices could also result in systematic exposure

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(1) Data are available on accidents and illnesses arising in SIC 495, Sanitary Services, which could encompass various disposal techniques (U.S. Department of Labor, 1976). However, these data are likely to be dominated by accidents in sewage works and in regular refuse collection.

leading to chronic poisoning. Chronic poisoning from industrial chemicals is considered by some authors to be a far greater threat to workers than acute poisoning (Munn, 1975), but statistical data are sparse as in many cases it is difficult to relate chronic illnesses to industrial exposure.[2]

Environmental damage and indirect threats to man could arise from failure or overflow of storage tanks, operating lagoons, containment dikes and sumps, which could result in destruction of vegetation and a variety of surface and groundwater pollution problems. Where wastes are flammable or highly reactive, fires and explosions could occur. Methodologies for calculating the physical effects and probabilities of many of these incidents for specific materials are presented by Arthur D. Little, Inc. (1975).

Transportation Accidents

Comparatively good data are available on the nature and frequency of transportation accidents. Many of these specifically address hazardous materials (Booz, Allen and Hamilton, 1970; National Academy of Sciences, 1976; Smith, 1976; Jones, et al., 1973). Typical hazardous material spill frequency and size data are given in Table B.1. Unfortunately,

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(2) Some clear cut exceptions--such as black lung disease and asbestosis--arise where a substantial industrial sector is exposed to a single disease-causing material.

TABLE B.1 SELECTED TRANSPORT ACCIDENT STATISTICS

Unless otherwise indicated, all data are events per billion kilometers.

Source and Details	Mode of Transport		
	Truck	Rail	Water (Barge)
Arthur D. Little[a]			
Hazardous chemicals			261[b]
Flammable liquids		144[c]	
Corrosive liquids		186[c]	
Tank Trucks (involving cargo loss)	17[d]		
Booz, Allen & Hamelton[e]			
Hazardous materials (Projections to 1980)	1119	20	0.68/billion tonne-km
Jones, et al.[f]			
Hazardous materials	1057[g]	8-11[h]	
Autos, all accidents	2140-12500[i]		
Arthur D. Little[j]	22[k]	12[l]	

SOURCES AND NOTES

[a]Arthur D. Little, Inc., 1975:29, 30; based on Arthur D. Little, Inc., 1974.

[b]Typical large capacities are up to 1816 tonnes (2000 short tons). Average spill size is approximately 48,450 liters.

[c]For 1965-70.

[d]For 1968-72. Typical tank capacities range from 22,700 to 37,850 liters (6,000 to 10,000 gallons). The average spill size is about 11,350 liters.

[e]Booz, Allen and Hamilton, 1970:15.

[f]Jones, et al., 1973:99-102.

[g]Based on FHA data for large carriers.

[h]For 1960-68; data may be conservative.

[i]Based on a variety of sources. (It is claimed that vehicle size does not affect accident frequency.)

[j]Arthur D. Little, Inc., 1973:111, Vol. II.

[k]For tank trucks, based on data from National Tank Truck Carriers Conference.

[l]For railroad cars, based on data from Association of American Railroads and Federal Railroad Administration.

the accident probability statistics show considerable diversity, depending on source and coverage.

Some authors emphasize the likely outcome of transportation accidents (Arthur D. Little, Inc., 1975; Jones, et al., 1973; Angell and Kalelkar, 1974), sometimes indirectly via studies of the control of hazardous material spills (Dawson, Skuckrow and Swift, 1970; Anon., 1974). The emphasis in most of these studies is on damage to human life and to property, especially through the mechanisms of fire and explosion.

Very few authors attempt to analyze the impact of transporation accidents on flora or fauna (non-human). In a paper that addresses choices in risk situations via the determination of a decision maker's utility functions, Kalelkar, Partridge and Brooks (1974) use a thirteen point scale to indicate the severity of land-based environmental impacts that are expected to arise from typical accidents during the transportation of specified hazardous materials. This scale, which is used in conjunction with the area affected, is shown in Table B.2.

Spills Into Water

Dawson and co-workers have addressed the problem of spills of hazardous materials (from both transportation

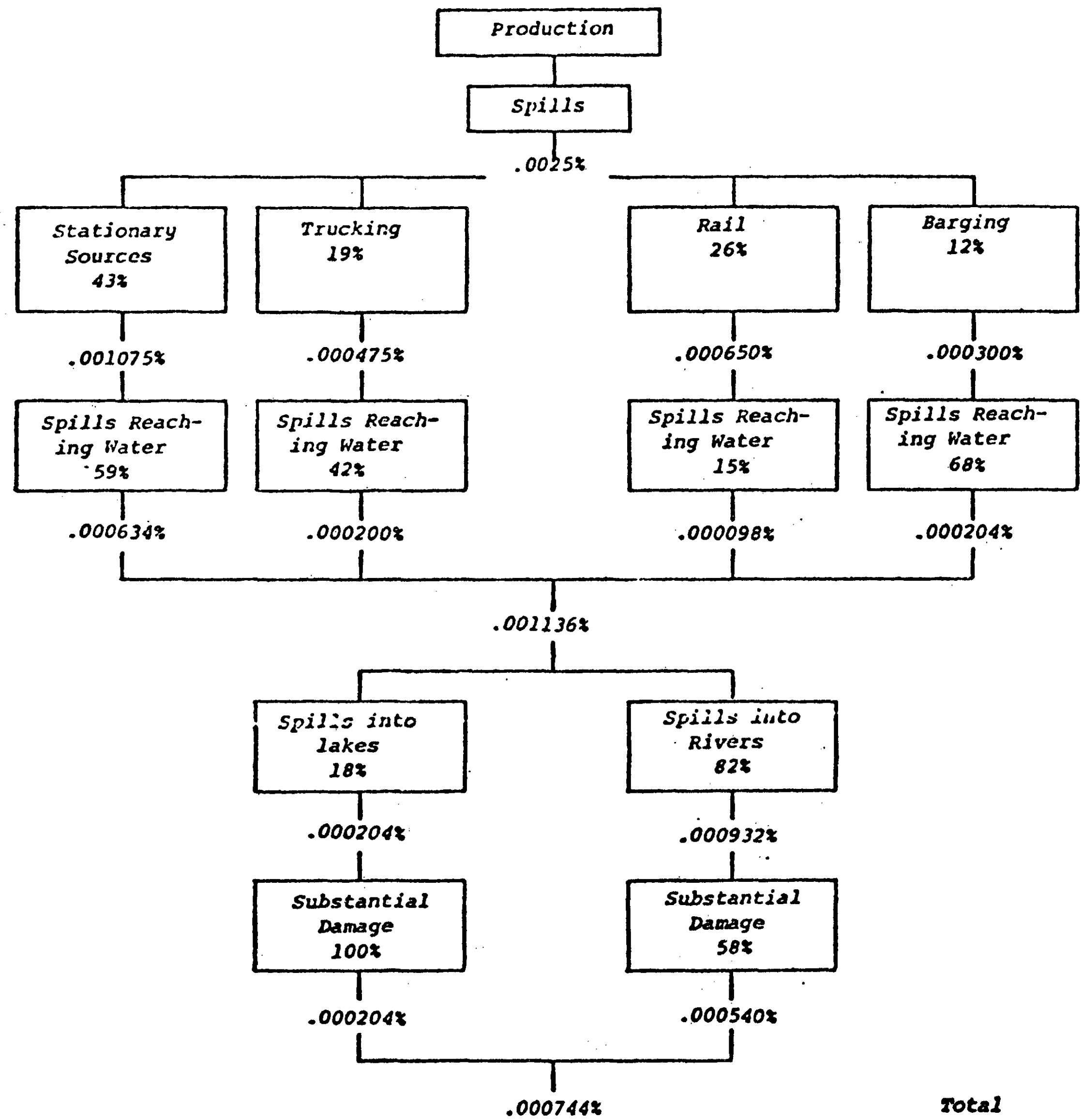
TABLE B.2 SCALE FOR ENVIRONMENTAL EFFECTS FROM HAZARDOUS CHEMICAL SPILLS

1. No effect.
2. Residual surface accumulation of harmless material such as sugar or grain.
3. Aesthetic pollution (odor-vapors).
4. Residual surface accumulation of removable material such as oil (requires more costly measures of abatement).
5. Persistent leaf damage (spotting, discoloration) but foliage remains edible for wildlife.
6. Persistent leaf damage (loss of foliage) but new growth in following year.
7. Foliage remains poisonous to animals (indirect cause of some deaths upon ingestion).
8. Animals become more susceptible to predators because of direct exposure to chemicals and a resulting physical debilitation.
9. Death to most smaller animals (consumers).
10. Short term (one season) loss of producers (foliage) with migration of specific consumers (those who eat the specific producer). Eventual reforestation.
11. Death to producer (vegetation) and migration of consumer (animals).
12. Death to consumers and producers.
13. Sterilization of total environment (decomposers, consumers, producers) with no potential for reforestation or immigration of species.

Source: Kalelkar, Partridge and Brooks, 1974:340.

accidents and stationary sources) that reach surface water-courses (Dawson, Stradley and Shuckrow, 1975:Vols. II and IV; Dawson and Stradley, 1975). Their approach determines the proportion of annual production of each material of interest that is spilt, and follows this through to provide an estimate of spills that result in "substantial damage" to aquatic systems. The estimates of damage are based on simple modeling of the dilution and transport processes and employ toxicological data for typical fish receptors (Dawson and Stradley, 1975). Figure B.1 illustrates this process for sulphuric acid; however, the proportion of production spilt (0.0025 percent) is believed to be typical of many hazardous materials (Dawson and Stradley, 1975:5) while the distribution between the four categories of spills and the proportions of these spills that reach the water are in fact based on aggregate data (Dawson and Stradley, 1975:5-7, 14). However, the proportion of the material spilled that causes "substantial damage" is expected to depend on the material.

It should be noted that the data shown in Figure B.1 appear to mask the importance of stationary sources in causing aquatic damage. Table B.3 presents some fish kill data which show that of kills attributed to industrial release and transport accidents, only 8 percent of the game fish and 28 percent of all fish were killed as a result of transport accidents.



SOURCE: Dawson and Stradley, 1975:25

FIGURE B1: Spills Into Water (For Sulphuric Acid)

TABLE B.3 FISH KILL DATA FOR THE UNITED STATES

(a) Historical Summary of Pollution-Caused Fish Kills, June 1960-December 1977

	1960[2]	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Number of States responding	38	45	37	38	40	44	46	40	42	45	45	46	50	50	50	50
Number of reports	289	413	421	442	590	625	532	454	542	594	635	860	760	749	721	624
Reports which state number of fish killed	151	265	246	304	470	520	453	364	469	492	563	759	697	703	648	543
Total reported number of fish killed	6,035,000	14,910,000	44,001,000	6,937,000	22,914,000	12,140,000	9,614,000	11,291,000	15,815,000	41,166,000	22,290,000	73,670,000	17,717,000	37,814,000	119,052,000	16,111,210
Average size of kill[1]	2,925	6,535	5,710	7,775	5,490	4,310	5,620	6,460	6,015	5,860	6,412	6,154	4,639	5,527	6,532	3,879
Largest kill reported	5,000,000	5,387,000	3,180,000	2,000,000	7,887,000	3,000,000	1,000,000	6,549,000	4,029,000	25,527,000	3,240,000	5,500,000	2,922,000	10,000,000	47,112,000	10,000,000
Number of reported incidents for each pollution source operation																
Agricultural	79	74	51	84	131	114	88	87	77	117	108	132	113	161	145	118
Industrial	103	169	209	199	193	244	195	139	177	199	213	231	189	196	168	122
Municipal[3]	24	52	33	60	120	125	87	91	122	84	120	162	167	146	169	90
Transportation	0	0	1	17	26	27	27	23	39	32	28	52	56	65	40	47
Other	33	58	47	27	17	23	38	35	23	33	28	64	72	56	74	78
Unknown	50	60	80	55	103	92	97	79	104	129	138	219	163	125	125	169
Total reports	289	413	421	442	590	625	532	454	542	594	635	860	760	749	721	624

Number of reports and fish killed by size grouping	1960[2] No. reports	1960[2] No. fish (millions)	1961 No. reports	1961 No. fish (millions)	1962 No. reports	1962 No. fish (millions)	1963 No. reports	1963 No. fish (millions)	1964 No. reports	1964 No. fish (millions)	1965 No. reports	1965 No. fish (millions)	1966 No. reports	1966 No. fish (millions)	1967 No. reports	1967 No. fish (millions)
1,000,000 or more	1	5.0	4	12.6	2	41.0	1	2.0	5	16.9	3	5.4	2	2.0	1	6.5
100,000 to 1,000,000	3	0.53	5	0.85	9	1.69	12	2.68	15	3.82	17	4.62	23	5.48	7	2.66
10,000 to 100,000	15	0.31	45	1.05	38	1.01	54	1.82	59	1.65	63	1.42	56	1.53	49	1.58
1,000 to 10,000	64	0.18	107	0.34	89	0.30	134	0.41	167	0.49	202	0.59	185	0.55	143	0.46
0 to 1,000	68	0.02	104	0.03	108	0.03	103	0.03	224	0.07	235	0.07	185	0.05	164	0.05
No size reported for incident	138		148		175		138		120		105		79		90	
Average duration of kill in days		2.95		2.64		2.59		3.18		2.44		2.57		2.71		3.34

Number of reports and fish killed by size grouping	1968 No. reports	1968 No. fish (millions)	1969 No. reports	1969 No. fish (millions)	1970 No. reports	1970 No. fish (millions)	1971 No. reports	1971 No. fish (millions)	1972 No. reports	1972 No. fish (millions)	1973 No. reports	1973 No. fish (millions)	1974 No. reports	1974 No. fish (millions)	1975 No. reports	1975 No. fish (millions)
1,000,000 or more	3	6.1	4	35.1	5	11.4	28	63.0	6	8.97	6	29.53	6	107.6	3	12.00
100,000 to 1,000,000	30	7.44	9	3.15	26	7.44	26	6.37	27	5.43	19	4.65	20	7.1	9	1.87
10,000 to 100,000	64	1.79	81	2.06	91	2.73	124	3.33	81	2.60	88	2.74	110	3.6	65	1.62
1,000 to 10,000	153	0.48	165	0.52	198	0.62	266	0.86	216	0.62	251	0.81	187	0.6	173	0.57
0 to 1,000	219	0.06	233	0.06	243	0.07	315	0.10	367	0.09	339	0.09	325	0.1	293	0.07
No size reported for incident	73		102		72		101		63		46		73		81	
Average duration of kill in days		2.99		3.11		3.25		3.35		3.40		2.72		3.58		2.18

[1] Derived after excluding reports of 100,000 kills or more as being unrepresentative.

[2] Reporting system in effect for last six months of 1960.

[3] Municipal operations include electric power-generating stations.

Source: U.S. Environmental Protection Agency, 1977c:4-5.

(p.1 of 2)

Table B.3 cont... (p.2 of 2)

(b) Historic Fish Kill Data

Year	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
For Reports Where Extent of Damage Was Reported											
River											
Number of Reports	189	240	259	271	339	292	251	219	264	356	487
Miles of Stream	1,204	1,686	1,448	2,203	1,440	1,300	989	1,039	1,565	2,358	1,865
Lakes and Reservoirs											
Number of Reports	25	50	25	49	57	38	46	33	37	98	111
Acres Affected	1,407	5,907	2,581	5,644	12,637	4,630	21,504	1,996	2,400	6,068	33,168

Source: EPA data taken from Dawson, Stradley and Shuckrow, 1975:IV-92, Vol. IV.

(c) Analysis of 1970 Kill Data

Source	Game Fish Killed	Non-Game Fish Killed
Agricultural Pesticides and Fertilizers	264,391	1,149,472
Industrial	3,250,252	6,569,241
Transportation	284,782	3,616,348
Other	177,482	307,759
Total	3,976,907	11,642,820

Source: Ibid, 1975:IV-93, Vol. IV.

Treatment Process Failures

One class of threat arises from the possibility that a waste may be subjected to some treatment process (e.g., detoxification, neutralization, immobilization), but that the treatment process does not work as intended. The result could be a waste that was more hazardous than anticipated. The variability in composition of waste streams makes this a real possibility, although it does not appear to be a problem that has attracted much attention.

Some treatment processes are comparatively straightforward, and easily checked. For example, simple acid--base neutralization is controlled by checking pH, so only a measurement error is likely to lead to an environmental threat. On the other hand, biological processes are sensitive to waste composition (Battelle N.W. Laboratories, 1974:90) and, where used, might be rendered inoperative by the presence of undetected materials in the waste stream. Worse, inorganic mercury [which is comparatively non-toxic in monovalent form (Venugopal and Luckey, 1975:21)] may be converted to the highly toxic methyl mercury (organic form) by anaerobic bacterial action (U.S. Environmental Protection Agency, 1974:8); hence it is not inconceivable that under adverse conditions a waste containing traces of mercury could become more hazardous after treatment.

A likely treatment threat scenario would be the failure of an incinerator to achieve the dwell time or temperature necessary to fully degrade the waste[3] or for the scrubber system to fail. Of course, it is possible to make measurements to detect virtually any of the failures that can be envisaged; however, in practice such measurements may not be made, or defective equipment may not be shut down.

Threats from Land-Based Disposal

Because waste disposal to land (both legitimate and covert) is both a very diverse and common disposal approach, there are more data on the threats that can arise from this approach than from other techniques. The EPA has collected and analyzed data on damage incidents that have arisen from land disposal of industrial wastes (Lazar, 1975/76; Lazar, 1975; Lazar, Testani and Giles, 1976). Detailed descriptions of some of these incidents have also been published (Ghassemi, 1976; Shuster, 1976a, 1977b, 1976c; U.S. Environmental Protection Agency, 1977b:155-167; U.S. Environmental Protection Agency, 1975a, 1975b, 1976; Carter, et al., 1975).

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(3) This might arise because the incineration parameters necessary to degrade the waste of interest are not adequately known.

Lazar (1975/76) has found that there are six major routes of environmental transport through which the land disposal[4] of hazardous waste can result in damage, as follows:

1. Groundwater contamination via leachate;
2. Surface water contamination via runoff;
3. Air pollution via open burning, evaporation, sublimation and wind erosion;
4. Poisoning via direct contact;
5. Poisoning via the food chain; and
6. Fire and explosion.

Table B.4 provides a matrix of transport mechanism versus disposal method for 421 damage cases arising from the land disposal of hazardous waste. It will be noted that groundwater and surface water contamination are the two most prevalent transport mechanisms, and that most incidents of direct contact poisoning arise from the category "other land disposal," i.e., "haphazard disposal on vacant properties, on farm land, spray irrigation, etc." (Lazar, Testani and Giles, 1976). The mechanism of "poisoning via the food chain" is not represented in Table B.4, largely because of the difficulty of tracing some such incidents back to a

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(4) In this context, "land disposal" includes lagooning, land application and landfilling (including dumping).

TABLE B.4 MECHANISMS INVOLVED IN INCIDENTS OF DAMAGE BY DISPOSAL METHOD

Disposal Method	Surface Impoundments	Landfills, Dumps	Other Land Disposal b)	Storage of Wastes	Smeltings, Slag, Mine Tailings
Number of Cases	89	99	203	15	15
Damage Mechanism (number of cases)					
Groundwater (259)	57	64	117	10	11
Surface Water (170)	42	49	71	-	8
Air (17)	3	5	9	-	-
Fires, Explosions (14)	-	11	3	-	-
Direct Contact Poisoning (52)	1	6	40	5	-
Wells Affected c) (140)	32	28	74	4	2

a) The tabulation refers to 421 cases studied thus far. The numbers in the matrix add up to more than 421, because several damage incidents involved more than one damage mechanism.
b) Haphazard disposal on vacant properties, on farmland, spray irrigation, etc.
c) Not included as a damage mechanism.

Note: The data presented in this table have been derived solely from case studies associated with land disposal of industrial wastes.

Source: Lazar, Testani and Giles, 1976:4.

specific source and also because one of the other identified transport mechanisms will normally be involved in the contamination of the lower order(s) in the food chain. However, some such incidents and potential incidents have been identified (Lazar, 1975/76).

Mechanisms of Water Contamination

The mechanisms by which surface waters and groundwaters can become contaminated from land disposal are of great interest in view of frequency of such pollution events.

Surface Waters: As already noted, Dawson and co-workers (see p.235) have developed simple models for predicting the impact of spills that reach surface waters. In addition to spills from transportation and in-plant accidents, surface water can become contaminated by the overflowing of lagoons due to exceptional climatic conditions (e.g., flash floods, 100-year floods, etc.) and the failure of dams, etc., due to poor design or earthquake.

It is a feature of all surface water pollution mechanisms that the contamination occurs rapidly, and that in most cases dilution and dispersion mechanisms (e.g., the bottom slime) limit the extent of the damage. This is borne out by the fish kill data presented in Tables B.3a and B.3b which show that the average kill duration is about 3 days, and that on the average only a few miles of river are affected. Lakes which have comparatively small in- and out-flows constitute an exception to these remarks; the duration of polluting incidents may be long, as the dilution mechanisms are slow (Dawson and Stradley, 1975:19).

Where pollutants reach estuaries, their physical behavior is complex, and their fate is highly variable (Dawson, Stradley, and Shuckrow, 1975:113-120, Vol. II).

Groundwater: Figure B.2 illustrates the processes by which groundwater can become contaminated. It will be seen that percolation or leakage of leachates(5) into water-table (unconfined) aquifers constitutes the major threat. In contrast to surface water pollution, this process may take years or decades to become apparent. First true leaching (of soluble and suspended materials derived from the solid portion of a waste) is a slow and often (depending on climatic conditions) an intermittent process. Secondly, groundwater moves comparatively slowly: flow rates for most aquifers range from meters per day to meters per year ["a few feet per day to a few feet per year" (U.S. Environmental Protection Agency, 1977b:98)], and the average residence time of groundwater in an aquifer is of the order of 200 years (U.S. Environmental Protection Agency, 1977b:103).

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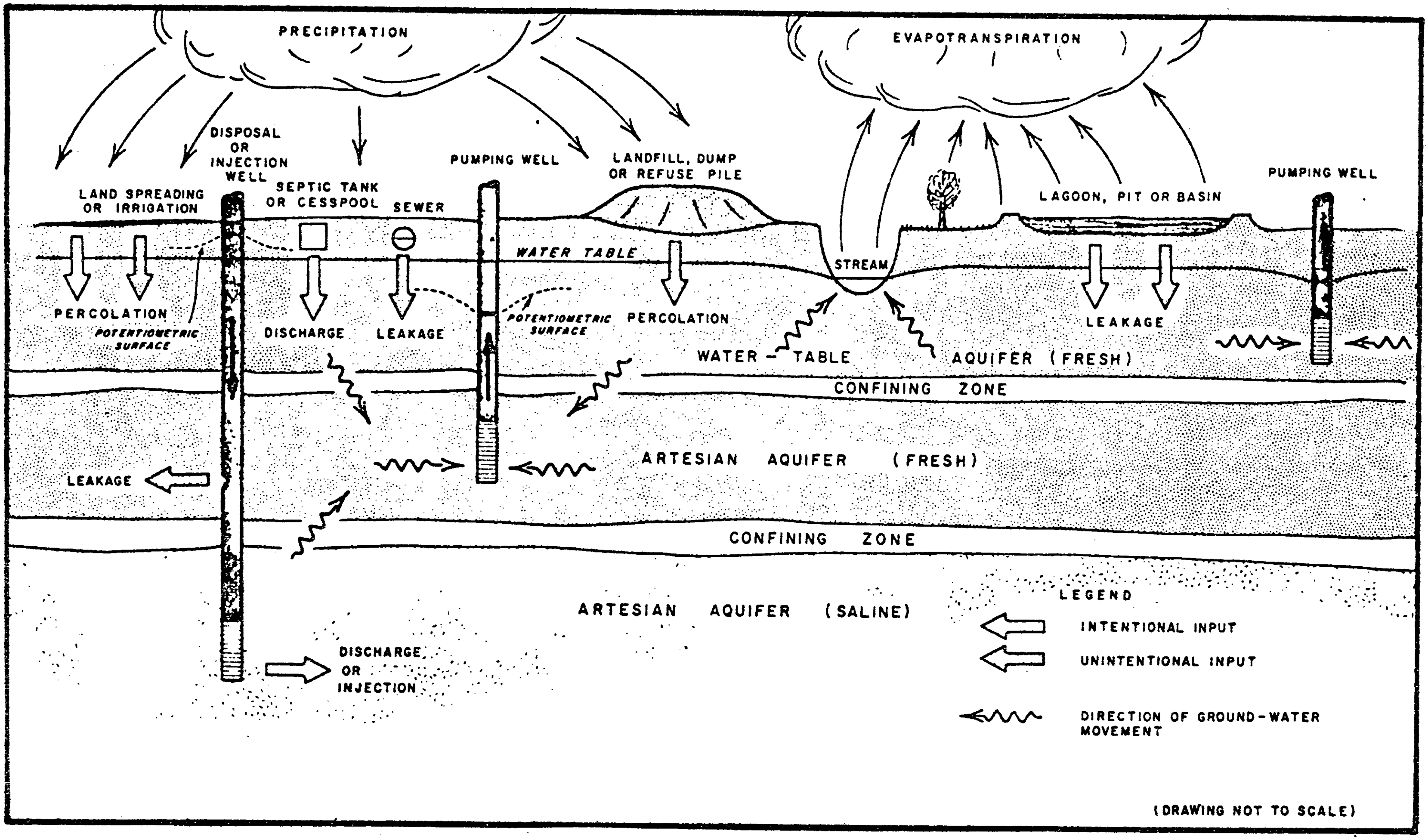
(5) Including direct seepage of lagoon contents, see Appendix A, footnote No. 4.



SOURCE: U.S. Environmental Protection Agency, 1977b:83

FIGURE B2: Contamination of Groundwater by Waste Disposal Practices

These long time constants are attested to both by theoretical (modeling) studies [Fenn, Hanley and DeGeare, 1975; Konikow, 1977; Schultz, 1978; Elzy, et al., 1974 (see also Elzy and Lindstrom, 1976)] and by numerous case studies of incidents involving leachates (U.S. Environmental Protection Agency, 1977b:155-167, 1976, 1975a, 1975b; Shuster, 1976a, 1976b, 1976c; Konikow, 1977; Walker, 1973). These studies also show that leachate contamination of groundwater is usually fairly restricted in its areal extent at any one time(6) but that the leachate frequently forms a plume or slug which travels in the direction of groundwater flow, often with little mixing. Naturally, individual details vary considerably, depending on the quantity and type of wastes involved, the climatic conditions at the disposal site and the characteristics of the aquifer, including its ability to attenuate the waste by reacting with it.

Table B.5 provides detailed data on 60 cases of groundwater contamination from landfills and dumps in the northeastern U.S. It should be noted that the mean annual

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(6) One of the larger recorded areas of contamination --approximately 3000 hectares of severe pollution and 8000 hectares over with traces of pollution could be detected--arose from discharge of several years of pesticide wastes to unlined evaporation ponds at the Rocky Mountain Arsenal, Colorado (U.S. Environmental Protection Agency, 1975b). The wastes contained a very high chloride concentration which enabled the extent of the contamination to be readily monitored (Konikow, 1977).

TABLE B.5 SUMMARY OF DATA ON 42 MUNICIPAL AND 18 INDUSTRIAL LANDFILL CONTAMINATION CASES

Findings	Type of Landfill: Municipal	Type of Landfill: Industrial
Assessment of principal damage		
Contamination of aquifer only	9	8
Water supply well(s) affected	16	9
Contamination of surface water	17	1
Principal aquifer affected		
Unconsolidated deposits	33	11
Sedimentary rocks	7	3
Crystalline rocks	2	4
Type of pollutant observed		
General contamination	37	4
Toxic substances	5	14
Observed distance traveled by pollutant		
Less than 100 feet	6	0
100 to 1,000 feet	8	4
More than 1,000 feet	11	2
Unknown or unreported	17	12
Maximum observed depth penetrated by pollutant		
Less than 30 feet	11	3
30 to 100 feet	11	3
More than 100 feet	5	2
Unknown or unreported	15	10
Action taken regarding source of contamination		
Landfill abandoned	5	6
Landfill removed	1	2
Containment or treatment of leachate	10	2
No known action	26	8
Action taken regarding ground-water resource		
Water supply well(s) abandoned	4	5
Ground-water monitoring program established	12	2
No known action	26	11
Litigation		
Litigation involved	8	5
No known action taken	34	13

Source: Miller, DeLuca and Tessier. In U.S. Environmental Protection Agency, 1977b:158.

potential evapotranspiration in this area is less than mean annual precipitation (U.S. Environmental Protection Agency, 1977b:154), a condition which encourages leaching from landfills.

Deep Well Injection: The primary threat from deep well injection is the contamination of a useable aquifer, but contamination of other valuable resources, and adverse chemical reactions are possible (Warner and Orcutt, 1973:690-692). In addition, there are two known instances where deep well injection has stimulated earthquakes (Raleigh, 1972:273-279).

There are several mechanisms by which aquifers could become contaminated, i.e.:

1) by lateral travel of injected waste to a region of freshwater in the same aquifer;

2) escape of waste into a fresh water aquifer through some failure of the injection well casing or through some nearby deep well that is not adequately cased or plugged;

3) vertical escape of the waste from the injection zone through confining beds that are inadequate because of high primary permeability, solution channels, joints, faults or induced fractures; and

4) indirect contamination whereby injection of the waste displaces saline water into a freshwater aquifer (Warner and Orcutt, 1973:691).

Note that deep well injection will inevitably cause some modification of the local groundwater system. If this technique is to be used, the management objectives should be to insure that whatever modification takes place does not have unanticipated effects. Again, the question of maintaining options arises. Saline water (usually defined as water containing 1000 mg/l or more of dissolved solids) has traditionally been regarded as a nuisance and is only used where no other source is available. However, as Nace (1973) has pointed out, advances in desalting technology are changing saline water into an extensive resource, and potential alternative uses should be considered before wastes are injected into a saline aquifer.

The behavior of wastes injected into deep saline aquifers has been modelled by many authors. Recent publications on this topic include a review by Reeder, et al. (1977) and a model developed for the U.S. Geological Survey (INTERCOMP Research Development and Engineering, Inc., 1976).

Environmental Impacts From Ocean Dumping

Unlike, say, the threat posed by a possible accident, it can be said with certainty that ocean dumping will have some effect on the marine environment. There will inevitably be some local contamination due to the mixing of the waste and the surrounding seawater;[7] hence the critical question becomes: will this effect be localized or dispersed, and what impact will it have on the marine ecosystem?

The dispersion and transport processes that determine the physical fate of a dumped waste are comparatively well understood, and given sufficient input data are in many situations capable of being modelled (Ocean Disposal Study Steering Committee, 1976:36). However, even if the immediate physical fate of the dumped material can be predicted, this is only the start of the waste's effect on the ecosystem. Complex chemical interactions can occur between the waste and the seawater (Ocean Disposal Study Steering Committee, 1976:22-23), and most authorities agree that our understanding of the processes that determine the biological impact is very limited. For example, in 1971, when discussing the impact of dumped industrial wastes Smith and Brown stated that:

> Th[is] information. . . represents virtually everything we know of the environmental effects of industrial wastes discharged at sea from barges. . . . This minute body of information is totally disproportionate with both the amounts of wastes handled and the potential damage that these wastes can do. (Smith and Brown, 1971:32)

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(7) If the wastes are containerized the most serious contamination may be delayed until corrosion has breached the containers.

More recently in a very broad study on ocean pollution, the National Academy of Sciences stated that:

> The greatest uncertainty in assessing the impact of ocean pollutants is the scarcity of data on their chronic toxicity. . . .
>
> Even if good experimental data were available on sublethal toxic effects of individual chemicals on representative species, it would be difficult to deduce effects on marine ecosystems. (National Academy of Sciences, 1975:6,7)

Nor is definitive information likely to be forthcoming in the near future. Another National Academy of Sciences study specifically directed towards waste disposal in the marine environment stated that:

> Once the assimilative capacity of a site and the limits on the rate of input of wastes are known, limiting conditions on waste composition, waste treatment, and waste dispersion or containment can be derived and a variety of designs to meet those conditions can be proposed. The necessary information for this is not now available, nor is it likely to be available in the near future. (Ocean Disposal Study Steering Committee, 1976:30)

In the absence of a detailed understanding of the interaction of wastes and the marine ecosystem, a "case study" approach could be used to provide a very general impression of the possible impacts. While most of the ocean disposal studies cited in Appendix A include descriptions of some of the observed environmental impacts of ocean disposal, very few specific data have been collected. Smith and Brown summarize the results of nine case studies on industrial wastes (Smith and Brown, 1971:27-32), while the two National Academy of Sciences studies catalogue environmental impacts that have been attributed to ocean disposal (Ocean Disposal Study Steering Committee, 1976:14-16) and the known effects of some chemicals on ocean life (National Academy of Sciences, 1975).

Probabilities That Threats Will Occur

General Discussion

The previous section has described categories of threat scenarios that may arise in hazardous waste management. For transportation accidents and for spills into water some data that relate to the probability of occurrence of such threats were included. However, the emphasis has been on identifying the character of the threat, and this step alone is of value in analyzing hazardous waste problems, as social behavior may be influenced by the nature of the threat without much reference to its probability. Nevertheless, it would be useful to know more about the probabilities that threats will occur, as these data would be an integral part of any complete cost-benefit or risk benefit analysis.

The initiating event (see Figure 4) is usually the key to determining the probability that a threat will occur, although the threat mechanisms determine the outcomes, and hence affect the probability of any specific outcome. Some initiating events, i.e., those associated with ocean dumping and deliberate discharge to sewer or waterway are not probabilistic in nature, while others such as sabotage and the effects of inadequate design or poor practice are inappropriate for a probabilistic approach. On the other hand, geologic and climatic events are amenable to probabilistic analysis, as are various forms of accidents (already discussed).

The probabilities of most geologic and climatic initiating events will be site-specific, and analysis of the more common climatic events is already a routine operation. For example, landfill sites in California are evaluated with respect to the 100-year flood level and the precipitation from a 10-year, 24-hour storm (California State Water Resources Control Board, 1976). Note that virtually every initiating event is capable of occurring at various magnitudes. Taken over a long time span, the large or stronger events almost invariably occur less frequently than smaller or weaker ones (e.g., a 100-year flood level will be lower than a 500-year flood level; weak earthquakes are more frequent than strong ones). Hence some judgment will be necessary as the critical magnitude of an initiating event, based on the simplifying assumption that initiating events that are smaller than the critical magnitude will not lead to any adverse outcome.

There has been some research on predicing the probabilities and outcomes of less likely initiating events. Much of this work has stemmed from analysis of the safety of various parts of the nuclear fuel cycle (Rasmussen, 1975), and in particular from the disposal of high-level radioactive wastes (Schneider and Platt, 1974:Vol.1; Energy Research and Development Administration, 1977; Claiborne and Gera, 1974). While this work has generally attempted to follow through the possible consequences of various initiating events via event trees, it is largely concerned with the danger from radioactivity, so the data are not generally useful for non-radioactive hazardous wastes. Deonigi (1974) provides a useful summary (with the emphasis on safety aspects) of the general methodology that has been developed for evaluating radioactive waste management concepts, while a related article by Burkholder, et al. (1976) concentrates on the fate of radioactive wastes that are leached from geologic storage (mine disposal).

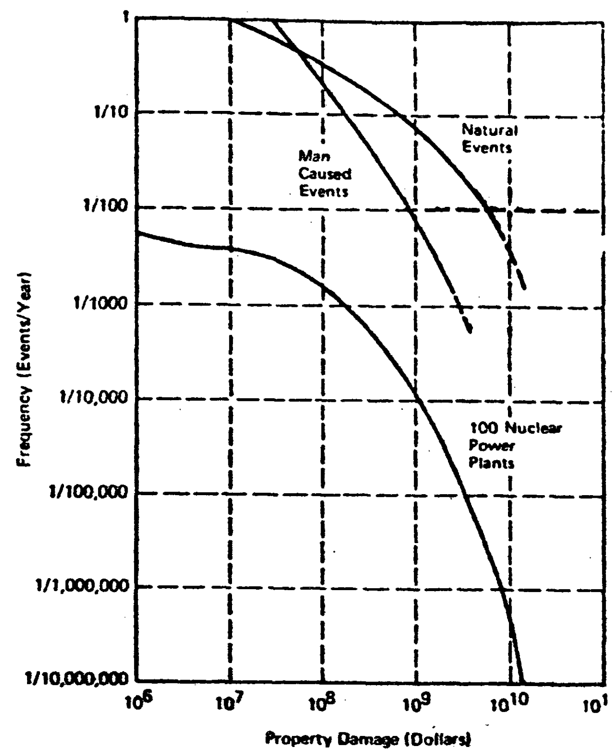
The data on the probabilities of various uncommon events and their outcomes that have been collected together for evaluating the safety of nuclear-related activities are available in two forms: (1) estimates of the probabilities of initiating events of sufficient magnitude to cause waste release from a specified form of disposal (usually mine disposal) and sometimes at a specified locaton, and (ii) trade-off relationships between the frequency of occurrence of these events and the damages caused (property damage dollars and human fatalities) for the entire U.S. The second form (which are available for both natural and man-caused events, see Figure B.3) cannot be used directly for assessing the probabilities of critical magnitude initiating events, but are a useful way of assessing the relative importance of different events.

Uncommon Natural Initiating Events

Many of the threats to the more secure techniques for hazardous waste disposal will be initiated by unlikely climatic and geologic events. Since the time scale of interest may extend to "perpetual care," not only sudden initiating events (such as earthquakes) but also gradual ones (such as erosion) could be of potential interest. Other than meteorite impact, which is regarded as a random process (Claiborne and Gera, 1974:15), the probabilities of all natural initiating events will be site-dependent to a lesser or greater extent, varying either with the general location (e.g., for earthquake) or with the specific details of the site (e.g., for flood). Various events are discussed below.

Frequency of Property Damage due to Natural and Man-Caused Events

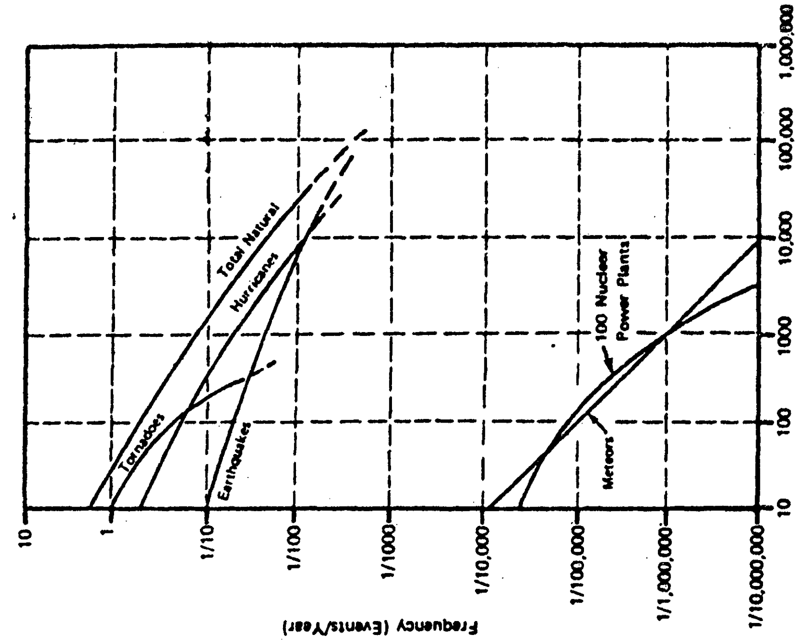
Notes:
1. Property damage due to auto accidents is not included because data are not available for low probability events. Auto accidents cause about $15 billion damage each year.
2. Approximate uncertainties for nuclear events are estimated to be represented by factors of 1/5 and 2 on consequence magnitudes and by factors of 1/5 and 5 on probabilities.
3. For natural and man caused occurrences the uncertainty in probability of largest recorded consequence magnitude is estimated to be represented by factors of 1/20 and 5. Smaller magnitudes have less uncertainty.



SOURCE: Rasmussen, 1975:A-3

FIGURE B3: Relationships Between Frequency and Magnitude of Disasters

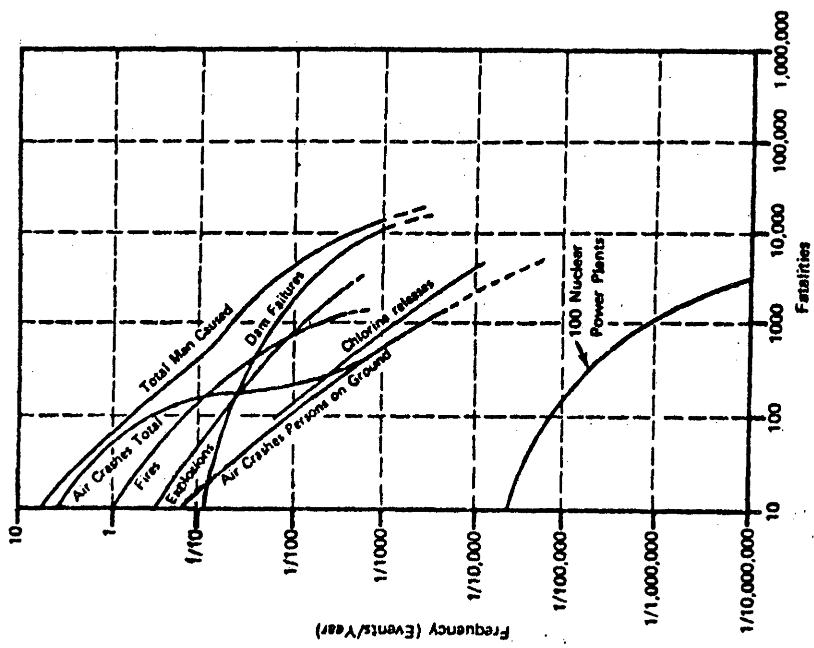
FIGURE B3 continued...



Frequency of Fatalities due to Natural Events

Notes: 1. For natural and man caused occurrences the uncertainty in probability of largest recorded consequence magnitude is estimated to be represented by factors of 1/20 and 5. Smaller magnitudes have less uncertainty.

2. Approximate uncertainties for nuclear events are estimated to be represented by factors of 1/4 and 4 on consequence magnitudes and by factors of 1/5 and 5 on probabilities.



Frequency of Fatalities due to Man-Caused Events

Notes: 1. Fatalities due to auto accidents are not shown because data are not available. Auto accidents cause about 50,000 fatalities per year.

2. Approximate uncertainties for nuclear events are estimated to be represented by factors of 1/4 and 4 on consequence magnitudes and by factors of 1/5 and 5 on probabilities.

3. For natural and man caused occurrences the uncertainty in probability of largest recorded consequence magnitude is estimated to be represented by factors of 1/20 and 5. Smaller magnitudes have less uncertainty.

SOURCE: Rasmussen, 1975:A-2

<u>Earthquake</u>: Seismic activity varies considerably within the U.S.A. Schneider and Platt (1974:3.27) use a threshold level of IX on the Modified Mercalli Intensity Scale which would result in the following effects:

> Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (J.L. Coffman and C.A. von Hake, quoted in Schneider and Platt, 1974:4.D.2, Vol. 2)

Schneider and Platt (1974:3.26) calculate that the probability of an earthquake of at least this intensity striking a generic U.S. east coast site is about 2×10^{-5} per year, while for a random point in California the probability would be some 2×10^{-2} per year. Clearly, better estimates of probability could be derived for specific sites. The risk from earthquakes would probably most affect storage structures, treatment facilities and lagoons. The impact on wastes in the solid phase (in landfills or mines) would probably be via changed water levels and paths.

<u>Faulting and Cracking</u>: Faulting is considered to be the most likely aspect of tectonic activity (other than earthquake) that could interfere with waste disposal (Schneider and Platt, 1974:3.22). Faulting or cracking

would most likely affect water paths, and would be of particular importance for deep well injection as it might cause saline aquifers to become connected to fresh water aquifers. Fault activities vary considerably within the U.S.A., but as an example, one estimate places the probability that a new fault will intersect an 8 square kilometer waste depository in the Delaware Basin, New Mexico, as 4×10^{-11} per year (Claiborne and Gera, 1974:41). On the other hand, a study relating to Aiken, South Carolina, states that there is insufficient knowledge of the mechanisms to estimate the probability that a small crack will traverse a stratum (Energy Research and Development Administration, 1977:V-44)

Volcanic Activity: Several authors consider that the probability of volcanic activity (in an area not currently active) is extremely low, but none care to estimate that probability (Schneider and Platt, 1974:3.21; Energy Research and Development Administration, 1977:V-44; Claiborne and Gera, 1974:31).

Erosion: The average rate of erosion for the entire U.S.A. is a few centimeters per thousand years, while maximum rates are of the order of meters per thousand years (Claiborne and Gera, 1974:43). However, Schneider and Platt point out, in the arid and semiarid areas of the U.S., river channel erosion can occasionally be rapid (e.g., of the order of a meter per decade) while cliffs (e.g., at the edges of mesas) can also retreat rapidly (Schneider and Platt, 1974: 4-45 to 4-47). In arid areas the flash floods associated with cloudbursts do not occur in well defined channels and can transport large quantities of material, possibly causing changes in drainage patterns (Schneider and Platt, 1974:4-47).

Erosion could primarily affect the long-term security of landfills, and the potential impact of flash floods and landslides on lagoons should also be considered when analyzing the siting of any land disposal facilities. The possibilities of glacial action and changes in sea level or the development of a lake have also been considered for the perpetual care of radioactive wastes (Schneider and Platt, 1974:passim).

Development of an Aquifer: Schneider and Platt (1974: 1.16, 1.17) include an interesting tentative estimate of the probability that an aquifer will develop where none currently exists, and that water will penetrate a mine disposal site (see also Deonigi, 1974). These data are presented in Table B.6. The probability that the water will penetrate the disposal tunnel and cavity is based on tunneling and natural gas storage experiences (Schneider and Platt, 1974: 3.23). The development of an aquifer could affect all forms of land disposal.

TABLE B.6 SAMPLE COMPONENTS OF RELEASE SEQUENCE PROBABILITIES FOR GEOLOGIC DISPOSAL

Failure Event	Probability of Waste Release: During Operational Period	During 1000 Years	During 1,000,000 Years
Aquifer Develops in the Region Where One Did Not Exist Previously	10^{-10} to 10^{-8}	10^{-6} to 10^{-4}	10^{-2} to 10^{-1}
Water Finds Path into Disposal Site	10^{-4} to 10^{-2}	10^{-4} to 10^{-2}	10^{-4} to 10^{-2}
Water Flow Cannot Be Controlled by Man	1	1	1
Water Is Flowing	1	1	1
Cumulative Release Probability in the Time Given	10^{-14} to 10^{-10}	10^{-10} to 10^{-6}	10^{-6} to 10^{-3}

Source: Schneider and Platt, 1974:1.17.

Hurricanes and Tornadoes: The strong winds associated with hurricanes and tornadoes would primarily affect surface structures (e.g., engineered storage) and could transport the contents of lagoons. Structure design to withstand the forces of high velocity winds is a normal engineering procedure.

The potential for damage from tornadoes has been evaluated with respect to nuclear power plants (see Rasmussen, 1975). The average incidence of a tornado at a nuclear power plant site has been calculated to be $5x10^{-4}$ per year, but only one percent of these tornadoes are expected to exceed the design criteria (Rasmussen, 1975:68-69).

Meteorite Impact: The probability of the impact of large meteorites is low. Claiborne and Gera indicate that the probability of a meteor of mass in excess of $2x10^{7}$ kilograms striking the earth is about 10^{-13} per square kilometer per year. A meteorite of the above size would make a crater of about 1 kilometer in diameter and 300 meters deep (Claiborne and Gera, 1974:15). Schneider and Platt (1974) quote data suggesting that the probability of a meteorite being capable of forming a crater more than 400 meters deep is 10^{-12} per square kilometer per year. Such craters could threaten any form of land disposal. Smaller meteorites are more common and the probability of a meteorite in the ten tonne range striking a large surface building has been estimated to be less than 10^{-10} per year. Even so, this appears to be an event that can be neglected in comparison with many other uncontrollable risks.

Uncommon Man-Caused Initiating Events

Aircraft Impacts: The effects of an aircraft crash (including possible fuel combustion) have been investigated for nuclear power plants and waste processing facilities, and for the transport of nuclear materials(8) (Rasmussen, 1975; Energy Research and Development Administration, 1977). The probability of a potentially damaging air crash at a reactor location in the U.S. that is more than five miles from any airport is estimated to be 10^{-6} to 10^{-8} per year (Rasmussen, 1975:69).

Sabotage: Several authors have attempted to estimate the probability that facilities containing radioactive wastes will be sabotaged (Energy Research and Development Administration, 1977; Schneider and Platt, 1974; Claiborne and Gera, 1974). They conclude that the probability is low because

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(8) The risk from aircraft during surface transport is very small compared to other types of transport accidents, but due to the large quantities of energy that might be involved is of interest for materials (such as high-level radioactive materials) that are containerized securely enough to resist spillage in most accidents.

there are more attractive targets for saboteurs. On the other hand, the security taken at any facility where sabotage could lead to disastrous consequences will reflect the attractiveness of the target, which will tend to even out the probabilities between different targets. Nevertheless, most techniques for the ultimate disposal of hazardous waste would not appear to be particularly vulnerable to sabotage, but treatment facilities and engineered storage could be. Given a reasonable level of security at hazardous waste management facilities it is difficult to predict the probability of a successful sabotage attempt without knowing more about the local political climate and alternative targets at the time.

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APPENDIX C

VALUATION OF THE EFFECTS OF HAZARDOUS WASTE MANAGEMENT TECHNIQUES

This appendix discusses the nature of control costs and indicates how some of the common environmental impacts can be valued.

Control Costs

Generator's Costs

Generator's costs include all costs that the generator of a waste incurs specifically in dealing with its waste disposal problem. Generator's costs are the only costs that are "internal" to a firm, and are therefore, according to classical microeconomic theory, the only costs that a firm is assumed to consider in its decision-making.

Generator's costs include any costs incurred by the generating firm to reduce the generation of hazardous waste, as well as those involved in waste separation, treatment and disposal. They should include taxes directly applicable to the waste handling and disposal operations (e.g., property taxes on relevant facilities or equipment), but not taxes that cannot readily be attributed to waste handling or disposal (e.g., income taxes). If the waste is subjected to any form of resource recovery, a credit for the value of the materials recovered (based on the cost of an alternative supply of that quality of material in that location) should be included, even if no market transaction is involved. Where a waste is consigned to another firm for treatment, transport and/or disposal, the charges for these services are part of the generator's costs.

Generator's costs are comparatively easy to determine for a given waste and location. Hazardous waste management costs have been determined for various industries and for various methods of treatment and disposal. However, many of these data are highly location-specific or waste stream-specific and are scattered throughout the literature. A few have been collated; for example, Battelle N.W. Laboratories (1974:Vol. II) provides costs for some widely applicable treatment modules; while Talley and Albrecht provide a comparison of costs for ultimate disposal techniques, presented in Table C.1. An EPA-sponsored study to update and collate cost data for a wide range of hazardous waste treatment and disposal techniques is currently in progress (U.S. Environmental Protection Agency, forthcoming).

A major problem that may be encountered in attempting to determine generator's costs for planning purposes is the variability of such costs with local conditions, even if

TABLE C.1 ESTIMATED COSTS OF SOME DISPOSAL TECHNIQUES

	Estimated Costs		
	Range	Average	"Normalized"
Land burial techniques			
Conventional sanitary landfill	\$1.98-\$4.74/tonne	\$3.30/tonne	\$0.99/m^3
Near-surface land burial containerized wastes		\$26.50/m^3	\$26.50/m^3
Sludge encapsulation and burial			
Operating experience of one company	\$7.80-\$31.80/m^3		\$7.80-\$31.80/m^3
Polymer encapsulation		\$26.40/m^3	\$27.20/m^3
Cement encapsulation		\$66.10/m^3	\$66.00/m^3
Asphalt		\$35.20/tonne	\$42.40/m^3
Deep burial	\$11.30-\$33.90/m^3		\$11.30-\$33.90/m^3
Engineered storage	\$106-\$177/m^3		\$106-\$177/m^3
Deep well injection	\$0.13-\$0.53/m^3		\$0.13-\$0.53/m^3
Ocean Disposal			
Bulk	\$0.66-\$10.50/tonne	\$1.87/tonne	\$1.87/m^3
Containerized	\$5.50-\$143.00/tonne	\$26.40/tonne	\$26.40/m^3

Source: Talley and Albrecht, 1974:27. (Data were converted from U.S. customary units.)

the level of environmental protection is not concurrently varied. Although disposal costs (for a given technique) are not, in general, sensitive to the precise composition of the wastes involved, treatment costs can vary considerably. For example, Arthur D. Little, Inc. showed a variation in total operating costs from 0.3 to 15.6 cents per liter (1973 data) for treatment of various wastes containing heavy metals.[1] Further, major economies for scale are possible: Arthur D. Little, Inc. (1973:196, Vol.II) assumed an exponent of -0.4 in the average unit processing cost-throughput relationship[2] for all treatment processes considered.

Disposal costs will, however, depend on geologic and climatic factors; such as the depth and injection pressure needed for deep well injection, and the suitability of the location for evaporation ponds, and the relative ease with which secure (chemical) landfills can be constructed. Talley and Albrecht's data (Table C.1) are based on a single source of data for each technique, and yet typically show variations

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(1) These wastes are dilute heavy metals, concentrated heavy metals and organics with heavy metals. Data excluded sludge disposal costs and were for waste stream volumes typical of large-sized, industrial plants (Arthur D. Little, Inc., 1973:48,49 Vol.I).

(2) The term "processing cost" appears to refer to labor and capital related costs only, and to exclude chemicals and utilities which were taken as constant unit costs (Arthur D. Little, Inc., 1973:55, Vol.I).

of 2:1 to 4:1; while the cost range shown for ocean disposal is far greater, "varying according to geographical area, type of waste, distance [from port] to the disposal area and annual volume of wastes handled" (Smith and Brown, 1971: 12).

Administrative Costs

Administrative costs include the costs of planning, promulgating regulations, monitoring compliance and prosecuting non-compliance with regulations, studying incidents and problems, and advising industry. These costs will be incurred by various levels of government, and by "watchdog" bodies that are concerned with environmental quality. Research and development costs should not be included, unless they are integrally associated with a particular approach to hazardous waste control.

It is often difficult to derive precise data on the administrative costs involved in a particular program area, due to multiple coverage by many government departments. For example, a legal department or a laboratory will probably handle the work of many program areas, and will not be restricted to hazardous waste. Fortunately, the analyst is primarily interested in <u>changes</u> in administrative costs as the approaches to hazardous waste control are varied, and these can more readily be estimated by assessing the cost of employing the additional staff directly needed to implement programs, together with an allowance for support from service departments, consultants, etc.

Few empirical data have been published on administrative costs, and those that have are generally broad in coverage.(3) However, it is widely held that administrative costs can vary substantially with different regulatory approaches. In their report, Decision Making for Regulating Chemicals in the Environment, the National Academy of Sciences stated:

> . . . Transaction costs are administrative costs incurred, usually by the regulating agency, in the process of collecting information and enforcing a regulatory decision. The extent of additional transaction costs is, of course, a function of the form of regulatory action taken. Great variation in transaction costs may exist depending on the regulatory option chosen, and their magnitude may itself be a factor in selecting an appropriate regulatory action. [Emphasis added.] (National Academy of Sciences, 1975:55)

Also, in assessing the potential efficacy of alternative institutional approaches to the management of hazardous wastes, Battelle N.W. Laboratories (1974:326, Vol.I) gave "federal cost" a weighting of one seventh in deriving an effectiveness ranking. Administrative costs can be expected to increase as the extent of regulation (as opposed to

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(3) For example, 1977 federal expenditures for standard setting and enforcement in relation to all pollution control activities were estimated to be $422 million (Council on Environmental Quality, 1976:350.)

achieving objectives by use of market forces) is increased, and *ceteris paribus*, as the degree of environmental protection or quality is increased.

Although crude, an approach that is sometimes adopted is to take administrative costs as a fixed proportion of some other major cost. For example, Moll, et al. (1975:4-6, 4-7) suggested that administrative and enforcement costs incurred by governments for pollution control activities might account to 10 percent of the annualized costs of the relevant industrial pollution controls.

Effluent fees or fines for the violation of standards may be used to internalize costs external to a firm and can thereby affect its behavior. However, because fines and effluent charges are only transfer payments between different categories of control costs, any contribution that they make to overall economic efficiency must be via changes in pollution control activities. In work oriented towards the control of fly ash emissions from power plants, Downing and Watson have analyzed the effect of an agency's enforcement activities on a firm's projected behavior under an assumption of cost minimization (Downing and Watson, 1974, 1977; Watson and Downing, 1976). They compared the effects of effluent fees with standards and fines, and examined the effects of using different compliance tests and numbers of inspections, as well as different levels of fine and effluent fee. One conclusion was, that for the parameters involved in the fly ash control situation, a firm's optimum strategy would involve frequent violation of standards (Watson and Downing, 1976:572). In recent work Downing and Kimball (n.d.) examine the pollution control behavior adopted by firms in a number of industries, and find that the firms appear to be controlling pollution to a greater degree than would be implied by a cost minimization strategy. Although Downing and Kimball examine a number of possible explanations, they are unable to satisfactorily explain the observed behavior.

Social Control Costs

This category of cost is introduced to catch hidden or intentional subsidies provided to enterprises that have to dispose of hazardous waste. For example, in order to encourage adequate disposal of wastes, governments might elect to provide landfill services at no cost, or at a cost below that which would be justified on an accounting basis. This would constitute an intentional subsidy which should be taken into account when comparing the total costs of alternative disposal techniques. A more subtle subsidy--and one that may not be restricted to services provided by governments--can occur where the opportunity cost or the replacement cost of a facility (such as a landfill) is higher than the historic cost or accounting cost.[4]

Social control costs--both deliberate and unintentional--can arise with most hazardous waste management techniques. Highway users, for example, may not pay the full cost of providing and maintaining the highway system. Where this type of cost exists it is important that its presence is recognized, and that it is included in the evaluation if it is a significant factor.[5]

Social control costs are external to the waste generator, who will therefore not take them into account in his decision-making. However, such costs might deliberately be incurred for some techniques in order to steer a generator's decisions toward ones that are efficient from a societal viewpoint, i.e., when all costs and damages are considered.

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(4) Even in absence of inflation, an accounting cost could readily understate the capital component of landfill costs. Often, the land employed was obtained at low cost; but with the growth of the community that it serves, both the opportunity cost reflecting the value of the land in alternative uses, and cost of replacing the facility with another that is functionally equivalent, would be far higher than the historic cost. Government charters may preclude landfill operation in such a way as to make a book profit, and individual firms often base their charges on historic costs, not recognizing the need to consider opportunity costs or to plan for facility replacement.

(5) In cost-benefit analysis a "shadow price" is sometimes used to reflect the true cost of a transaction, as opposed to the actual money cost, if any. This is equivalent to adding the social control cost to the generator's cost.

Valuation Of Environmental Impacts

Theoretical Considerations

Willingness-to-Pay

The valuation of environmental impacts is frequently more difficult than the valuation of control costs as there are no established markets for many effects (e.g., a change in water quality). Although some authorities consider that monetary values should not be assigned to certain effects (Tihansky, 1975:142), in principle it is almost invariably possible to impute a value from some sort of "willingness-to-pay" survey or equivalent measure. This involves asking affected consumers how much they would be willing to pay to receive a specified benefit, even though it might be impossible or infeasible to collect such payments. Because it is often difficult to develop a willingness-to-pay survey that is not subject to bias, willingness-to-pay is frequently imputed from some observed behavior.

The term willingness-to-pay is frequently used to encompass two separate concepts which can lead to quite different results under certain circumstances. Thus there is a distinction between an individual's willingness-to-pay to obtain increased utility, and the compensation that an individual would demand to accept a reduction in utility[6] (Freeman, 1976:II-13, II-14). If an individual's marginal utility of income is approximately constant (as where the changes are very small compared to total income) the two measures can be taken as equivalent (Freeman, 1976:II-13, II-14). However, in some circumstances the distinction can be important as willingness-to-pay is limited by an individual's income, whereas compensation demands are not, with the result that some individuals may indicate that they would not accept certain situations at <u>any</u> level of compensation (Prato, 1974:58). Thus, the compensation that an individual would require to accept a reduction in his life expectancy or to undertake an activity that carries a given chance of death, could be far greater than the payment that he would be prepared or able to make to increase his life expectancy by a similar amount or to avoid an activity that has the same chance of death (Hirshleifer, Bergstrom and Rappaport, 1974: 23).

The measurement of willingness-to-pay for environmental improvement is difficult, as individuals can have strong incentives for concealing their true preferences (Mäler and

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(6) In accordance with common practice, in this dissertation the term "willingness-to-pay" will be employed to cover either measure, except where the distinction is important.

Wyzga, 1976:80). Thus, in responding to a questionnaire or in a bidding game it is in the interest of those responding to overstate their willingness-to-pay if their responses carry no financial obligations. If the amount they will actually pay is essentially independent of their responses, they are likely to promote the perceived improvement in the quality of the environment to the maximum extent possible by exaggerating their responses. On the other hand, if there is a direct individual financial obligation associated with the responses, it is in the interest of an individual to understate his response in the hope that other persons will bear the brunt of improvement costs. (This is an example of the "free rider" problem that can arise with public goods.) In the context of valuation of amenity benefits, Mäler and Wyzga (1976:80-81) suggest ways in which it may be possible to obtain a balance between these two opposing effects by making an individual partly financially responsible for his statements. However, it appears that it has not as yet been found feasible to apply this technique to the estimation of environmental benefits, so the questionnaire approach is likely to result in a biased valuation.

The Consumers' Surplus

In valuing some environmental effects it is necessary to determine the consumers' surplus, or more commonly to evaluate a change in the consumers' surplus. This is of particular importance where no market (or an imperfect market) exists for the product. For example, the total value of a recreation opportunity is often evaluated by determining the consumers' surplus which (if income effects are neglected) is the triangular areas on a demand curve above the price actually paid. This area represents the total that consumers would be prepared to pay to receive that benefit (e.g., recreational opportunities in a park), above any price that they actually paid (e.g., an entry fee). A discriminating monopolist would be able to capture the entire consumers' surplus by charging each individual exactly what he was prepared to pay for the benefit. If pollution reduces the attractiveness of recreational opportunities in the park, then the demand curve will be lower, and the cost of that pollution (as far as its effect on the park is concerned) will be the reduction in the consumer's surplus.

Where the distinction between willingness-to-pay to obtain a product or service and the compensation required to forego it is significant, there are two different measures of the consumers' surplus. The "compensating variation" measures of the consumers' surplus in the former case, while the "equivalent variation" measures it for opportunities foregone. For a normal (as opposed to inferior) good, the compensating variation is smaller than the area under the demand curve, which in turn is smaller than the equivalent variation. However, where income effects are negligible, the three measures coincide (Mishan, 1971a:325-338). In practice, although goods having zero income effect are uncommon, the effect is often sufficiently small for the area under the demand curve to be used with acceptable accuracy in cost-benefit analyses (Mishan, 1971a:338).

Unfortunately, analysis of environmental problems is complicated by the fact that consumers can be highly emotional about giving up their rights, with the result that the two measures are not equivalent. This situation was, for example, found to pertain to waterfowl hunting (Brown and Hammack, 1972), and to the public's stated views about changes in air quality in the Four Corners area (Randall, Ives and Eastman, cited in Prato, 1974). As it is very difficult to design survey instruments that elucidate genuine responses to willingness-to-pay questions (and especially to those that relate to compensation required), there may be considerable uncertainty about the true magnitude of a consumers' surplus.

Valuation of Environmental Impacts in Practice

The remainder of this appendix is devoted to describing how some common environmental hazardous waste management activities can be valued.

Destruction and Damage to Man-made Property

This is the easiest category of environmental damage to value. In most cases replacement cost will provide a suitable method of valuation, where the replacement is functionally equivalent to the damaged item. While in many cases this can be assessed on the basis of the cost of a similar item (less an allowance for depreciation where appropriate), there will be situations where direct replacement is inappropriate. For example, where wells are irreversibly contaminated, the damage cost should include the cost of providing an alternate water supply. Provision of an alternate water supply from a different source is likely to be far more costly than drilling a direct replacement for the original well.

On the other hand, there could be circumstances in which the appropriate replacement cost was less than that of replacing the damaged item with a direct equivalent. Due to changing technology, the direct replacement of some structures (e.g., a fire-damaged barn) with a physically identical structure could be more costly than replacement with a functionally equivalent structure of different design. Of course, replacement of damaged property with something that is functionally equivalent but physically different could also cause a social impact, by changing the aesthetic value associated with the property.

Damage to Human Life and Health

Loss of Human Life: The valuation of human life has recently been discussed by Hirshleifer, Bergstrom and Rappaport (1974), Zeckhauser (1975) and by Linnerooth (1976, 1975a, b). Linnerooth identifies six approaches as follows:

> (i) The human-capital approach. This values each life according to the discounted future earnings of the beneficiary.
>
> (ii) The insurance approach. This values each life on the basis of individual life-insurance decisions.
>
> (iii) The court-decided compensation approach. Here information from court awards for fatal accidents or diseases is used to value each life.
>
> (iv) The implicit-value approach. This values each life according to values implicit in past decisions affecting human mortality. ....
>
> (v) The portfolio approach. This compares changes in mortality risk with the entire portfolio of risks assumed by society.
>
> (vi) The utility, or willingness-to-pay approach. This values risk reduction by the public's preferences or willingness to pay for this reduction.
>
> (Linnerooth, 1976:295)

The human capital approach is probably the best known and widely used, although it has been criticized on the grounds that it values livelihood and not lives (Linnerooth, 1976: 296). Within this approach there is an important subdivision between the gross value version which evaluates an individual's lifetime earnings, and the <u>net value</u> version which only considers the economic loss that would be suffered by others should that individual die, i.e., it excludes his consumption or maintenance cost (Linnerooth, 1975b:3). Despite this significant philosophical distinction (as an individual's consumption is likely to be a large portion of his earnings), values derived by both versions of the approach have clustered around $200,000 (in 1958 to 1974 dollars) (Linnerooth, 1975b:2-14).

The next three approaches (ii, iii and iv) have not received as much attention as that of the human capital approach, and can lead to a wide range of results. For example, life valuations derived from the implicit value approach have ranged from $9,000 to $9 million (Linnerooth, 1976:296). On the other hand, there is evidence that court-decided compensation is related to the human-capital approach, as loss of life court awards are frequently based on the expected future earnings of the deceased.

A major difficulty associated with all of the first four approaches is that they can lead to the conclusion that for some sectors of society, lives have no value. These sectors are non-wageworkers (e.g., homemakers and retired persons) and persons with no dependents (for the insurance approach). Although there are ways around this problem, it does point up the inadequacy of these approaches.

The last two approaches are of particular interest for cost-benefit and risk-benefit analyses as they express mortality risk in probabilistic terms as opposed to dealing with *ex ante* identifiable persons. Thus they are considered appropriate to decisions where life expectancy or the probability of death is altered (Linnerooth, 1976:295; 1975b:17,18), as is the case in hazardous waste management decisions.

By far the most widely known example of the portfolio approach is the work of Starr (1969; 1972) who drew the important distinction between risks undertaken voluntarily and those which are involuntary. This approach has been criticized by several authors (Slovic, Fischhoff and Lichtenstein, 1976; Linnerooth, 1975b; Mishan, 1971b), essentially on the grounds that the sociopolitical decision-making process reflected in these data does not reveal the true public preference for risk-benefit trade-offs.(7)

The willingness-to-pay approach (vi) is advocated by some authors as the only conceptually valid way of valuing life, i.e., by basing the valuations on utility (Mishan, 1971b; Schelling, 1968). The approach is potentially capable of recognizing non-linearities in the risk-benefit trade-off

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(7) This topic is discussed in more detail in Appendix D.

relationship,[8] but is fraught with difficulties in use. There have been a few questionnaire type surveys (see Linnerooth, 1975b), and Thaler and Rosen (1973) have attempted to use the "risk premium" associated with the remuneration for some jobs (see p. 292) to obtain a value of life. Once again, both the survey and the "risk premium" results suggest a value of life in the region of $200,000 (based on small increases in mortality).

Damage to Human Health: The valuation of sickness and accidents appears to have received less attention than loss of life. Most valuations appear to be based on the human-capital approach, plus an allowance for medical expenses. This approach is, of course, implicit in Workman's Compensation and other insurance schemes, and such data could be used as a measure of work-related damages to life and health.

Values of lost workdays derived from the human-capital approach do not include an allowance for pain and suffering. This factor (together with allowances for medical expenses)

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(8) For example, an individual might accept a 0.1 percent decrease in survival probability in order to receive $200. If this applied to many individuals it would lead to an *ex post* life valuation of $200,000. However, the same individual might require a million dollars to accept a 50 percent reduction in survival probability (leading to an *ex post* life valuation of $2 million), and would probably be unwilling to accept any compensation--however great--in exchange for certain death. Thus in this example the *ex ante* risk-benefit trade-off relationship is non linear (see Hirshleifer, Bergstrom and Rappaport, 1974:21, *et seq.*).

is often present in court awarded injury compensation. In some empirical studies, an allowance for pain and suffering has been included as a proportion of the other costs of accidents and illness [e.g., 25 percent of monetary costs (Garwood and Newby, cited by Tihansky, 1976)] but in most studies no explicit allowance has been made.

The National Academy of Sciences (1977:161, 162) recently used $50 per working day as the lost income that would result from a disability, and argued that the non-working population was included indirectly in their calculations via resource transfers. Unfortunately, the National Academy of Sciences' study did not estimate the associated reduction in medical costs that would result from reduced disabilities, nor did they make an allowance for pain and suffering. Several other authors have also used the $50 per lost work-day figure (e.g., Brewer, 1976; Hub, et al., 1973). However, Hub, et al. (1973) restrict the valuation of accidents to those that are "external" to the risky situation to avoid double counting (i.e., they assume that the labor cost for a worker exposed to health risks reflects the costs of these risks). This is the same concept as the wage "risk premium" mentioned above.

The distinction between "internal" and "external" risk-bearers is important, since it implies that if the "risk premium" correctly reflects the additional risks undertaken, we need not evaluate the risk to life and limb of workers normally involved with hazardous waste management activities, and only need to consider (involuntary) risks to bystanders. Thus, part of the wages paid to an operator at a hazardous waste disposal facility should, in theory, reflect the higher level of job-related risk over that of a similar job dealing with non-hazardous materials. While the risk premium may be reasonably accurate in an occupation like underground coal mining where there is a history of accidents and illness (e.g., black lung disease) known to the workers (see Otway and Cohen, 1975), it is less likely to accurately reflect the risk in a hazardous waste management facility because in most cases the risks will be poorly defined.

Involuntary risks to bystanders' lives and health can arise in many ways from hazardous waste management activities. For example, the risk incurred by individuals along waste transport routes are involuntary, as are those that arise from undetected contamination of water supplies or foodstuffs due to waste leaching or overflow.

Damage or Destruction to Animals, Vegetation and Land Ecosystems

Commercial Crops and Livestock: Commercial crops could be damaged or destroyed by overflow from lagoons or treatment facilities, and could be affected by airborne pollution from nearby hazardous waste facilities. Land application could affect subsequent crops on the same site, while animals could eat or drink contaminated materials.

It is probably reasonable to assume that agricultural products face a market of pure competition. In this event, destruction of commercial crops and stock animals can readily be valued at market prices, although savings that arise from not needing to harvest and market the crop of products could be subtracted if significant. Clean up costs should be included where necessary, and due allowance should be made for long-lived effects, such as reduced crop yield or the need to plant less valuable crops in future years.

Valuation of Wildlife, etc.: Although damage to land-based ecosystems from hazardous waste spills and air pollution is likely to be quite localized, the damage potential to aquatic systems is probably one of the more important environmental impacts that can arise from hazardous wastes (see Appendix B). Methods of valuing wildlife and associated ecosystems, both land and aquatic, largely amount to the valuation of recreation opportunities in natural surroundings. Recreation might include hunting, fishing, camping, hiking, boating, etc. In addition, there may be an "option value" associated with the preservation of natural environments, which will be discussed later.

Ashton, Wykstra and Nobe (1974) list and discuss six recognized approaches[9] to the valuation of non-market supplied recreational opportunities, as follows:

> 1. Expenditure method - consisting of measures of the value of recreation in terms of the total direct private expenditures on recreation.
>
> 2. Gross National Product method - an attempt to measure the contribution of recreation to GNP.
>
> 3. Consumers' Surplus method - determining the willingness of individuals to pay for various quantities of recreation.
>
> 4. Cost method - uses the cost of supplying recreational facilities as a measure of the benefits derived therefrom.
>
> 5. Market value method - based upon fees charged at private resorts as a proxy for the value of public-supplied facilities.
>
> 6. Monopoly revenue method - relies upon the estimated revenue that would be obtained by a monopolist [non-discriminating] owning a recreation site as a measure of the benefits.
> (Ashton, Wykstra and Nobe, 1974:11,12)

The most important approaches are the expenditure method and the consumers' surplus method. The expenditure method is simple to apply and is widely used: Ashton, Wykstra and Nobe, (1974:13) cite a variety of studies that have resulted in valuations of \$3.89 to \$28 per recreation

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(9) Although some of these approaches are seriously flawed, they are discussed here because the reader may find them in use and should therefore be able to recognize them and understand their limitations.

day (in 1952 to 1966 dollars). One approach to the consumers' surplus method is to ask consumers what they are willing to pay for the recreational opportunities. While attractive theoretically, this approach is fraught with practical difficulties. Alternatively, in both the consumers' surplus and monopoly revenue methods, travel distances, and hence differential travel costs can be used to impute a value (or rent) for recreational opportunity (Ashton, Wykstra and Nobe, 1974:16-18, 22-25).

The cost method is conceptually unsound and is rarely, if ever, used nowadays; while its successor, the market value method is difficult to use in practice. The appropriate version of the gross national product method involves tracing the contributions to regional or national income that arises from the recreational activities of interest (Ashton, Wykstra and Nobe, 1974:14-16). Thus this method includes secondary effects and would be inconsistent with other valuations used in this study. Note, however, that each method discussed here is not merely a different way of arriving at the same result, but is in fact a different measure of the value of recreation. Fortunately, the consumer surplus and monopoly revenue methods generally give results that are similar in magnitude to those obtained by the expenditure method (Ashton, Wykstra and Nobe, 1974), so that the significant philosophical differences need not cause too many problems in practice.

Other useful discussions on the valuation of recreation may be found in Clawson (1972); Clawson and Knetsch (1970); Krutilla and Fisher (1975); Krutilla (1972); Edwards, et al. (1976); and Pearse (1968). Most work has concentrated on the valuation of a recreation-day as this is most readily measured. However, in many situations it may be desirable to be able to value individual species (this is particularly useful for fish as it permits fish kill data to be used). For "consumptive" or "harvested" species it is common to deduce an average animal value from the number of hunter-days (often estimated from license data), the average expenditure or some other measure of the value of a hunter-day, and the number of animals harvested (Ashton, Wykstra and Nobe, 1974:30). Valuations yielded by this procedure have been used within a cost-benefit analysis framework to determine the cost of destroying areas of wildlife habitat, based on the number of animals that the habitat would support (Norman, et al., n.d.).

Unfortunately, the average animal value approach has some serious drawbacks. Firstly, for the purpose of evaluating any specific wildlife kill, a marginal value should ideally be used. Secondly, it values animals as though they were harvested, and does not take account of the need to propagate the species for future years. Finally, it cannot be applied to non-harvested species.

There have been some attempts to overcome these difficulties. Brown and Hammack (1972) have developed a questionnaire-based methodology (applied to migratory waterfowl) to derive a marginal value for game animals that recognizes the variability of hunting success and the effect of constraints such as the bag limit. Inevitably, a major difficulty associated with determination of marginal rather than average values is the more complex data requirements; this is probably why most analysts use average values.

The need to propagate the species is usually taken into account by valuing breeding areas or young in terms of the yield to harvestable adults and the value of these adults. For example, Brown and Hammack (1972) derive a valuation for nesting areas based on survival probabilities and hunting yields, while the Oregon Department of Fish and Wildlife (1977) has developed similar methods for valuing spawning gravel and brood fish in anadromous fisheries. This approach does not take account of changed competition for food, the effect of reduced populations on hunting activities and yields, but to attempt to do so would indeed be a profound undertaking.

Valuation of non-harvested wildlife presents greater difficulties. While similar methodologies to those used for arriving at the value of a hunter-day can be used to determine the value of a recreation-day, the valuation of specific species is very difficult. As far as the author is aware, non-harvestable species valuation has only been attempted once (Norman et al., n.d.) and in this case, "the values were derived by reviewing the consumptive [harvestable] values and making subjective comparisons" (Norman, 1977). Thus, in this case the value of a harvested black bear was established at $6,400; the value of a grizzly bear (which is not harvested) was subjectively set at $20,000 on the basis of comparison with the black bear.

Fish and Other Aquatic Life Kills in Surface Waters

Damage to Non-Commercial Fishing, etc.: The considerations that apply to the valuation of non-commercial fishing and to water-related recreation have already been discussed under the valuation of wildlife, etc.

Damage to Commerical Fishing: While land-based crop and animal losses can reasonably be valued at market prices, valuation of lost commercial fishing is more difficult, as in this case resources are primarily expended in harvesting the fish (as opposed to raising the crops or animals) and therefore, it would be possible to arrive at a zero valuation for reduced fishing yield, if the resources could be employed in alternative uses that were equally productive. In practice, the resources are likely to be immobile, except in the very long run[10] and Brown et al. (1976) concluded that the benefits of increased yields can be valued at market prices to the fishermen plus an increase in the consumers' surplus. The change in the consumers' surplus arises because the demand for fish (salmonids in this case) is assumed to be local, and an increased catch causes a decrease in price.

Similar arguments could be applied to decreases in yield due to hazardous waste incidents, but unless the incident was such as to have a substantial effect on the local catch, the decrease in the consumer's surplus could be neglected. If the physical effects were permanent, the loss to society could probably be restricted to several years or at the most

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(10) Gordon (1972:95) argues that the operation of a typical competitive fishery is such as to yield no net economic rent, and that some fishing grounds may be exploited at a level of negative marginal productivity. He states that fishermen are one of the least mobile of occupational groups, and that they will work for less than the "going wage."

Bromley (1969:39-47, 144), who provides an interesting discussion of the economics of ocean fisheries, confirms the low mobility of resources, and argues that some of the unique features of the commercial fishing industry justify the observed labor immobility on grounds of social efficiency.

Much additional information on the economics of fisheries (and of other renewable resources) amy be found in Peterson and Fisher's (1977) survey of the economics of extractive resources.

to one generation, as the resources would not be immobile forever,

The Impacts of Ocean Dumping: Valuation of the environmental impacts of ocean dumping is made difficult by the diversity of possible effects (see Appendix B). It may, however, be useful to identify and value the activities that are at risk from ocean dumping. These include: commercial and sport fishing, ocean recreation opportunities (skin diving, swimming, etc.) and general tourism. The valuation of fishing and recreation has already been discussed; tourism is most commonly valued in terms of its commercial impact by using tourists' expenditures as a base. Because tourists' expenditures are usually assumed to be exogenous to the area, secondary (multiplier) effects are commonly included. In general, this study disregards such effects, but the local impact of multiplier effects probably should be noted when lost tourism is considered.

Some estimates of economic damages from actual hazardous materials and oil spills are available. For example, clean-up costs for oil spills have ranged from \$0.13 to \$4 per liter (Enk, 1974). However, available estimates have rarely, if ever, attempted to evaluate all costs (Enk, 1974).

Changes in Property Values

The concept that pollution will affect land values and that land or property values can thereby be used as some measure of the public's perception of pollution has received much attention from environmental economists. Unfortunately, analysis of empirical data is far from simple and has met with only limited success (Fisher and Peterson, 1976). Most attention has been paid to the impact of air pollution on property values, it being argued that property value differentials provide an indication of individual willingness-to-pay to reduce pollution. The theoretical underpinning and the practical problems associated with the use of land rents or property values as a measure of external effects are described by Schmalensee, et al. (1975:92-172). However, there remains some debate as to exactly what can be inferred about pollution from property value data (see Polinsky and Shavell, 1975).

The results of several empirical studies of air pollution on property values are discussed by Waddell (1974:43-49). An indication of the magnitude of the effect is provided by Waddell's (1974:53,55) conclusion that an increase of 0.1 mg $SO_3/100\ cm^2$-day (which would represent a doubling of the background rate for sulphation in the U.S.) would decrease residential property values by $100 to $600.

Tihansky (1975:147,148) cites some studies which attempted to relate property values to water pollution. Unfortunately none of these studies provided clear cut results that could be helpful in evaluating hazardous waste management problems.

Schmalensee, et al., attempted to assess the impact of sanitary landfills on adjacent residential property values. The authors concluded that:

> . . . A study of values of residential property adjacent to four sanitary landfills in Los Angeles County revealed a general lack of significant detrimental environmental effects. In the one case where truck noise associated with the fill had a negative effect on property values, both proximity and view of the fill had positive effects due presumably to the anticipated transformation of the fill to a recreational site. (Schmalensee, et al., 1975:2)

It should be noted, however, that this result related to well-operated sanitary landfills, where air and water pollution were not problems.

Except perhaps where there is severe air pollution, it appears that changes in property values are quite local.(11) Thus this aspect of the adverse impacts of hazardous waste management techniques can be minimized by locating any site well away from residential and other susceptible properties. As landfills used for the disposal of hazardous waste are unlikely to be converted to recreational sites, increases in property values would not be anticipated.

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(11) For landfills, the effects do not appear to extend beyond one or two miles (see Schmalensee et al., 1975:338-346).

While property values may reflect actual physical pollution, they may also reflect psychological influences. The fear that property values may be reduced is frequently encountered when landfill sites are being considered, and local citizens will often oppose the establishment of a landfill for this reason(U.S. Environmental Protection Agency, 1976:109). Despite the safeguards used in a well-operated chemical landfill or other waste management facility the situation may be exacerbated when it comes to hazardous waste operations, reflecting a greater degree of perceived threat. The author is aware of two instances in which industrial waste disposal sites were closed as a result of public pressure. While incidents of this type are complex, it does appear that concern about property values was involved in both cases.(12)

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(12) The Antioch, California, landfill and lagooning facility operated by a subsidiary of Industrial Tank Company, was closed as a result of public pressure after a housing subdivision was built adjacent to it. The residents of the subdivision complained of air pollution, but continued to press for closure after the lagoons had been filled in and capped. The same company operates two other treatment and disposal sites in the San Francisco Bay area, but after "very emotional" hearings was unable to secure a land use permit for a proposed site near Brentwood, California (Schwarzer, 1977). To avoid a repetition of the Antioch situation, the company has obtained control of a "buffer zone" of several thousand acres (used for agricultural purposes) around its 280-acre Benica, California, site (Balisteri, 1977).

An industrial waste disposal site near Pasco, Washington, operated by Resource Recovery Corporation was closed after the Franklin County Commissioners refused to renew its land

Changes in property values are of particular importance with respect to equity since changes that are caused by a hazardous waste activity can in part be regarded as transfer payments. (These transfer payments would be between those whose property values had fallen and those whose had risen; and, to the extent that the price changes did not reflect changes in utility, between a seller and a buyer of a property.) In addition to these transfer payments, there is the overall external effect of the hazardous waste management activity on the welfare of the householders. An adverse impact will, in aggregate, reduce the utility of the properties to the householders, thereby decreasing welfare.

To summarize: One can be reasonably sure that some hazardous waste management techniques will--like many industrial activities--affect the value of adjacent properties. These changes in value are indicative of external effects associated with the hazardous waste management activities but only provide a true measure of the external effects under very limited circumstances (Schmalensee, et al., 1975: 100-107; see also, Fisher and Peterson, 1976:20-23). In

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use permit. The company has attempted to establish operations elsewhere in eastern Washington but has met with opposition to its proposals (Stradley, Dawson and Cone, 1975:120,121). The Pasco site closure occurred after a newspaper had suggested that its handling of the herbicide 2,4-D could threaten local grape crops. However, it was later demonstrated that no such physical damage had occurred (Cook, et al., 1977).

practice, changes in property values are largely important with respect to equity.

Aesthetic Factors and Option Value

This category of effects is included to cover individuals' values that do not normally enter the market place. The effects are highly indirect: an individual does not necessarily have to observe the environmental feature of interest to possess these values. They may conveniently be divided into aesthetic value, existence value and two types of option value.

Aesthetics may enter into the valuation of most of the environmental effects already discussed--for example, property values and the willingness-to-pay for recreation opportunities partly reflect aesthetic considerations. However, there may be situations where only aesthetic values are involved, such as the attractiveness of a river with clear water as opposed to turbid water, and the discussion here is intended to cover those situations.

Since changes in these non-market values[13] between different hazardous waste management schemes are difficult

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(13) There are no "zero levels" of aesthetic and existence values, so for these factors, costs must be expressed in terms of differences. Option values, however, do have zero levels and, hence, it is possible to use absolute values if desired.

to measure, the analyst may in some cases simply wish to identify these costs rather than place a dollar value on them. However, there are techniques that can permit values to be assigned to these costs, and these are discussed below.

Aesthetic Value: The aesthetic value of concern here is what might be termed "environmental aesthetics", as opposed to the aesthetics of art, design, city planning, etc. Thus, it is the value that an individual places on the physical environment to reflect that individual's taste, desire for beauty, for "natural" surroundings, etc.

No direct costs can be associated with most changes that offend or please a person's environmental aesthetic values. Virtually the only way of placing a dollar figure on this type of aesthetic value would be some measure of willingness-to-pay, derived either directly from questionnaires or bidding games, or indirectly from studies of human behavior such as the travel studies used to value recreation benefits.

Some authorities propose the use of a Delphi technique(14) to estimate aesthetic damages (Kennedy, et al., 1976:3-19;

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(14) Delphi techniques are widely used in technological forecasting and to some extent in technology assessment. The method involves the use of a panel of experts who through a controlled interactive process attempt to reach consensus in answering certain questions which usually involve prediction. For more details of the Delphi method see Linstone and Turoff (1975).

CONSAD Research Corporation, 1975:107; Mäler and Wyzga, 1976:77). However, while the Delphi method might have some promise for identifying different aesthetic considerations and previous relevant research, the use of the opinions of a panel of experts as a surrogate for those of the public is questionable.

Existence Value: In addition to the aesthetic value of the environment to an observer of that environment, there may be an "existence value" associated with the environment. This is value that some persons place on knowing that something exists, even if they never expect to see it or benefit from it (Fisher and Peterson, 1976:6,9). This value is largely associated with major irreplaceable features of the environment(15) (e.g., the Grand Canyon) and with rare or endangered species.(16) Existence value can include the

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(15) A good example of this aspect of existence value was provided by one of the comments on the E.I.S. for the prototype federal oil shale leasing program. It appeared to come from an old man in Ohio, who evidently did not want some of the canyons in the vicinity of the oil shale formations destroyed by depositing spent shale in them. He said, "...I have never seen a canyon, let alone those in Colorado, Wyoming, and Utah....please do not destroy the beauty of what God put there...if it cost more to keep the land and animals I would rather spend the extra money." (Burris, 1973.)

(16) The drive to preserve the only known habitat of the Snail Darter on the Little Tennessee River which may halt a major dam project provides an extreme illustration of such a valuation (Cook, Cook and Gove, 1977). Thus, in this case some individuals are essentially saying that the preservation of this specie is worth more than the tens of millions of dollars

possible scientific benefits from preserving a specie, an ecosystem or a natural feature, but also includes an aesthetic aspect that values diversity, etc.

Determination of existence values again involves attempting to ascertain individual's willingness-to-pay to preserve that existence, and is probably even more difficult to accomplish than determining aesthetic values. Nevertheless, confrontations such as that over the Snail Darter illustrate the very high existence values that some people attribute to rare environmental features.

Option Value: Option value refers to the benefits of keeping an option available. Like existence value, it is only relevant to irreversible actions that foreclose some future use of the feature of interest. The best known example is probably Krutilla's analysis of the benefits of maintaining Hell's Canyon in its natural state (Krutilla and Fisher, 1975:84-150). Key aspects of the analysis are that a decision to dam the Snake River in Hell's Canyon would be irreversible, that in the future the value of the recreational benefits conferred by maintaining the river in its natural state is likely to increase, whereas technological advance (in alternative power sources) is likely to reduce the real

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irretrievably committed to the dam project. (Note, however, that in this case the costs of preserving the snail darter will not fall on those advocating preservation.)

value of hydroelectric power generated by the dam(s). Thus in this case, the implications of technical change are said to be "asymmetric" (because the supply of wilderness areas cannot be increased) (Krutilla, 1967), and maintaining a natural environment is expected to make an important contribution to man's future welfare.

There has been some debate as to exactly what option value represents, and how it differs from the consumer's surplus. It is generally held that option value can take two forms: one (often called option demand) that represents a risk aversion premium associated with uncertain future demand (and which is in addition to consumers surplus), while the other reflects the benefit of not undertaking an irreversible project while society waits for improved information about the benefits of alternative uses of our resources (usually the environment) (Fisher and Peterson, 1976:6,7). It is this second form of option value that has potentially important implications for hazardous waste management. As Arrow and Fisher (1974) point out, where a pollutant is nondegradable (i.e., it may have irreversible effects) any decision about its discharge to the environment should take into account the option value associated with delaying any action until more data about its effects and about alternatives are obtained (Arrow and Fisher, 1974).

This option value must be balanced against the increased costs associated with the delay.

General: While it is easy to postulate existence values and option demand, a pervasive difficulty with such "non-user effects" is to determine the number of people who hold these values. These numbers can be very large--for example, the Alaska pipeline issue must be known to a large proportion of the U.S. population, and hence, even if only a small percentage of these people are concerned about the potential damage to the environment, the non-user benefits of environmental preservation could be substantial (see Bishop and Ciccheti, 1975).

Another aspect of aesthetic values, existence values and the option demand arising from risk aversion should be mentioned. This is that values are likely to vary substantially among individuals. It is even possible to postulate changes that would provide a positive aesthetic benefit to some individuals and a negative one to others.[17] While individuals may place differing valuations on market-traded goods (giving rise to the consumer surplus), in most instances the variation is probably larger with non market-traded goods,

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(17) Consider the choice between farming land and leaving it as a wilderness. Some people may prefer wilderness, seeing farming as the introduction of a non-natural ecological monoculture. Others may prefer to see the land farmed, associating farming with a satisfying traditional way of life.

e.g., recreational opportunities. If the results of willingness-to-pay surveys on improving the environment can be trusted, this variation can be very large (several orders of magnitude) for aesthetic and existence values. (Taylor and Avitable, forthcoming.)

This variation in individuals' raises some difficult questions for decision-makers. These questions essentially revolve around equity: to what extent it is reasonable to provide or deny very large benefits to a few individuals when the benefits to most others are small? A similar problem arises where individuals' true willingness-to-pay (or to take avoiding action) is limited by a low discretionary income. If this low willingness-to-pay is accepted at its face value, one may be making the judgment that society should value the welfare of that person less than that of an affluent person. This type of implication should be considered when alternative policy approaches are evaluated.

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APPENDIX D

RISK AND DECISION-MAKING

Considerations of risk appear in several places in this study. The purpose of this appendix is to interrelate the various aspects of risk, to provide limited further information about some of these aspects and to provide the interested reader with an entry to the wealth of risk-related literature that may be relevant to decision-making about hazardous wastes.

Aspects Of Risk

The term "risk" has different implications to different people. Rowe (1975:1), in a broad discussion of many aspects of risk, defines risk as

> . . . the potential for realization of unwanted, negative consequences of an event or combination of events to individual groups of people or to physical and biological systems.

Risk only becomes relevant when it affects decision-making and all decision-making involves some element of risk, even if the potential negative consequences of a decision are as simple as failing to maximize utility or satisfaction in a choice between two competing products. However, risk does not play a significant role in every decision, and hence only a limited proportion of decisions would be perceived by a decision-maker as being risk-related. It is possible to classify decision-making on the basis of whether the viewpoint used is predominantly personal, economic or societal.

Risk taking in personal decisions might involve social behavior, such as the acceptability of drug taking to peer groups; or it might relate to an individual's well being or safety, such as a decision to risk the consequences of swimming in polluted water. Note that risks are taken voluntarily as a result of personal decisions.

Many business decisions involve predominantly economic risks. The basic uncertainty need not be economic; it could, for example, be a question of the ability of the firm's management to adequately control a project, or it may be that it involves an unproven technology. However, to the business firm the ultimate consequences of an unsatisfactory performance in these areas will be measured in economic terms. The upwards adjustment of a required rate of return to reflect the perceived riskiness of a project is one way in which decision-makers allow for economic risks.

Another important aspect of economic risk-taking is insurance decisions. Insurance spreads the risk of the adverse economic consequences from what is usually a comparatively unlikely event over many individuals. The basis of insurance is that many individuals (or organizations) prefer to pay a premium (which is in excess of the expected value of the loss due to the transaction costs involved) rather than risk the chance of serious economic consequences should specified events occur. These events are usually those over which the insured has little or no control, such as natural disasters, e.g., flood (no control), automobile accident (little control). The fact that individuals will pay a premium to obtain insurance illustrates a widely observed phenomenon; that many people are "risk averse," and prefer to minimize the potential for adverse consequences. However, individuals often exhibit risk proneness in some decisions; for example, research has shown that individuals frequently do not carry insurance against high loss, low probability events (see p. 328).

Where risks have the potential to affect large numbers of persons they become <u>societal</u> risks. However, perhaps the most important aspect of societal risk is that the risks are largely incurred involuntarily. The distinction between voluntary and involuntary risks appears to be of practical as well as philosophical significance, as it appears that, for a given economic benefit, the public is willing to accept voluntary risks that are greater than involuntary risks (see p. 290, p. 332).

Another key feature of societal risks is that individuals can make decisions that affect many others. In some cases these decisions are made by persons who (implicitly or explicitly) represent the public, but in others they are made by individuals in the light of their own specific interests. In the latter case, society often finds a way to constrain or control the decisions so that the public interest is not unduly damaged; for example, certain methods of disposing of hazardous waste may be prohibited by law as being too harmful to the environment.

There are many situations in which decisions are not purely personal, economic or societal; in some cases all three facets can be present. For example, if an individual decides to transport some obsolete and potentially dangerous explosives over the public highways, this could be viewed as a personal risk-taking decision. However, it also has societal implications via the risks to bystanders, and economic implications to the individual transporting the explosives, to his dependents and to society (via road use costs, etc.).

Many risks have a technological element, even though the threat-initiating event may be natural. It may be that the technology itself is not completely reliable or understood (e.g., weather modification), that the man-technology combination is not secure (e.g., is a nuclear power station really fail-safe?) or that technology is used to mitigate or minimize the effects of natural risks (e.g., design of buildings to resist earthquakes).

Many risk data for specific technologies, e.g., transport accident statistics, are readily available. Some of these that are applicable to hazardous waste management are presented in Appendix B on environmental threats. A problem sometimes encountered in such work is the quantification of risk where historic data are unavailable or inadequate. One approach proposed to remedy this deficiency uses envelope curves to describe risk--consequence relationships (Kastenberg, McKone, and Okrent, 1976; Okrent and Whipple, 1977; Starr, 1972).

Recently, there has been much research on the risks that complex technological systems pose to mankind; the preeminent example being electric power generation from nuclear or other fuels. (For example, see Okrent, 1975; Starr, Greenfield and Hausknecht, 1972; Rasmussen, 1975; U.S. Atomic Energy Commission, 1974; Barrager, Judd and North, 1976.) An associated development has been the growing use of "technology assessments." While the objective of a technology assessment is to evaluate all the effects of the use of a technology, including direct costs and benefits, the emphasis is on long range consequences and side effects (National Academy of Engineering, 1972:3). Consequently, technology assessment is closely associated with risk evaluation. Technology assessments have been performed in such areas as precipitation augmentation (Weisbecker, 1974), transport of LNG and oil, and nuclear proliferation and safety (U.S. Congress, Office of Technology Assessment, 1977).

Decision-Making Under Uncertainty, And Risk Aversion

It is widely held that most individuals are risk averse. In the context of economics, this follows from the assumption that the marginal utility of wealth decreases as an individual's wealth increases, i.e., it is of the form shown in Figure D.1 (Slovic, et al., 1977:238).

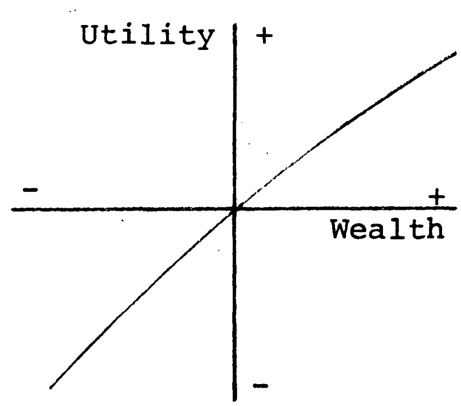

FIGURE D1: Utility of Wealth For a Risk Averse Individual

Consider a decision-maker faced with a situation where he has a choice between (A) a certain \$1 million pay-off and (B) a probability p=0.5 of a \$2 million pay-off together with a p=0.5 of a zero pay-off. If the decision-maker is indifferent between choices (A) and (B), he is risk neutral since the expected value of choice B is \$1 million, i.e., the same as (A). If he prefers (A) to (B), he is risk averse; however, should he prefer (B) to (A) he is risk prone. Similar arguments apply to expenditures and loss of utility. A risk-averse decision-maker might, for example, prefer to spend \$1 million to avoid a potential waste problem rather than face a 90 percent probability of needing no expenditures together with a 10 percent probability of having to spend \$10 million to contain the problem.

The above statements do not provide any information about the extent of the risk aversion (or risk preference) that a decision-maker exhibits. This could be measured by determining the expected value of the uncertain situation at which the decision-maker was indifferent between this and the certain outcome. To extend the waste containment example above, a decision-maker who will spend \$2 million to avert the specified risk is risk averse; a decision-maker who will spend \$3 million to avert the same risk is more risk averse. Maurer (1977) discusses ways of characterizing the extent of risk aversion, and discusses some common empirical risk tolerance functions which can be used to quantify risk aversion.

While individuals may exhibit risk prone behavior over small ranges, human behavior is generally characterized by risk aversion for monetary risks (Maurer, 1977:36). Consequently, some authors have suggested that where choices can be couched in purely economic terms a specified degree of risk aversion can be built into the decision-making process (Okrent and Whipple, 1977:21-22). The concept includes the suggestion that we should be less risk averse in decisions concerning essential services (e.g., in deciding to have a public electricity supply), than in "peripheral services" that are not particularly beneficial to society or where an almost equivalent function could be performed by many alternative means (e.g., use of PCB's in transformers).

The above discussion of risk aversion dealt with comparatively straightforward choices that are primarily economic in nature. Utility theory has traditionally been used to provide a theoretical basis for decision-making under uncertainty. It also facilitates the analysis of problems in which it is difficult to place a monetary value on some outcomes. (For example, see Von Neumann and Morgenstern, 1953; Ellsberg, 1961; Keeler and Zeckhauser, 1969; Fishburn, 1964, 1965; Raiffa, 1968; Fischer, 1975.)

Research on insurance and gambling decisions has developed empirical data about individual's behavior when faced with a variety of uncertain situations many of which are somewhat complex (Slovic, 1972a; Slovic and Lichtenstein, 1968, Slovic, et al., 1977). If the individual is assumed to make logical decisions on the basis of utility, some of these findings can be surprising. For example, it appears that people are less inclined to insure against low probability, high loss events than high probability, low loss risks. This could be constructed as implying risk prone behavior, but an alternative explanation could be that there is a threshold level of probability for a damaging event below which individuals do not consider it worth carrying insurance (Slovic, et al., 1977). Extending this result, and drawing on other work, Slovic, et al. conclude that when dealing with insurance against risks from natural hazards there are many social and psychological factors that bear upon an individual's decision (Slovic, et al., 1977:255-256; Slovic, Kunreuther and White, 1974; Kunreuther and Slovic, 1978).

Because utility theory alone is not entirely satisfactory for explaining observed behavior, an alternative psychology-based approach, now termed "bounded rationality", has been proposed (Simon, 1956, 1959). Bounded rationality postulates that individuals do not think probabilistically, and that they try to avoid the necessity of directly facing uncertainty in decision-making (Slovic, Kunreuther and White, 1974:190). It is assumed that an individual's cognitive limitations force him to construct a simplified model of the world, and that the decision-making goal becomes "satisficing" rather than optimizing. There is empirical evidence that the way in which individuals process information is central to their decision-making procedures, which supports models of the bounded rationality type (Slovic, Kunreuther and White, 1974; Slovic, 1972b; Tversky and Kahneman, 1974; Fischhoff, 1976).

It appears that there is a tendency for economic decisions made by groups to be more risky than by individuals, and that individuals' risk-taking levels also increase following group discussion (Clark, 1971; Kogan and Wallach, 1967; see also Slovic, 1972b:796). This phenomenon has been called "risky shift." However, it is a complex subject, and groups will make less risky decisions under some circumstances (Cartwright, 1973).

Risk And Society

One of the most difficult tasks with which a decision-maker can be faced is the need to decide upon a level of risk for society to bear.[1] The dilemma of choosing between comparative safety at the expense of low cost-effectiveness versus greater risks but higher effectiveness--provided nothing goes wrong--has spawned such article titles as "How Safe is Safe Enough?"[2] (Fischhoff, et al., 1976; Slovic and Fischhoff, n.d.), and "Balanced Risk: An Approach to Reconciling Man's Need with His Environment" (Wiggins, 1975). Ideally, one would like to be able to optimize the level of risk to which the public is exposed, but it is not an easy task to determine what the public really wants, the difficulty being greatly compounded by the "fuzziness" of the data.

Otway and Pahner, who addressed risks in the context of technological systems, see risk on a series of levels:

- physical, biological risks to man and the environment;
- the perception of these risks by individuals;
- the potential risk to the psychological well-being of individuals based upon these perceptions; and
- the risks to social structures and cultural values as influenced by the collective

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(1) A decision-maker will have a personal risk-aversion (related to others' perceptions of how well he has performed his job) which may not coincide with the level of risk aversion that is optimal for society. This personal factor is disregarded in the following discussion.

(2) It appears that Starr (1969:1237) was the first author to specifically pose the now well known question "how safe is safe enough?"

> psychological states of individuals. (Otway and Pahner, 1976:123)

Otway uses the term "risk assessment" to describe the process of incorporating social values into risk-related, societal decisions (Otway, 1977; Otway and Pahner, 1976; Otway, 1975). Risk assessment is seen as consisting of two major components: risk estimation and risk evaluation. Risk estimation involves identifying and quantifying the risks associated with a particular option, i.e., it is the largely technical side of risk assessment. Some material on risk estimation has been presented in Appendix B. Risk evaluation involves determining the acceptability of these risks to society (Otway and Pahner, 1976:124-126; Slovic and Fischhoff, n.d.).

There are two principal approaches to risk evaluations:

(i) the "revealed preference" method, and

(ii) the "expressed preference" method.

(Fischhoff, et al., 1976:1,2).

The basis of the revealed preference method is the assumption that

> . . . by trial and error society has arrived at a nearly optimal balance between the risks and benefits associated with any activity. One may therefore use economic risk and benefit data from recent years to reveal patterns of acceptable risk-benefit tradeoffs. Acceptable risk for a new technology is defined as that level of safety associated with ongoing activities having similar benefit to society. (Fischhoff, et al., 1976:1,2)

The expressed preference method, which has also been called the "controlled experiment" method (Otway and Pahner, 1976) and the "psychometric survey" (Fischhoff, et al., 1976); Okrent and Whipple, 1977), depends on using a survey or questionnaire to find individual responses to risk, or specific risk attributes (Okrent and Whipple, 1977:1).

Starr (1976; 1972; 1969) is the best known proponent of the revealed preference approach. He essentially compared risk of death with a valuation of the benefits received by the individual from the relevant activity. In most cases benefits were valued by assuming that they were equal to the average expenditures by an individual on that activity. This analysis led Starr to the following conclusions:

> . . . (i) The indications are that the public is willing to accept 'voluntary' risks roughly 1000 times greater than 'involuntary' risks. (ii) The statistical risk of death from disease appears to be a psychological yardstick for establishing the level of acceptability of other risks. (iii) The acceptability of risk appears to be crudely proportional to the third power of the benefits (real or imagined). (iv) The social acceptance of risk is directly influenced by public awareness of the benefits of activity, as determined by advertising, usefulness, and the number of people participating. . . . (Starr, 1969:1237)

The principal criticism of this approach is that the actual risk levels are not known to the public, and hence that the judgments will be based on perceived risks rather than actual risks.[3] The literature presents several other criticisms of the revealed preference approach, including the argument that the sociopolitical decision-making process does not reveal the true public preference for benefit-risk trade-offs, that revealed preferences do not differentiate between what is "best" and what is traditionally acceptable, and that they illustrate past values, not current ones (Okrent and Whipple, 1977; Linnerooth, 1975; Fischhoff, et al., 1976). Also Lave (1972) argues that Starr's distinction between voluntary and involuntary exposure is explained by the "public good" nature of the involuntary exposure situations, and essentially arises from the large number of persons exposed.

In addition to the conceptual difficulties associated with the revealed preference approach, Staff's quantitative findings are also subject to doubt. Otway and Cohen (1975) have reanalyzed Starr's data, and show that the results are excessively sensitive to the assumptions made and to the

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(3) This criticism is supported by work by Lichtenstein, et al., which illustrates that the public's judgment on the relative mortality risk from various causes (diseases, accidents, etc.) is far from accurate (Lichtenstein, et al., 1978; Slovic, Fischhoff and Lichtenstein, 1976). The biases in the responses were attributed to disproportionate exposure to the various causes (due to variation in coverage by the newsmedia), and also differences of memorability or imaginability of various events (Lichtenstein, et al., 1978:1; Slovic and Fischhoff, n.d.).

way in which the data are handled. They conclude that simple mathematical relationships of the type suggested by Starr are unlikely (Otway and Cohen, 1975:1). In particular, Otway and Cohen did not replicate Starr's well known ratio of one thousand to one for the required benefits from risks undertaken involuntarily as opposed to voluntarily. Some recent unpublished work has suggested that a three to one ratio may be more appropriate (Slovic, 1978).

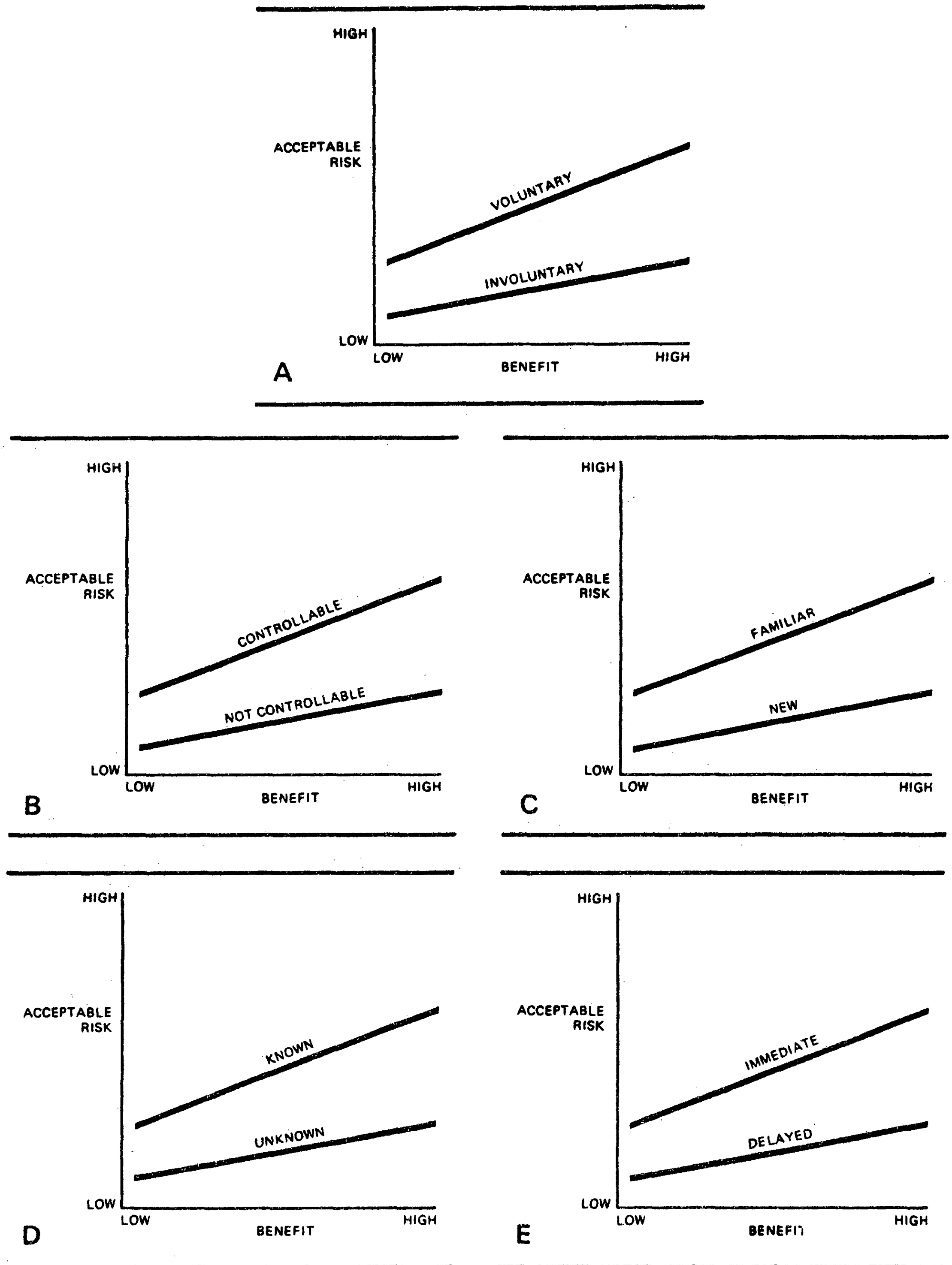
The expressed preference approach has been the subject of investigation by workers at Decision Research (Fischhoff, et al., 1976; Slovic and Fischhoff, n.d.; Slovic, n.d.) and by Otway and others (Otway, 1975, 1977; Otway and Pahner, 1976), but has not, as yet, been widely applied. The principal disadvantage is that it measures attitudes, not behavior; and that it is difficult to project attitudes to behavior (Otway and Pahner, 1976:126; Okrent and Whipple, 1977:1,2).

In one particularly interesting study, Fischhoff, et al., (1976) examined the way in which, for a given level of benefit, risk attributes affected the acceptability of a risk. Although this study was restricted to a small sample of members of the League of Women Voters and their spouses in Eugene, Oregon, it confirmed Starr's general finding that risks undertaken voluntarily were more acceptable than non-voluntary ones, and it also found that the acceptability of risk increased where the risk was controllable, familiar, known and with immediate consequences. These results are illustrated in Figure D.2 and have the effect of favoring low technology activities against high technology activities (Fischhoff, et al., 1976:24). Additionally, the degree to which an activity's risk was potentially catastrophic, dread and likely to be fatal also negatively influenced acceptability (Slovic, n.d.:6-8).

Although the expressed preference approach reflects the public's views, it has already been shown that these views are liable to be colored by inaccurate ideas on the magnitude of risks, etc. One way to correct for this would be to provide appropriate accurate data to the respondents. Slovic and Fischhoff provide a useful listing of the factors that can cause both erroneous views and erroneous analysis dealing with risk estimates (Slovic and Fischhoff, n.d.: 3-18).

The two methods discussed above provide, in theory, means for determining an optimum level of risk acceptable to society. A method that involves aspects of both has been advocated by Rowe:

> . . . For any given activity, he proposed adjusting the risk levels reflected in historical data according to the degree of the inequity induced by a particular activity (i.e., risks



SOURCE: Slovic, n.d.:7.

FIGURE D2: Determinants of Acceptable Risks as Indicated by Revealed and Expressed Preferences

> accruing to individuals other than those who reap the benefits) and the controllability of its risk. Greater inequity and less control dictate lower permissible risk. (Slovic and Fischhoff, n.d.:36)

Another method of determining risk acceptability is to argue that a risk that is reduced to well below the "noise level" should not be of significance. Thus, if a risk is far smaller than that posed by natural, unavoidable hazards, it is claimed that it should be acceptable low.(4) (Otway, 1975:5, 1977:4). A variety of historic data have been collected on risks that can be used for this approach; many data are included in the materials cited above, Baldewicz, et al. (1974), provide a fairly comprehensive listing, while Tonnessen and Cohen (1977) provide data on naturally occurring hazardous materials in deep geologic formations as perspective for the relative hazard of burial of nuclear wastes. The disadvantage of this approach is that the public may not perceive the relevant risk to be insignificantly low, and further, even if they did, they may not find this argument acceptable.

The widely observed and continuing opposition to nuclear power, despite a variety of assurances from "the experts"

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(4) While Rasmussen (1975) showed that the predicted nuclear power risks were much lower than the risks from a variety of other man-made and natural hazards, he did <u>not</u> make any judgment on the acceptability of nuclear power risks.

suggests there are some risks that much of the public simply does not want to accept.[5] Thus, some people hold that there can be "unacceptable" risks, but the National Academy of Engineering (1972:11,12) study on benefit-risk decision-making argues that all risks should be viewed within an incremental benefit-risk framework. However, the material presented in this appendix does suggest that the public's perceptions of, and attitudes toward, different types of risk should be taken into account by societal decision-makers when performing risk-benefit trade-offs.

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(5) Public attitudes to nuclear power have been widely researched, and a number of explanations for public opposition have been put forward. For example, see Fischhoff, et al., (1976); Slovic and Fischhoff (n.d.:18-21); Pahner (1975); Otway and Fishbein (1976, 1977); Otway (1977); Maderthaner, et al. (1976), and Louis Harris and Associates, Inc. (1976).

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