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Treatment of Hazardous Waste

Proceedings of the Sixth Annual Research Symposium

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TREATMENT OF HAZARDOUS WASTE

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Edited by:

David Shultz

Coordinated by:

David Black
Southwest Research Institute
San Antonio, Texas 78284

Project Officer

Robert E. Landreth
Solid and Hazardous Waste Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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FOREWORD

The Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of the environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is the first necessary step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and the solid and hazardous waste pollutant discharges from municipal and community sources; to preserve and treat public drinking water supplies; and to minimize the adverse economic, social, health and aesthetic effects of pollution. This publication is one of the products of that research -- a vital communications link between the researcher and the user community.

These proceedings present the results of completed and on-going research projects concerning the treatment of hazardous wastes.

Francis T. Mayo
Director
Municipal Environmental
  Research Laboratory

PREFACE

These proceedings are intended to disseminate up-to-date information on extramural research projects dealing with the treatment of hazardous wastes. These projects are funded by the Solid and Hazardous Waste Research Division (SHWRD) of the U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory in Cincinnati, Ohio. Selected papers from work of other organizations were included in the Symposium to identify closely related work not included in the SHWRD program.

The papers in these proceedings are arranged as they were presented at the Symposium. Each of the ten sessions includes papers dealing with major areas of interest for those involved in hazardous waste treatment technology.

The papers are printed here basically as received from the authors. They do not necessarily reflect the policies and opinions of the U.S. Environmental Protection Agency or Southwest Research Institute. Hopefully, these proceedings will prove useful and beneficial to the scientific community as a current reference on the treatment of hazardous wastes.

ABSTRACT

The Sixth Solid and Hazardous Waste Research Division Research Symposium on treatment and disposal of hazardous waste was held at the Conrad Hilton Hotel, Chicago, during March 17 - 20, 1980. The purpose of the symposium was two-fold: (1) to provide a forum for a state-of-the-art review and discussion of on-going and recently completed research projects dealing with the management of hazardous wastes and (2) to bring together people concerned with hazardous waste management who can benefit from an exchange of ideas and information.

Bound in two volumes, Treatment and Disposal, the proceedings of the symposium are published to provide a copy of all papers in the order presented. In this document, the Treatment volume, the following five technical areas are covered:

(1) Waste Sampling and Characterization
(2) Waste Treatment and Control
(3) Pesticide Treatment and Control
(4) Thermal Destruction Techniques
(5) Economics

CONTENTS

CURRENT RESEARCH ON HAZARDOUS WASTE
ASSESSMENT AND CONTROL

Albert J. Klee
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

ABSTRACT

One of the basic objectives of the Resource Conservation and Recovery Act of 1976 (RCRA) is the regulatory control of hazardous waste from generation through disposal. The U.S. Environmental Protection Agency has been charged with implementing the RCRA regulations pertaining to hazardous waste treatment and control. To provide the support necessary for fair and appropriate regulations requires a vigorous research program. It is the charge of the Solid and Hazardous Waste Research Division (SHWRD), Municipal Environmental Research Laboratory, Cincinnati, Ohio, to carry out research involving hazardous waste assessment and control.

The SHWRD hazardous waste assessment and control program consists of research that can be categorized into four distinct areas. Environmental impact assessments evaluate the effects of treatment/disposal operations on the environment. Treatment technology development investigates methods that appear promising for the detoxification of hazardous wastes. Techno-economic assessment studies investigate the feasibility, in terms of cost and technology, of both existing and promising treatment processes. Pesticide disposal research looks at the technology, feasibility, and environmental impact of methods for the safe disposal of waste and excess pesticides. Presently the SHWRD has several active research projects in each of the four subcategories. The purpose of this paper is to present a synopsis of the individual research projects that form the hazardous waste assessment and control program.

INTRODUCTION

Approximately 35,000,000 tons of hazardous waste were generated in the United States during 1976 and the rate of generation grows yearly. It has been estimated that 90 percent of the hazardous waste disposal in this country is inadequate to prevent contamination of surrounding environmental media such as groundwater, surface water and air. The introduction of hazardous substances into the environment via their disposal can create serious public health problems as evidenced by the situation at Love Canal in New York. As chemical technology increasingly creates new substances, many of which are toxic, there is the assurance that hazardous wastes will continue to be generated in increasing amounts.

The Solid and Hazardous Waste Research Division (SHWRD) is currently active in research for the assessment and control of hazardous waste. The principal objective of this research program is to produce economical and environmentally acceptable technologies for the treatment/disposal of unwanted hazardous wastes. To best accomplish this, the SHWRD performs four subcategories of research pertaining to hazardous waste assessment and control. These categories are (1) environmental impact of hazardous waste, (2) development of effective treatment technologies, (3) techno-economic assessment of hazardous waste control technology, and (4) effective pesticide disposal. What follows is a narration of specific research projects being performed according to the subcategories of the hazardous waste assessment and control

program.

ENVIRONMENTAL IMPACT ASSESSMENT

The treatment of hazardous wastes would be useless if the treatment process merely shifted the environmental problem from one media to another. It is essential to demonstrate that a particular treatment process successfully reduces or eliminates the deleterious effects of the hazardous waste on the environment. To this end, the Solid and Hazardous Waste Research Division (SHWRD) conducts studies that determine, in measurable, objective terms, the intermedia effects (effects on air, land, and water) of hazardous waste treatment and control operations.

The importance of good air quality is well recognized. Increased human health problems, as well as property damage such as accelerated corrosion of paint and coatings have been correlated with declining air quality. Several hazardous waste treatment processes and operations have the potential to severely impact ambient air quality at and surrounding the site of operation. Landfill operations, handling and transfer stations, chemical/physical treatment facilities and storage stations all encompass processes that must be regarded as potentially hazardous to air quality. To determine the actual impact of these facilities on air quality, the SHWRD is conducting a study to measure, analyze, and report on the levels and types of air pollutants in and around a series of selected hazardous waste management facilities in the United States (1). Approximately ten facilities representing a variety of different operations and geographical locations, will be analyzed. Four of these facilities will be selected for intense monitoring. Tests shall include grab and continuous monitoring for gas, vapor, dust, and other pollutants which will then be analyzed for type and quantity in the laboratory. Air monitoring locations will be arranged at key site locations around the plants, in accordance with specific terrain, population, weather, and prevailing wind conditions. The results of the study will be presented in a final report for guidance in future air quality legislation or regulation enactment.

An assessment of the environmental impact of reconditioning pesticide and organic chemical containing barrels and drums is being initiated by the SHWRD (2). The rinsing and detoxification procedures required to recondition barrels and drums create a rinsate that may be toxic, depending upon the contaminants in the barrel. The disposal of this rinsate creates the opportunity for introduction of hazardous substances to the air, land, and water. The purpose of this study is twofold. The primary purpose is to determine the nature and extent of multimedia pollution caused by barrel and drum reconditioning. This is being accomplished through a multimedia sampling and analysis procedure at the site of selected reconditioners. A second objective is to determine the efficacy of the existing reconditioning processes for destruction/detoxification of pesticides, organics, and other constitutents contained in the drums.

Much work remains to be done in the areas of hazardous waste characterization and quantification, and characterization of treatment/disposal methods for these wastes. Certain waste streams often require individualized treatment schemes to achieve maximum detoxification. Knowledge of the contents and magnitude of various waste streams allows research monies to be directed toward solving the problems created by the more ubiquitous streams. Without such quantitative information, efficient allocation of funds to develop appropriate treatment schemes may not occur.

In an effort to determine which hazardous waste streams merit priority attention, either on the basis of quantity generated or need for adequate treatment/disposal technology, the SHWRD is conducting a study to estimate the magnitude of various hazardous industrial waste streams and the quantities of hazardous waste undergoing particular methods of disposal (3). Estimates obtained in this study are derived from existing data contained in state, local, and regional government hazardous waste surveys as well as existing federal reports. The information generated from this study should provide a secure foundation upon which the hazardous waste assessment and control program may function.

TREATMENT TECHNOLOGIES

The development of technologies for treatment/detoxification is central to any hazardous waste control program. It is through treatment that a hazardous substance may be altered to render it innocuous to human health and the environment.

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Treatment process may take several forms, including biological, physical, chemical, thermal, and isolation; they range from those specific to one substance to processes that are effective for a wide variety of wastes. The SHWRD is presently active in most treatment areas in an effort to minimize the harmful effects of hazardous wastes on the environment.

The continuing disposal of hazardous wastes in landfills and surface impoundments is rapidly depleting the number of suitable sites for these facilities. Much of the waste that is land disposed of could undergo any of a variety of treatment/detoxification techniques. Substituting treatment/ detoxification for land disposal could produce a number of desirable effects including saving valuable land space for waste requiring land disposal, decreasing groundwater contamination at land disposal sites and increasing the possibility for resource recovery. Research to further develop existing physical/ chemical techniques, such as electrolysis or fixation, for recovery, isolation, or neutralization of inorganic chemical waste is being pursued by the SHWRD (4). Emphasis is being placed on the development of treatment strategies that will benefit the small manufacturer and those generators that will be most impacted by federal waste pretreatment regulations. This effort is also concentrating on developing treatment schemes for those hazardous inorganic wastes most frequently received at public treatment/disposal facilities. The intensive investigation of technologies and publicly disposed of inorganic wastes which characterize the early stages of this work will give way to a demonstration/verification of four treatment schemes.

Another hazardous waste physical-chemical treatment process that is being investigated is encapsulation (5). Two encapsulating techniques, Resin Fusion Process (RFP) and Atmospheric Temperature Resin Curing Process (ATRCP), are being evaluated to determine their effectiveness in preventing the introduction of hazardous substances to the environment. Encapsulates produced by the RFP and ATRCP are characterized by tough, flexible plastic jackets reinforced by stiff, load bearing fiberglass casings. The RFP employs thermosetting polyolefins, with a fiberglass matrix for strength, surrounded by 1/4" polyethylene (seamless). Special fusing equipment is required for thermo-setting, and container size is preset by the size of this equipment. Encapsu-

lates produced by the RFP withstand physical and chemical stresses above projections for landfill. The ATRCP employs brushing (or eventually spraying) resin upon fiberglass encasements. The fiberglass is capable of being "laid" directly on the container, and no thermal curing is necessary. The ATRCP appears at this time to have distinct advantages over the RFP due to its atmospheric temperature curing, which should be beneficial in field operations or where different sizes of containers exist. Like the RFP, the ATRCP withstands physical and chemical stresses above projection for landfill. ATRCP, however, requires a higher priced, specialized resin.

Cementitious encapsulation is also being studied as part of the encapsulation project. Cementitious materials are being investigated as agents for encapsulating small containers. The most effective concrete mix is one with a high degree of water impermeability and low shrinkage potential.

Several projects investigating thermal treatment/detoxification processes are at varying stages of development. A novel approach involving decomposition by microwave plasma is being studied as a treatment alternative for the complete and safe detoxification of numerous, highly toxic waste streams which might defy other, more conventional disposal means (6). EPA became aware of this technology through a search for new and novel techniques in 1974, learning that this method had achieved notable success with nerve gas simulants.

The hardware employed consists of a quartz tube reactor chamber containing a flow of oxygen carrier gas. The reactant species is introduced to the chamber and is activated with a microwave power source. Pesticides or other gaseous, liquid, or solid hazardous materials are fed into the reactor and can be totally decomposed in this oxygen plasma due to intense electron energy. The reaction is conducted at reduced pressures thus insuing leak-light operation. Monitors are used to detect microwave leakage, with automatic shutdown in the case of loss of vacuum, oxygen flow, or the plasma state. Automatic GC measures reaction products.

To date several compounds have been detoxified in the unit which treats waste at a rate of 5-7 lb/hr. These include PCB, PMA, Kepone, Malathion, and a carcinogenic Navy red dye. The U.S. Army (Edgewood

Arsenal) successfully utilized the EPA 5-7 lb/hr unit for detoxification of small quantities of DDT.

Currently in Phase III of the project, the unit is being scaled up to handle 10-30 lb/hr. Early in this phase, the quartz packing overheated, forcing its removal from the reactor. Substances are now introduced in the gaseous phase to evaluate system performance. Should these detoxification tests prove successful, future efforts may address the evaluation of methods for prevolatilization of liquids and solids and/or solving the packing overheating using different packing materials or configurations.

A study involving thermal decomposition is examining the thermal destruction characteristics of a number of pesticides and other organic hazardous wastes (7). This research is being accomplished through the use of a "Thermal Degradation Analytical System" (TDAS). The TDAS is a small laboratory system that, through the process of thermal decomposition, yields sound reproducible results on decomposition time and temperature requirements. This system eliminates the need for costly and time consuming pilot scale test burns.

Upon introduction to the TDAS, the organic waste substance is immediately volatilized. The substance is then subjected to degradation/recombination reactions at high temperatures (500-1,000°C). All products of these reactions are analyzed by GC-MS. This permits hazard characterization of the products as well as determination of the most optimal conditions for total destruction of a substance.

The results generated from the TDAS study provide a data base for another ongoing incineration study (8). A major project currently underway is investigating various aspects of incineration to evaluate its effectiveness as a thermal disposal technology. Incinerator design capabilities, efficiency of various air pollution control devices, materials handling problems and suggested alternate disposal solutions to difficult waste streams such as organometallic compounds are being determined in this study. Several hazardous wastes are undergoing tests for thermal destruction efficiencies in an effort to determine design and handling considerations for a wide variety of waste streams. Wastes being examined include PCB's from spent capacitors,

pentachlorophenol stillbottoms, PBB contaminated wastes, still bottoms from chlorinated pesticide manufacturing processes, paint sludges, and others.

End use of the data generated for this research effort will be to supply design and implementation information to those programs charged with permitting disposal operations in order to accept or reject certain wastes. By establishing lower limits on operating conditions for incineration technology, certain design considerations will be incorporated that will minimize energy requirements and other design problems. The lower limits will also permit controlling agencies to establish operating conditions from a supporting data base rather than requiring extremely severe conditions due to an insufficient data base.

The SHWRD is initiating research on a method for the degradation of toxic halogenated, organic substances (9). The assortment of halogenated organics that have been introduced to the environment are among the most persistent substances known to man. Past treatment methods, which were of limited success, employed such extreme (and expensive) conditions as greatly reduced reaction temperatures and air-free reaction systems. The treatment scheme to be investigated here will react halogenated organics with molten sodium containing polymeric liquids, such as polyethylene glycols. Bench scale studies performed previously by the grantee using this scheme were effective in producing a complete, self-sustaining degradation reaction. This study will initially be concerned with discovering the mechanism of the degradation reaction and the most optimal operating parameters. After these initial determinations, a scale-up of the process for demonstration is planned.

TECHNO-ECONOMIC ASSESSMENTS

Though quite important, the development of new hazardous waste treatment technologies is not sufficient to insure their effective use. These new processes must be proven technically and economically feasible before widespread acceptance by hazardous waste generators will occur. As part of the hazardous waste assessment and control program, the SHWRD conducts investigations that assess the techno-economic feasibility of new and emerging hazardous waste control technologies.

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Hazardous waste streams often contain small amounts of hazardous substances dis-solved or suspended in recoverable solvents or water. The cost of treatment/disposal for such a dilute waste is high relative to the concentration of the hazardous component. Separation and concentration of dilute waste streams into hazardous and nonhazardous components prior to treatment would reduce the quantity of waste to be treated and, as a result, the cost of treatment. Research is currently underway here to evaluate the technical feasibility of, modify, or develop concentration processes that will place hazardous substances in the physical form most amenable to cost-effective ultimate disposal/detoxification (10). This work should prove most beneficial for those facilities, such as surface impoundments and severely contaminated lagoons, where concentration of the hazardous component is desirable for cost-effective treatment/disposal.

Hazardous waste control is an ever-evolving field. Waste streams containing newly created chemicals or substances only recently determined to be hazardous can be unresponsive to traditional methods of treatment/disposal. Because of this, it is essential that an awareness of new treatment technologies be maintained. In keeping with this philosophy, a project is beginning that will assess the technical and economic feasibility of new and emerging hazardous waste control technologies (11). A state-of-the-art data bank will be developed covering all emerging or future hazardous waste control technologies. In addition, treatment techniques will be correlated with specific disposal problems and pollutants. This project will provide a directory of promising waste technologies from which the future direction of hazardous waste control can be determined.

The treatment and control of hazardous wastes are not without costs. In addition to the obvious costs to the generator for treatment/disposal services, there are indirect costs assumed by those located in close proximity to the treatment/disposal site. Research is ongoing to determine costs associated with hazardous waste treatment/control technology (12). These costs may be fully measurable whereby they are referred to as direct market costs or they may be less tangible and known as nonmarket costs. An example of a direct market cost would be a decline in value of

land adjacent to a waste facility. Illnesses attributed to waste facilities are examples of "nonmarket" costs.

Emphasis here will be focused on the less tangible and difficult to assess "nonmarket" effects of hazardous waste. Particular attention will be focused on risk management policies as perceived by selected government agencies. The various methodologies will be evaluated and related to the problem of hazardous waste. An assessment will be conducted of economic-based strategies that might be employed to supplement direct regulation of hazardous wastes, and recommendation made for further study of those options ranking high by the evaluative criteria.

An effort that identifies cost-effective treatment/disposal technologies for the management of hazardous wastes in the electroplating and metal finishing, inorganic chemicals, and organic chemical and pesticides industries is currently being conducted (13). Technologies such as lagooning, concentration, flocculation, chemical fixation, landspreading and encapsulation are being evaluated according to cost-effectiveness in complying with RCRA (Subtitle C) requirements for treatment and disposal of hazardous wastes. Emphasis is being placed on the applicability of the options and results to meet the needs of managers of municipal hazardous wastes.

PESTICIDE DISPOSAL

Pesticide containing wastes can enter the environment in a variety of ways. The application of excessive pesticides to vegetation increases the probability that fugitive amounts of pesticides will escape into the air or soil. Contaminated rinsate from pesticide containing barrels and drums, if disposed of improperly, can contaminate ground or surface waters. Because certain pesticides have been demonstrated to be hazardous or toxic, the SHWRD has been charged with developing methods to insure their safe treatment or disposal.

One common incidence of waste pesticide generation arises from excess usage by farmers and applicators. To properly dispose of these wastes, SHWRD has undertaken a project for the design, construction and evaluation of acceptable pesticide disposal systems for agricultural applicators, commercial applicators, and

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for research and development centers (14). These disposal systems take the form of concrete pits, containing soil and limestone layers which hold the pesticide formulation until evaporation or microbial degradation can occur. The degree to which environmentally hazardous compounds are broken down in the pit determines the pit's overall effectiveness.

The concrete constructed pits have been chemically analyzed for several pesticides and biologically for surviving microorganisms. The aqueous phases contained less than 2 ppm of the chemicals while the soil contained concentrations up to 300 ppm. The pesticide degrading bacteria have been identified as gram negative rods of the genus pseudomonos. Both chemical and microbiological studies are in progress at this time. Volatilization studies were performed to determine the extent of pesticide vapors escaping to the atmosphere. While volatilization does occur for selected higher vapor pressure pesticidal formulations, the majority of degradation occurs in the pit by microbes. Under controlled conditions, volatilization does not pose a serious threat.

A project is currently underway to design roof and unroofed evaporative pits suitable for treatment of excess pesticides generated by aerial applicators (15). A mathematical model describing the area and volume requirements of evaporation ponds, both roofed and unroofed, will be developed and tested. Three basic methods for control of excess pesticides are being developed and evaluated. These are the closed loop systems which collect and contain waste pesticides for reuse on subsequent applications, channel containment systems which are land disposal systems consisting of channel dykes, and evaporative pit systems. Evaporative pits appear to have the most widespread practical application. The determination of whether a roof increases the effectiveness of a pit depends on the climate of the area. For areas with high evaporation and low precipitation, an unroofed pit is more suitable. For areas having high precipitation and low evaporation, a transparent roof that intercepts precipitation but does not hinder sunlight is ideal. As a result of this study, final guidelines will be developed for designing and operating evaporative pits to dispose of waste pesticide solutions.

An interagency agreement between the EPA and the U.S. Army Medical Bioengineering Research and Development Laboratory is being used to evaluate the use of filtration/adsorption techniques and equipment for treatment of pesticide wastewaters for reuse or safe discharge to sewers by Army installation pest control facilities (16).

A filtration/adsorption system is being assembled from commercially available equipment and/or equipment constructed in the laboratory. It is being designed for batch treatment operation using an activated carbon element and, if necessary, additional elements employing other adsorbents (diatomaceous earth, imbiber beads, amberlite resin, etc.). It has the capacity to handle up to 1000 gallons of wastewater per batch treatment and should provide an effluent water that is suitable for reuse in the facility or for discharge into a sanitary sewer. The filtration system is compatible with the present wastewater collection system in the plans for the Ft. Eustis pest control facility. It is anticipated that this system will include a pump to move the wastewater from the facility's waste collection tanks through the filtration equipment into a second storage tank where the treated water will be held until chemical analysis has verified that it is safe for reuse or disposal. An additional tank may be required to store the treated water for reuse in the facility.

Pesticide containers are required by law to carry on the label instructions for disposal and storage of excess pesticides and containers. Reliability and intelligibility of these statements has been questionable in the past. To determine the effectiveness of label statements in preventing the unnecessary introduction of pesticides into the environment, the SHWRD has initiated a project to develop data requirements and testing protocols to better evaluate existing disposal and storage recommendations (17). After evaluation has been accomplished, new and improved label directions for proper storage and disposal of excess pesticides and containers will be developed.

CONCLUSION

Hazardous waste control is a rapidly changing, expanding and uncertain field. As this summary of SHWRD research projects

has shown, the treatment and control of hazardous waste is a complex discipline involving economic and social as well as technological considerations. The nature of this paper prohibits in-depth discussion of the technical rationale and experimental results of the individual projects. Those interested in obtaining more detailed information are directed to the following reference section which lists SHWRD contacts for each project in the hazardous waste assessment and control program.

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QUANTIFICATION OF MUNICIPAL DISPOSAL METHODS FOR INDUSTRIALLY GENERATED HAZARDOUS WASTES

Hugh J. Van Noordwyk
Acurex Corporation
Mountain View, California 94042

ABSTRACT

Many industrial wastes are sent to public disposal facilities which often actively solicit such materials. One common technique is to use a favorable rate structure coupled with an uncritical analysis of the potential environmental effects which the wastes may have on ground water or land use options.

The Municipal Environmental Research Laboratory (MERL) of the Office of Research and Development of the Environmental Protection Agency has the charter to develop data on public sector waste disposal requirements and perform research to develop needed disposal technologies. There are no known compilations of the broadly based (i.e., nationwide) data pertaining to public sector disposal of industrial hazardous wastes. These data are needed to accomplish effective research program planning. In a recent study, Acurex Corporation attempted to compile and review for MERL all readily available data on this topic within the level of effort permitted by time and budget constraints.

The main purpose of this study was to quantify the amount of industrial hazardous waste disposed of in public sector facilities. This analysis sought to quantify industrial hazardous wastes by waste types, by waste disposal methods, and by the generator's Standard Industrial Classification (SIC) code. Limited data was available on these topics. After an extensive search for data, five SIC codes which included major contributions of hazardous waste were successfully analyzed for their hazardous waste contributions to the municipal sector.

INTRODUCTION

At present, there are no nationwide quantitative data compilations on industrial by generated toxic and hazardous wastes which undergo municipal treatment and/or disposal. As part of the Municipal Environmental Research Laboratory, the Solid and Hazardous Waste Research Division must assess, develop, and demonstrate technologies which can render innocuous any toxic or hazardous waste discharged to the municipal sector. Developing specific technologies which will have the greatest impact on the treatment/disposal of hazardous waste requires a knowledge of the character of the waste. This paper presents the findings of a recent study conducted in this regard by Acurex Corporation. Information contained in this paper, such as specific wastes generated, the industrial origin of these wastes, and the current methods of disposal will provide a portion of the data base necessary for future research.

Objectives

The objectives of Acurex's study were to quantify the amounts and specify the types of hazardous waste generated by various industries for those wastes disposed of in public disposal facilities. In addition, differences in the way in which wastes from various industries are treated and disposed of were examined.

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Scope of Work

The lack of broadly based (i.e., nationwide) data compilations on this topic required extrapolation of existing piecemeal data to achieve the objectives. Therefore, Acurex's scope of work contained the following tasks:

Collecting data; potential sources of data were thought to be compilations or surveys by government agencies, expert opinion, and crosscheck of data from private sector generators of wastes and from private disposal sites

Assessing collected data and developing an analytical model for extrapolation of local data to national scope

Using the analytical model to perform the extrapolation and provide answers to the questions:

-- How much hazardous waste is being generated nationally by various industries?

-- What part of industry-generated hazardous waste is disposed of in public facilities?

-- What differences exist in the way hazardous wastes from various industries are treated and disposed of in public disposal facilities?

In estimating nationwide patterns of industrial waste disposal, the work effort was to be prioritized by ranking industries according to the nature of their wastes, since achieving results for all industries might not be possible.

Report Organization

Conclusions and recommendations derived from our study are given in the next section.

Then the approach originally chosen to achieve the stated objectives is reviewed. During the study, the approach was modified because of conclusions reached after assessing the data initially collected. The reasons for modifying the approach are described along with the modified approach.

The data sources used are discussed; data characteristics and their usefulness are then described.

Finally, the model used and the results achieved by the model are given.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

The following conclusions were drawn from our study:

Industrial hazardous wastes which are disposed of municipally present less acute environmental and safety hazards in their disposal than industrial hazardous wastes which are disposed of onsite or in offsite private facilities. However, in terms of possible chronic environmental hazard, the municipally disposed wastes have a high hazard potential because of their heavy metal content and other persistant toxic chemicals such as halogenated organics.

Municipal disposal of industrial hazardous waste handles just over 9 percent of all such waste generated. Over 99 percent of this portion ends up in municipal facilities not designed for its incorporation. Long term environmental problems can be expected from such disposal methods.

Over 18 million megragrams (Mg) of hazardous waste are generated per year by the industries studied. If recent estimates which put national hazardous waste generation between 28 and 36 million Mg per year are correct, then at least half of the country's hazardous waste has been surveyed during our study. If about 9 percent is being disposed of in the municipal sector, then between 2.5 and a little over 3 million Mg per year are going to some form of municipal disposal.

Recommendations

Two recommendations were made as a result of our study and are detailed in the next two sections.

Data Base Improvement --

It would be useful for program planning if the EPA could establish basic information gathering requirements to compile hazardous waste information on a national basis. Such information requirements should include common units of measurement, common conversion factors, and, for each SIC code waste quantity, the distribution by waste type and by disposal method. Such information could be generated by survey or by initiating a state manifest program for hazardous wastes. Accuracy to within ~10 to 20 percent would provide better planning data than currently available.

Further Useful Work --

Studies should be made of specific industries' hazardous waste contributions to municipal disposal systems. This preliminary study could serve as an indicator in prioritizing these studies. Industries which contributed to municipal systems almost 90 percent of the hazardous wastes reviewed in this paper were, in order of rank: petroleum refining, inorganic chemicals, plastics and synthetics, pesticides, and leather tanning and finishing. Such studies should also encompass those hazardous wastes being disposed of in private offsite facilities.

Criteria could also be developed which would allow municipal disposal facilities to determine whether they could handle particular hazardous wastes.

APPROACH

The original approach, the reasons (based on an analysis of the data search experience and the information collected) why this approach was abandoned, and the revised approach which was used are briefly reviewed here.

Original Concept

Several states, notably California, Texas, and Maryland, have been collecting data for several years on the disposal of industrial wastes. California and Texas have been requiring waste disposal manifests from waste generators, transporters, and disposers. California had computerized useful data. In 1977, Texas officials had stated their plans to Acurex staff to issue summary data in 1978. Maryland had performed a survey of waste generation and disposal for about one-third of the industrial firms in that state and had issued a summary report, as had several other states in which survey data was collected.

These data might provide enough credible information about wastes from particular SIC codes to allow extrapolation for those SIC codes for the entire United States. Data gathered from private industry generators and various disposal sites would then provide spot crosschecks on specific SIC waste estimates.

Assessment of Initial Data Collection Results

Acurex attempted to collect data from the 48 contiguous states. Thirty-one responded. These data were generally inconsistent, both within individual reports and between reports from different states. In addition, the data were extremely sketchy, incomplete, and reported in a nonuniform fashion.

As an example, some reports gave statewide totals for various kinds of waste. Others gave statewide totals (for all waste kinds) by SIC code. Very few reports gave the crucial datum of type-of-waste-by-SIC code. (Several state reports did. Unfortunately, those reports were for states which generate only minor fractions of national waste totals, and we did not wish to base extrapolations on such a limited base.)

There was apparently no consensus on the meaning of hazardous waste. An operational definition of this term has been needed since its incorporation into the Resource Conservation and Recovery Act of 1976. No operational definition had been adopted by the completion of this study; thus, it was not possible to

test (operationally) or otherwise establish that a given waste was or was not hazardous. (As a result, this study generally tried to include the descriptors present in the data sources which were used to draw our conclusions.)

Revised Approach

As stated above, data in the state reports often were not detailed enough. However, several state reports provided data on the types of wastes, by SIC code. Others gave data on the method of disposal by SIC code.

The Office of Solid Waste had previously created a sequence of contractor reports. Each of these assessment studies addressed the wastes in a major industrial category. A review of these reports indicated that they contained credible nationwide totals for quantities of industrial wastes, although they rarely specified the method of disposal by type of waste for the industrial category addressed. Some of these reports attempted to provide both total waste and hazardous waste quantities.

At this point, it became important to examine whether a combination of these data could be used to reach useful conclusions.

Reaching conclusions appeared probable for several SIC codes. These SIC codes have two important characteristics:

● According to the OSW contractor reports, these industries are believed to generate substantial portions of the total quantity of hazardous waste created each year.

● These industries correlate substantially with the proposed listing of hazardous waste streams (Federal Register, December 18, 1978, pp. 58958-58959).

The approach chosen uses the OSW assessment reports as an initial source for the total (nationwide) quantity of waste, subject to further crosschecking. If quantitative estimates of disposal methods or waste types were lacking in these reports, then these kinds of data were sought from the state reports. State report estimates (particularly those published most recently) were also used to crosscheck quantity estimates. Where these two data sources proved inadequate, other data were sought.

Extrapolation appeared feasible for data from SIC codes 28, 29, 30, 31, and 36. These SIC codes appeared to generate about 47 percent of the total quantity of hazardous wastes listed in the OSW assessment reports. They also included a major portion of the proposed listed hazardous waste streams.

The last section of this paper summarizes the data collected and the results obtained using the revised approach. The results achieve the stated objectives.

DATA SOURCES

In the data acquisition phase of this project, we called on various potential governmental data sources to request current information on quantities and compositions of industry-generated waste streams and their methods of disposal. Pertinent data was also sought from documents already catalogued in Acurex library files. Additional EPA or EPA contractor reports were sought as were other contractor reports, journal articles, and expertise from specific individuals or private concerns. Table 1 lists many of the data sources and tells where data were received.

Many states have conducted hazardous waste studies. Since these efforts are not coordinated nationally, the state agency conducting the study may have been any one of several, including: Department of Public Works, Office of Solid Waste, Solid Waste Management Section, Department of Environmental Quality, or Department of Water Resources. Each has its particular responsibilities, scope of authority, and resources. The appropriate agency was contacted in every state except Alaska and Hawaii which only dispose of minimal amounts of hazardous wastes.

For economic and liability considerations, industrial companies control and monitor their waste streams. Information-seeking efforts were focused

TABLE 1. HAZARDOUS WASTE DATA SOURCES

Source	Information provided
Trade/technical associations	
National Solid Waste Management Association	No
National Center For Resource Recovery	No
Minnesota Association of Commerce and Industry	No
Association of Metropolitan Sewerage Agencies	Yes
Water Pollution Control Federation	No
Hazardous Materials Control Research Institute	No
National Council of the Paper Industry for Air and Stream Improvement	No
Federal governmental agencies	
U.S. EPA Hazardous Waste Management Division/OSW	Yes
U.S. EPA Regional Offices (all 10 offices)	Yes, by Region X
U.S. EPA Effluent Guidelines Division/OWPS	No
Department of Commerce	Yes
Department of Energy	No
State governmental agencies	
48 contiguous states	Yes, by 31 states
Disposal facilities or companies	
Industrial Tank Company (two California locations)	Qualitative
Los Angeles County Landfill (California)	Qualitative
Ventura County Landfill (California)	Qualitative
San Diego County Landfill (California)	Qualitative
Rollins Disposal Services (Texas, New Jersey)	Qualitative
ENSCO Hazardous Waste Incinerator (Arkansas)	Qualitative
Industrial organizations	
Aluminum Company of America	Yes
American Standard Inc.	No
Bethlehem Steel Corp.	No
Boise Cascade Paper Group	No
Boysen Paint Co.	Yes
Brown Group Co.	No
Evans Products Co.	Yes
General Dynamics Corp.	No
General Electric Co.	No
Georgia Pacific Corp.	Yes
Goodyear Tire and Rubber Co.	No
W. R. Grace & Co.	No
Hewlett-Packard Co.	Yes
Johns-Manville Corp.	No
Johnson & Johnson	No
Kelly-Moore Paint Co., Inc.	No
Monsanto Co.	No
Ogden Manufacturing and Sales Inc.	No
Owens-Corning Fiberglass Corp.	No
Owens-Illinois Inc.	No
U.S. Gypsum Co.	Yes
U.S. Steel Corp.	Yes
Warner Lambert Co.	No
Weyerhaeuser Co.	No
Union Carbide Corp.	Yes
Eastman Kodak Corp.	Yes

on several of the "Fortune 500" companies, since complete data from any one of these would have potential value for this study.

Trade associations were a potential source of data from industry; in compiling information volunteered by their members, they provide the anonymity desired by many individual companies. Qualitative data were provided from several associations; others referred us to data already furnished to the OSW.

Managers of disposal services and sites estimate amounts of wastes to fix fees and may also request a description of waste components. Such data are often unverified but are useful for rough estimates. As hazardous waste manifest requirements become more widely required and more uniform in content, these data will be more useful, particularly if, as in California, monthly and annual summary data are compiled.

Acurex's in-house collection of EPA and contractor documents was used. Additional reports were acquired through literature searches.

UTILITY AND CHARACTERISTICS OF THE DATA COLLECTED

Hazardous waste generation and disposal data were received from approximately 50 percent of the sources listed in Table 1. Several hundred EPA and contractor reports were also analyzed after reviewing their abstracts. These abstracts were obtained from the Solid Waste Information Retrieval System (SWIRS) computerized data base.

State Reports

Forty-eight state agencies with waste disposal data were reached by telephone. Information relating to waste generation and waste disposal was sought. Thirty-one state agencies responded by sending complete or partial reports, report summaries, tabulated data, or computer printouts. Table 2 summarizes the types of information received from state agencies.

The data provided by the state agencies was only partly useful since they did not use a uniform definition of

a hazardous waste or a consistent method for obtaining or tabulating quantitative waste generation and disposal information.

Since no uniform criteria existed to define which solid wastes were hazardous, wastes of similar characteristics were reported as hazardous in some states while in others they were not.

For example, New Jersey specifically listed the wastes considered hazardous, while Maryland used a set of criteria based on bioconcentration, flammability, toxicity, or corrosiveness to establish a working definition of hazardous wastes. Several states defined hazardous waste as "...any waste, or combination of wastes, of a solid, liquid, contained gaseous, or semisolid form, which because of its quantity, concentration, physical, chemical, or infectious characteristics may (a) cause, or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness, or (b) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed." Unfortunately, no method was usually provided to test whether a given waste was or was not hazardous according to this definition. According to this definition, different wastes were considered hazardous by various states.

The lack of uniformity with which state agencies conducted their hazardous waste surveys made it difficult to use much of the data contained in the state reports for the study.

The state agencies generally obtained hazardous waste data through questionnaires mailed to all known or to some fraction of known waste generators. Based on the initial responses received, some agencies conducted actual plant surveys. Others attempted to promote additional responses by telephone or undertook second mailings of the questionnaire. In most states, waste generators were not legally obligated to respond to state surveys. Consequently, many generators chose not to do so.

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TABLE 2. SUMMARY OF STATE REPORT DATA

EPA region	State	Report or data available	Received	Report date	Waste quantity data base[b]	Waste Identified by SIC[c]	Disposal quantitatively identified[d]	Remarks
I	Maine	Yes	Yes	6/78	S/E	Yes - 2/12	Partial - SIC/CAT	
	New Hampshire	Yes[a]	No	...	...	...	...	
	Rhode Island	Yes	Yes	3/77	S	Yes - 3/23	Yes - SIC/CAT	
	Vermont	Yes[a]	Yes	...	S	Yes - 4/15	Yes - SIC	Status report received, survey not complete
	Connecticut	Yes	Yes	8/77	S/E	Yes - 2/11	Yes - CAT	
	Massachusetts	Yes	Yes	10/76	S/E	Yes - 3,4/16	No	
II	New York	Yes[a]	Yes	...	S	Yes - 4/203	No	Draft copies of report components have been received -- final report not available. 1/75 preliminary report received
	New Jersey	Yes	Yes	1974	Estimate	Yes - 2,3/23	No	
	Delaware	Yes	Yes	10/78	S	No	Yes - CAT	
III	Maryland	Yes	Yes	5/77	S/E	Yes - 2/18	Yes - CAT	
	Pennsylvania	Yes	Yes	11/76	Estimate	Yes - 2,3/19	No	
	Virginia	No	...	...	...	...	...	
	West Virginia	Yes	Yes	...	S/E	Yes - 2/8	Yes - SIC/CAT	Portions of preliminary draft received
IV	Kentucky	Yes	Yes	1/78	S	No	Yes - CAT	
	Mississippi	Yes	Yes	8/75	S	Yes - 2/13	No	
	Alabama	No	...	...	...	...	...	
	Georgia	No	...	...	...	...	...	
	Florida	Yes	Yes	11/77	S	Yes - 4/39	Yes - SIC	
	So. Carolina	Yes	Yes	9/78	S/E	Yes - 2/12	Yes - CAT	
	No. Carolina	Yes[a]	No	...	...	...	...	
	Tennessee	Yes	Yes	1971	S	No	No	Report addressed solid wastes generated, not hazardous waste
V	Illinois	No	...	...	...	...	...	
	Indiana	No	...	...	...	...	...	
	Minnesota	Yes	Yes	10/78	S/E	Yes - 2,3, 4/32	Yes - CAT	
	Wisconsin	Yes	Yes	1977	S/E	No	No	
	Ohio	Yes[a]	Yes	...	S	No	Yes	Very brief summary of results received
	Michigan	No	...	...	...	...	...	
VI	Arkansas	No	...	...	...	...	...	
	Oklahoma	Yes	Yes	3/78	Not specified	No	Yes	Very limited data
	Texas	Yes	...	...	Manifests	Yes	Yes - CAT/SIC	Data available in files only
	Louisiana	Yes	Yes	11/78	S	Yes 2,3, 4/~50	No	Report presented limited quantitative data
	New Mexico	No	...	...	...	...	...	Survey recently started
VII	Iowa	Yes	Yes	4/77	S	Yes - 2/16	Yes - CAT	
	Missouri	Yes	Yes	...	...	No	No	Brief summary received; specific survey data available on file
	Kansas	Yes	Yes	3/77	S/E	Yes - 2/14	Yes - CAT	
	Nebraska	Yes	Yes	12/76	S	Yes - 3/32	Yes - CAT/SIC	
VIII	Montana	Yes	Yes	12/77	S	Yes - 2/15	Yes - CAT/SIC	
	No. Dakota	No	...	...	...	...	...	
	So. Dakota	No	...	...	...	...	...	
	Wyoming	No	...	...	...	...	...	
	Colorado	No	...	...	...	...	...	
	Utah	No	...	...	...	...	...	
IX	California	Yes	Yes	1976,	Manifest/S	Yes - 4/Many	Yes - CAT/SIC	Two regional studies and computer printouts of manifest data for various parts of the state
	Nevada	Yes	No			...	...	...	Regional waste survey for Reno and Las Vegas. No state wide data
	Arizona	Yes	Yes	1977	S/E	Yes - 2/12	No	1974/1975 reports received
	Hawaii	Not contacted	...	...	...	...	...	
X	Washington	Yes	Yes	12/74	S/E	Yes - 3/42	No	
	Idaho	Yes	Yes	6/73	S	Yes - 3/30	No	Report primarily addressed solid
	Oregon	Yes	Yes	3/74	S/E	Yes - 2,3, 4/15	Yes - SIC/CAT	waste management with no hazardous waste data given
	Alaska	Not contacted	...	...	...	...	...	

[a]Report was being prepared or data were still being collected as of the end of 1978
[b]The letter "S" signifies that hazardous waste data was developed by a survey of waste generators; "E" signifies that survey data was extrapolated to represent state-wide totals
[c]"Yes" if quantified waste data were presented by SIC code; "X/XX" indicates the number of digits for each SIC category and the total number of categories, respectively
[d]"Yes" if waste disposal was addressed quantitatively; "SIC" signifies that waste disposal information was presented for SIC categories
"CAT" signifies that waste disposal information was presented for waste categories, (e.g., acids, bases, oils, solvents, etc.)

The quantitative accuracy of the data in these reports varies from state to state depending how the survey was conducted. Data obtained from actual plant visits by state solid waste agency personnel appears more reliable than data obtained from questionnaires. Some state agencies attempted to extrapolate the data collected to estimate total hazardous wastes generated statewide. Other states made no efforts at extrapolation. Many state reports do not clearly identify the basis for the reported data; they do not identify whether the reported data represent only respondent generators or whether they represent all waste generators within the state. Much effort was spent in determining unreported facts such as these.

Another shortcoming of the hazardous waste generation and disposal data provided by the state reports is that waste quantities are not classified uniformly from one state to another. Many states categorize overall waste quantities by SIC code while other quantitatively classify waste quantities by waste characteristics, (i.e., solvents, acids, bases, and oils).

Disposal information also was not reported in a uniform manner. Of the 20 states which quantitatively identify waste disposal by disposal method, the majority only presented information which identified the disposal method by waste type. Table 3 reproduces an example from the Minnesota report.

Disposal methods for specific waste types were quantitively identified by SIC categories in 10 of the 31 state reports. Unfortunately, the waste quantities generated by these states are only a small fraction of the national total. Adequate disposal data from the largest waste generator states such as Texas, Louisiana, Ohio, New York, Illinois, and Pennsylvania, were not available.

Only a small number of the state reports which listed waste disposal data by SIC generators further identified wastes which end up in the municipal sector. Disposal of wastes by landfill or sewering was identified in some reports. However, ownership of the landfill or wastewater treatment plant was usually not identified.

Published Data Sources

Approximately 450 literature abstracts obtained through the SWIRS computerized data base were reviewed. Although many of these documents report quantitative waste generation values, the majority do not report the values in detail nor do they address disposal methods quantitatively on a regional or national basis.

One important series of contractor-prepared reports, sponsored by the EPA's Office of Solid Waste, describes hazardous waste practices in major SIC categories. These 15 reports characterize and quantify the land-destined hazardous wastes generated by selected industries and also attempt to characterize treatment and disposal technologies currently being practiced by those industries. A tabulation of the 15 contractor reports is given in Table 4.

These assessments reported provide useful hazardous waste generation and disposal data. The reports assess specific industries on a nationwide basis. Some of the reports list the significant production units within the industry. Hazardous waste streams generated by most of the industries are characterized and quantified. Data was obtained from literature sources and actual plant surveys. In some cases, the results use data from the sampling and analysis of waste streams.

Disposal of hazardous wastes by each specific industry is generally addressed in these reports by categorizing practical treatment and disposal technologies as: (1) those which are currently and commonly practiced by the majority of waste generators (level I technology); (2) those which are the most environmentally sound methods currently employed (level II technology); and (3) those which will provide adequate health and environmental protection (level III technology). Each level of treatment and disposal technology is identified. Either the number of generators using

TABLE 3. WASTE TYPES (IN TONS) AND DISPOSAL METHODS[a]

Waste	Municipal	NPDES permit	Incineration	Sanitary landfill	Land-spreading	Lagooning	Resource recovery	Trash hauler	Chemical treatment	Other	Totals
Oil	164.5	. . .	64.5	259.1	30.3	. . .	131.5	18.9	. . .	56.0	725
Solvents	1.9	. . .	535.4	81	4.2	. . .	1422.4	75.5	. . .	24.4	2145
Flammables	. . .	. . .	135.7	. . .	3827	. . .	. . .	. . .	. . .	247.5	4210
Oxidizers	2.2	. . .	3	. . .	. . .	. . .	. . .	. . .	. . .	. . .	5
Explosives	. . .	. . .	2	. . .	. . .	. . .	. . .	. . .	. . .	. . .	2
Irritants and corrosives	21.5	. . .	4	456.8	9	1803	2.4	3.8	. . .	46.3	2347
Wastewater sludges	1.6	. . .	. . .	4200	2460	. . .	. . .	. . .	. . .	200	6861.6
Pesticides	. . .	. . .	. . .	0.04	. . .	. . .	. . .	. . .	. . .	. . .	0.04
Paints	0.3	. . .	377	278.4	2.5	. . .	787.5	94.4	. . .	. . .	1540
Heavy metals	8.9	3.5	. . .	. . .	. . .	. . .	. . .	. . .	45.2	. . .	58
Other poisons	4.3	. . .	3.4	. . .	. . .	4	. . .	. . .	33	. . .	45
Other	0.4	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Totals	206	4	1125.0	5275.3	6333	1807	2343.8	192.6	78.2	574.2	17938

[a]"The Impact of Hazardous Waste Generation in Minnesota," October 1977

TABLE 4. OSW INDUSTRIAL HAZARDOUS WASTE ASSESSMENT REPORTS

Industry	SIC	Prepared by	Date	EPA no.	NTIS no.
Metals mining	10	Midwest Research Institute	9/1976	SW 132c	PB 261 052
Textiles	22	Versar, Inc.	6/1976	SW 125c	PB 258 953
Inorganic chemical	281	Versar, Inc.	3/1975	SW 104c	PB 244 832
Rubber and plastics	282, 30	Foster D. Snell, Inc.	3/1978	SW 163c.1-4	PB 282 070-073
Pharmaceuticals	283	Arthur D. Little, Inc.	1976	SW 508	PB 258 800
Paint and allied products	285	Wapora, Inc.	9/1975	SW 119c	PB 251 669
Organic chemicals, pesticides, explosives	286, 2879, 2892	TRW Systems	1/1976	SW 118c	PB 251 307
Petroleum refining	2911	Jacobs Engineering Co.	6/1976	SW 129c	PB 259 097
Petroleum rerefining	2992	. . .	1977	SW 144c	PB 272 267
Leather tanning and finishing	3111	SCS Engineers, Inc.	11/1976	SW 131c	PB 261 018
Metal smelting and refining	33	Calspan Corp.	4/1977	SW 145c.1-4	PB 276 169-172
Electroplating and metal rinishing	3471	Battelle Columbus Labs	9/1976	SW 136c	PB 264 349
Special machinery manufacturing	355, 357	Wapora, Inc.	4/1977	SW 141c	PB 265 981
Electronics components manufacturing	367	Wapora, Inc.	1/1977	SW 140c	PB 265 532
Storage and primary batteries	3691, 3692	Versar, Inc.	1/1975	SW 102c	PB 241 204

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each technology level or the quantity of wastes disposed of by each method is reported. The amounts disposed of in municipally owned or operated sites could generally not be determined from these reports although some estimates were given.

Industrial Data Sources

None of the 26 companies contacted during this study had survey data in the form of reports which could be made available on short notice. Some companies did attempt to estimate quantities of waste generated by their plants by SIC code. Nine firms responded; the information obtained was fragmentary. Two sources estimated the percent of their wastes going to the municipal sector. Their data were used to crosscheck the state report data for the SIC codes involved. No data on waste stream compositions was provided.

Our opinion was that most of these companies would be willing to provide data. However, the time constraints of this program proved incompatible with the length of time required for decisions to be reached and data to be assembled within the corporate structures we approached.

Other Sources

Office of Solid Waste --

The Hazardous Waste Management Division of the Office of Solid Waste provided a summary of hazardous waste quantities generated by EPA region and state. Unfortunately, these data could not be correlated with either the assessment reports or state data. (We were told that this summary was prepared from the assessment reports, but were unsuccessful in correlating the OSW summary quantity values with these reports.)

Region X provided "An Evaluation of the Status of Hazardous Waste Management in Region X," December 1975. This report described how certain wastes within various SIC codes are disposed of in the Pacific Northwest and was used as a crosscheck.

Trade/Technical Associations --

The Association of Metropolitan Sewerage Agencies furnished a report, "Field Report on Current Practices and Problems on Sludge Management," June 1976. These data were not specific enough to be used in this study. Other trade associations had already furnished data to the OSW; we were referred to these reports and compilations.

Summary

As discussed earlier, the decision was reached during the data collection phase to use the assessment report data for waste quantity information, and the state reports and other data sources for waste type and waste disposal method information. After the data collection phase, we reviewed the available information, and decided whether enough information had been collected to determine useful estimates for the whole United States.

This question was answered affirmatively for portions of five SIC codes. In the next section, the data and estimates reached for these SIC codes are reviewed.

NATIONAL HAZARDOUS WASTE AMOUNT QUANTIFICATION

To quantify national amounts of industrial hazardous wastes by waste types and their disposal methods for various SIC codes, a specific methodology was used. This section describes that methodology, and the results of its use.

Methodology

The methodology employed was stated briefly in an earlier section of this paper. A more detailed explanation follows.

EPA hazardous waste assessment reports were analyzed to determine the information contained on hazardous waste quantities, waste types, and disposal methods for the particular SIC code(s) addressed by these reports. Projected national amounts of hazardous or potentially hazardous waste for these different SIC codes for 1977 were assumed valid since the reports' most current

surveyed national figures were for 1972, 1973, 1974, or 1975.

After tabulating these data by waste types and their disposal methods for specific SIC codes, comparisons were made to state hazardous waste studies data. Hazardous waste treatment information and other pertinent comments were annotated during this tabulation.

Data from state studies were used to modify the information in the assessment report if the state data were particularly comprehensive, of high quality, or could be used to fill in gaps. These facets were partly assessed in discussing with state agency staff members how each report was prepared. In addition, we compared specific SIC code characteristics in a particular state to the national characteristics of that code. This comparison included percentage of populations represented by the SIC code, distribution of manufacturing activities by SIC code subdivisions, and any other beneficial information. This was not an easy task because of the variability in state report formats. Only a few states provided data which allowed thorough comparison.

Standard Industrial Classification (SIC) Codes Addressed

The data were assessed for usefulness in determining national amounts of industrial hazardous waste by waste types and their disposal methods. This determination was only possible for those SIC codes addressed by the hazardous waste assessment reports because of the inconsistancy of the state studies and other data sources.

SIC Codes Potentially of Interest --

The SIC codes of interest initially included all manufacturing SIC codes in which significant quantities of industrial hazardous waste were thought to be generated. This set included codes 26 through 39, except for code 32.

Following data analysis for quality and utility, enough data existed for only the SIC codes which had EPA assessment reports. These reports addressed SIC codes 22, 28 through 31, 33, and 34 through 36.

Criteria for Choosing --

The principal criterion for choosing candidate SIC codes for further quantification was the availability of data that could be used to determine the national quantity of hazardous waste by waste types and disposal methods.

The importance of the SIC code in amounts or severity of industrial hazardous waste was not the determining factor in this choice. However, OSW's proposed list of hazardous waste streams included streams from six of the nine SIC codes addressed by the assessment reports.

Results of Applying Choice Criterion --

After this review, the following codes were chosen for quantification of their industrial hazardous wastes by waste types and disposal methods:

SIC code number	Name
28	Chemicals and allied products
29	Petroleum refining and related industries
30	Rubber and miscellaneous plastic products
31	Leather and leather products
36	Electrical and electronic machinery, equipment and supplies

Actually, only those portions of these two digit SIC codes, which were addressed by the assessment reports, were included in this study. Based on the available data, we estimate that these SIC code segments generate the bulk (approximately 90 percent) of their code's hazardous waste. These SIC code segments are listed in Table 5.

The SIC code segments listed in Table 5 included 94 of the 95 industrial processes named as those which generate hazardous wastes in EPA's proposed rules for defining and classifying hazardous wastes in the December 18, 1978 Federal Register.

TABLE 5. SIC CODE SEGMENTS ADDRESSED BY EPA HAZARDOUS WASTE
ASSESSMENT REPORTS WHICH WERE INCLUDED IN OUR STUDY

SIC code segment number	Name
281	Industrial inorganic chemicals
282	Plastics materials and synthetic resins, synthetic rubber, synthetic and other manmade fibers, except glass
283	Drugs
285	Paints, varnishes, lacquers, enamels, and allied products
286	Industrial organic chemicals
2879	Pesticides and agricultural chemicals, NEC[a]
2892	Explosives
291	Petroleum refining
2992	Lubricating oils and grease
301	Tires and inner tubes
302	Rubber and plastics footwear
303	Reclaimed rubber
304	Rubber and plastics hose and belting
306	Fabricated rubber products, NEC
311	Leather tanning and finishing
367	Electronic components and accessories
3691	Storage batteries
3692	Primary batteries, dry and wet

[a]Not elsewhere classified

Example of a National Industrial
Hazardous Waste Amount Quantification:
Batteries Industry, SIC 3691/3692

Hazardous waste types, amounts, and their methods of disposal were obtained from the appropriate assessment report; in this case it was: "Assessment of Industrial Hazardous Waste Practices, Storage and Primary Batteries Industries," Versar, Inc., January 1975, Report No. PB 241 204. Information available in this assessment report included the quantity of each waste type and general information on disposal methods for the entire batteries industry. Total hazardous waste stream quantities (on a wet basis) were given for each waste type for 1973, 1977, and 1983. Hazardous constituents were also given on a dry basis for the same years. The extrapolations for 1977 were chosen, as they were for all other SIC codes in our study, because they most closely approximated current waste generation quantities.

The state hazardous waste reports were then consulted. The distribution of disposal methods (i.e., onsite and public versus private) was determined from these reports. Any changes in disposal methods between 1973 and 1977 were also assessed and used to modify disposal methods distribution estimates. State report data used included data from Arizona, Maine, Nebraska, Oregon, Vermont, and Florida. The EPA Region X report was also used. Tables 22 and 23 summarize our results for "Industrial Hazardous Waste Quantities by Disposal Method" and "Waste Types and Typical Hazardous Waste Constituents by Process," respectively for the batteries industry.

Summary of National Industrial Hazardous
Waste Amount Quantification

The results of our study are given in the following sections by SIC code.

Industrial Inorganic Chemicals, SIC 281 --

Table 6 gives the subcategory distribution of 1977 hazardous waste totals for SIC 281. It also shows the amount of hazardous constituents of these wastes (on a dry basis) in each subcategory and gives total SIC 281 hazardous waste and hazardous constituents quantities.

The distribution of disposal methods are given in Table 7. The preponderance of hazardous waste from SIC 281 is disposed of onsite, primarily in ponds or general purpose landfills. Private offsite disposal accounts for 10 to 20 percent of the total; public offsite disposal accounts for about 11 percent or 427,000 Mg, mostly to general purpose landfills.

Plastics and Synthetics, SIC 282 --

Industrial hazardous waste quantities classified by disposal method are given in Table 8 for SIC 282. The bulk of wastewater sludges which go to unknown disposal facilities may well end up in municipal landfills, but this is not certain.

Hazardous constituents in the wastes of this industry include organics (toxics and flammables) and some heavy metals.

Pharmaceuticals, SIC 283 --

As shown in Table 9, this industry incinerates the majority of its waste; the remainder is either treated and disposed of or recovered. A very small amount ($\leq$90 Mg/year) of mixed solvent is disposed of in municipal sewers.

Paints and Coatings, SIC 285 --

It was not possible to determine specific disposal methods used for each waste type for this industry. Table 10 shows the number of plants which used particular disposal options in 1972 for specific waste types.

The bulk of raw material packaging wastes and dust from air pollution control equipment is disposed of in routine periodic pickups. These routine pickups are the same ones in which ordinary trash such as paper would be removed for disposal, commonly to municipal landfills. Therefore, the assumption is that half ends up in a public facility and half in a private facility. Wastewater sludge and spills and spoiled batches are probably picked up by contract haulers and disposed of in private sites. Waste organic cleaning solvent is either recovered or incinerated onsite or offsite.

TABLE 6. SIC 281 -- INDUSTRIAL INORGANIC CHEMICALS

Subcategory	Name		Hazardous waste -- 1977 Mg/year, wet basis (dry basis)
2812	Alkalies and chlorine		109,000 (56,000)
	Hazardous constituents (Mg, dry basis)		
	Asbestos	3,800	
	Chlorinated hydrocarbons	1,200	
	Lead	900	
	Mercury	120	
	Sodium/calcium sludge	1,500	
	Total	~7,500	
2813	Industrial gases		Negligible
2816	Inorganic pigments		507,000 (229,000)
	Hazardous constituents (Mg, dry basis)		
	Antimony compounds	14	
	Arsenic compounds	0.3	
	Cadmium compounds	60	
	Chromium and its compounds	3,560	
	Cyanide compounds	150	
	Lead compounds	1,700	
	Mercury compounds	0.3	
	Zinc compounds	330.6	
	Total	~5,800	
2819	Inorganic chemicals, NEC, industry		3,270,000 (2,030,000)
	Hazardous constituents (Mg, dry basis)		
	Arsenic	5.6	
	Chromium	0.4	
	Fluoride	50,500	
	Nickel	0.9	
	Phosphorus	5,300	
	Total	~55,800	

Total SIC 281 industrial hazardous waste
   Wet basis -- 3,884,890 Mg
   Dry basis -- 2,317,470 Mg
Total SIC 281 industrial hazardous waste
Hazardous constituents (Mg dry basis)

Antimony compounds	14	
Arsenic and its compounds	6	
Asbestos	3,800	
Cadmium compounds	60	
Chlorinated hydrocarbons	1,200	
Chromium and its compounds	3,560	
Cynide compounds	150	
Fluoride	50,500	
Lead and its compounds	2,600	
Mercury and its compounds	120	
Nickel	1	
Phosphorus	5,300	
Sodium/calcium sludge	1,500	
Zinc compounds	330	
Total	~69,100	

aReference 1

TABLE 7. SIC 281 -- INDUSTRIAL INORGANIC CHEMICALS[a]

Distribution of industrial hazardous disposal methods

Disposal method	Onsite	Offsite Private	Offsite Public
Pond storage/disposal	20-29	2-4	. . .
Burning/incineration	. . .	<1	. . .
High-temperature processing	1-2	. . .	. . .
Municipal sewers	. . .	. . .	1
Burial			
Specialized disposal sites	<0.1	0.1	. . .
General purpose landfills	45	3	11
General purpose landfills approved for hazardous wastes	. . .	5	. . .
Approved landfills for large volume hazardous waste	3	≤ 1	1
General purpose secured landfill	. . .	≤ 5	. . .
Deep well injection	. . .	≤ 1	. . .
Ocean barging	. . .	≤ 1	. . .
Totals	69-79	10-20	11
Mg/Year, 1977 (Wet basis)	2,680,000- 3,070,000	388,000- 777,000	427,000

Total industrial inorganic chemicals industry hazardous waste: 3,885,000 Mg/year, 1977 (wet basis)

[a]References 1, 14, 16, 18, and 20

TABLE 8. SIC 282 -- PLASTICS AND SYNTHETICS[a]

Industrial hazardous waste quantities by disposal methods

Waste type	Total hazardous waste Mg/year, 1977 (wet basis)	Disposal methods Mg/year, 1977 (wet basis)			
		Onsite	Offsite		Unknown
			Private	Public	
Liquid phenolics	322,000	161,000[b]	161,000[b]	. . .	. . .
Phenolic sludges	44,000	44,000[d]	. . .	. . .	. . .
Amino resins	20,700	. . .	20,700[c]	. . .	. . .
Still bottoms	54,200	27,100[e]	27,100[e]	Minor quantities	. . .
Catalyst wastes	5,360	5,360[b]	. . .	. . .	. . .
Wastewater sludges	284,000	. . .	. . .	. . .	284,000[f]
Totals	~730,000	~237,500	208,800	Minor quantities	284,000

[a]References 2, 14, and 17
[b]Drummed and stored
[c]Incinerated
[d]Drummed or lagooned
[e]Incinerated; since the distribution was not given, parity was assumed
[f]Small amount to landfills of unknown locations; the remainder to unknown disposal methods

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TABLE 9. SIC 283 -- PHARMACEUTICALS[a]

Industrial hazardous waste quantities by disposal method[b]

Waste type	Total hazardous waste Mg/year, 1977 (wet basis)	Disposal methods Mg/year, 1977 (wet basis)				
		Onsite Incineration	Other[c]	Offsite (private)		
				Incineration	Landfill	Recovery[d]
Mixed solvents	15,400	6,240	. . .	9,160	. . .	. . .
Nonhalogenated solvents	26,900	10,740	. . .	16,200	. . .	. . .
Halogenated solvents	3,900	870	. . .	3,000	. . .	. . .
Organic chemical residue	15,000	6,120	1,530[e]	5,800	1,800	. . .
High inert content wastes containing:						
• Flammables only	1,900	490	. . .	460	950	. . .
• Heavy metals or corrosives	1,900	. . .	. . .	. . .	1,900	. . .
Heavy metal waste	3,300	. . .	. . .	. . .	2,600	670
Aqueous mixed solvents	2,800	970	90[f]	1,700	. . .	. . .
Aqueous alcohol	700	280	. . .	400	. . .	. . .
Antiviral vaccines	350	115	115[g]	120	. . .	. . .
Other biologicals (toxoids, serum)	230	. . .	230[f]	. . .	. . .	. . .
Returned goods and contaminated or decomposed active ingredients	600	60	120[g]	. . .	420	. . .
Totals	73,300	26,000	2,100	36,800	7,700	670

[a]References 3, 14, and 17
[b]Does not include deep well disposal of certain liquid hazardous wastes. This type of disposal occurs almost exclusively onsite. Common constituents of such waste include acetates, ammonia, bromides, chlorides, alcohols, esters, ethers, ketones, and other organics.
[c]Disposal method explained below in footnotes for each entry in table.
[d]The recovery considered here is heavy metal recovery from waste since solvent recovery is a very common onsite practice at pharmaceutical plants and extremely difficult to quantify.
[e]Diluted and sent to onsite biological wastewater treatment facility.
[f]Treatment in onsite biological wastewater treatment facility or sewered to municipal system
[g]Autoclaved onsite and disposed of offsite in either a municipal or private landfill
[h]Material is crushed and slurried with water, and the resultant slurry is sent to an onsite biological wastewater treatment facility.

TABLE 10. SIC 285 -- PAINTS AND COATINGS[a]

Industrial hazardous waste quantities by disposal method

Waste type	Total hazardous waste Mg/year, 1977 (wet basis)	Disposal methods No. of plants, 1972 (basis: 1,544 plants)			
		Onsite		Offsite	
		Incineration	Landfill[b]	Incineration	Landfill[b]
Raw material packaging wastes[c]	2,000	5	70	50	1,470
Wastewater sludge	2,300[d]	. . .	50	. . .	1,070
Spills and spoiled batches	11,800	. . .	70	. . .	1,470
Waste organic cleaning solvent	94,800	5	50	20	950
Dust from air pollution control equipment	1,800	. . .	50	. . .	950
Total	112,700				

[a]Reference 4
[b]The term landfill may include open dumps, sanitary landfills, secured landfills, etc.
[c]Plant total for disposal methods adds to more than the total number of plants since some plants use two or more disposal methods
[d]This value is from: "Waterborne Wastes of the Paint and Inorganic Pigments Industries," Southern Research Institute, EPA-670/2-74-030, March 1974

Hazardous constituents in paints and coatings include organics (toxics and flammables) and heavy metals.

Organic Chemicals, SIC 2861, 2865, 2869 (except 28694) --

Consistent information was unavailable on the types of waste in this industry. Each state report had its own listing of waste types. The assessment report did not specify waste types other than to mention several in its text. Consequently, no quantification by waste type was possible. Typical wastes for this industry include solvents, corrosives (acid and bases), sludges (heavy metal and paint), still and tank bottoms, oils, toxics (organic and inorganic).

Table 11 depicts the distribution by disposal method for the total hazardous waste generated by the organic chemicals industry in 1977. We estimate that municipal disposal accounts for 20 percent or less of offsite disposal. The offsite disposal total given in the table appears low and should be increased to between 5 and 15 percent of the total. This is primarily caused by the increased use of contract incineration and solvent recovery vendors. The amount going to municipal disposal would still be fairly low even with this revised offsite estimate. It would be somewhere between 2 and 5 percent of the total and would go primarily to some form of landfill.

Pesticides, SIC 28694/2879 --

Disposal location for the pesticides industry was extremely difficult to ascertain from the available data. This is reflected in Table 12 by the fact that no entries are given in the offsite (public) and (private) columns for the various disposal methods, but entries are given in the site undetermined column. This column is footnoted to indicate the estimated distribution between offsite (public) and (private) disposal methods.

Hazardous wastes for this industry include waste pesticides; pesticide contaminated items such as packaging materials; cleanup residues such as contaminated articles, wastewater, solvent, and floor sweepings; and other miscellaneous waste types.

Explosives, SIC 2892 --

Very little hazardous waste from the explosives industry is disposed of in municipal facilities. The bulk of these wastes is disposed of onsite (by open burning or landfill). A small amount is handled by contract disposal firms (by open burning or chemical detoxification). Table 13 gives waste types, amounts, and the distribution of disposal methods for both the private explosive and government-owned contractor-operated (GOCO) segments of this industry.

Petroleum Refining, SIC 2911 --

Municipal landfills are responsible for accepting approximately 23 percent of the hazardous waste generated by this industry (Table 14). This waste is composed of the waste types listed in Table 15. Hazardous constituents of each waste type are also included in this table. No breakout was possible as to which waste types are disposed of municipally. It can only be assumed that a portion of each waste type finds its way to municipal landfills.

Petroleum Rerefining, SIC 2992 --

Table 16 depicts hazardous waste disposal by waste type for petroleum rerefining. Public landfills accept almost 10,000 Mg/year of this industry's hazardous waste. Most of this waste has been treated before disposal to inhibit heavy metal leaching . Hazardous waste constituents of the waste types are given in Table 17.

Rubber Products, SIC 30 --

Over 70 percent of the hazardous waste generated by this industry finds its way to either general purpose or approved hazardous waste municipal landfills (Table 18). Principal hazardous constituents of the waste are oils, toxic organics, and heavy metals.

Leather Tanning and Finishing, SIC 3111 --

Public disposal of hazardous waste accounts for 91,700 Mg/year or over 50 percent of the total hazardous waste generated by this industry. Table 19 shows the distribution of quantities of hazardous waste by disposal method, onsite and offsite, private and public.

TABLE 11.   SIC 2861, 2865, 2869 (EXCEPT 28694) --
            ORGANIC CHEMICALS[a]

Industrial hazardous waste quantities by disposal method
Mg/year, 1977 (wet basis)

Method	Quantities	
	Onsite	Offsite[b]
Landfill	483,000	113,000
Incineration	2,250,000	51,000[c]
Controlled	(699,000)	. . .
Uncontrolled	(1,550,000)	. . .
Deep well	6,540,000	. . .
Biological treatment/lagoon	565,000	. . .
Recovery	267,000	. . .
Landfarm	NA[d]	. . .
Totals	~10,100,000	164,000[e]

Total organic chemicals industry hazardous waste:
10,300,000 Mg/year, 1977 (wet basis)

[a]References 5 and 14
[b]Predominantly private except for minor portions
(<20%) disposed of legally, illegally, or unknowingly
in municipal landfills and/or incinerators
[c]Largely controlled (>90%) due to regulations which
contract incinerator operations must satisfy to
destroy a variety of wastes
[d]Not available
[e]The amount given here is believed to be low. The
actual quantity disposed of offsite is believed to be
between 5 and 15 percent of the total.

TABLE 12. SIC 28694/2879 -- PESTICIDES[a]

Industrial hazardous waste quantities by disposal methods
Mg/year, 1977 (wet basis)

Method	Onsite	Offsite (public)	Offsite (private)	Site undetermined
Landfill	175,000	. . .	. . .	75,000[b]
Incineration	. . .	. . .	. . .	100,000[c]
Storage[d]	81,000	. . .	. . .	. . .
Recovery	. . .	. . .	. . .	50,000[e]
Unknown[f]	. . .	. . .	. . .	144,000
Totals	256,000	Not available	Not available	369,000

Total pesticides industry hazardous waste: 625,000 Mg/year, 1977 (wet basis)

[a]References 5, 14, 17, 19, and 20
[b]This amount is split between offsite public and private.
A conservative estimate would be 25,000 Mg to offsite public
disposal and 50,000 Mg to offsite private disposal.
[c]Largely offsite private (>95%) and controlled (>90%) due to regulations
that contract incinerator operations must satisfy to destroy a variety
of wastes.
[d]In drums or open piles
[e]This amount is split between onsite and offsite private. It is believed
that recovery occurs almost exclusively onsite with only a minor portion
(<1%) recovered offsite.
[f]Includes onsite and offsite private chemical detoxification and subsequent
disposal, usually offsite landfill (public and private); deep well disposal
(minor); and other unspecified disposal methods.

TABLE 13. SIC 2892 -- EXPLOSIVES[a]

Industrial hazardous waste quantities by disposal method						
Industry segment	Waste type	Total hazardous waste Mg/year, 1977 (dry basis)	Disposal methods Mg/year, 1977 (dry basis)			
			Open burned[b]	Landfilled	Sold	Other[c]
Private explosives industry	Fixed high explosive waste	~460	>430	Negligible	<5	<26
	Blasting agents	~1,200	>1,100	Negligible	<12	<74
	Subtotals	~1,700 (~5,500-wet basis)	>1,500	Negligible	<17	<100
Government-owned, contractor operated (GOCO) explosives industry	Explosive wastes	4,900	4,800	. . .	140	. . .
	Explosive contaminated inert wastes	14,700	13,700	1,000	. . .	. . .
	Other hazardous wastes[d]	250	90	140	20	. . .
	Subtotals	~19,900[e]	18,600	1,140	160	. . .
Explosives industry grand totals		~21,500 (~25,400-wet basis)	20,100	1,140	~180	<100

[a]Reference 5
[b]Predominantly onsite, >90 percent
[c]Includes chemical detoxification and subsequent disposal; usually landfill, deep well disposal, spray irrigation, lagooning, etc.
[d]Includes spent activated carbon from processing aqueous hazardous wastes (open burned), red water from TNT purification (evaporated and sold), organic solvents from propellant manufacture, and wastewaters containing dissolved and suspended RDX/HMX
[e]Dry basis = wet basis

TABLE 14. SIC 2911 -- PETROLEUM REFINING[a]

Method	Onsite	Offsite	
		Public	Offsite
Landfill	355,000	428,000	107,000
Lagoon	284,000	. . .	289,000
Landspread	334,000	. . .	4,000[b]
Incinerate	40,000	. . .	
Totals	1,013,000	428,000	400,000

Industrial hazardous waste quantities by disposal method
Mg/year, 1977 (wet basis)

Total petroleum refining industry hazardous waste: 1,840,000
Mg/year, 1977 (wet basis)

[a]References 6, 17, and 20
[b]Distribution unknown

TABLE 15. SIC 2911 -- PETROLEUM REFINING[a]

Waste types and hazardous constituents	
Waste types	Constituents
Leaded gasoline sludge	Organic lead vapors, phenols, and heavy metals
Cooling tower sludge	Heavy metals
Crude tank bottoms	Oil and heavy metals
Dissolved air flotation (DAF) float	Oil and heavy metals
Exchanger bundle cleaning sludge	Oil and heavy metals
Slop oil emulsion solids	Oil and heavy metals
Once-through cooling water sludge	Oil and heavy metals
Waste bio sludge	Oil and heavy metals
Storm water silt	Oil and heavy metals
Spent lime from boiler feedwater treatment	Oil and heavy metals
Kerosene filter clays	Oil and heavy metals
Nonleaded tank bottoms	Oil and heavy metals
API separator sludge	Oil and heavy metals
Lube oil filter clays	Oil and heavy metals
FCC catalyst fines	Heavy metals
Coke fines	Heavy metals
Neutralized hydrofluoric acid alkylation sludge	Oil and heavy metals

[a]Reference 6

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TABLE 16. SIC -- PETROLEUM REREFINING[a]

Industrial hazardous waste quantities by disposal method

Waste type	Total hazardous waste Mg/year, 1977 (dry basis)	Disposal methods Mg/year, 1977 (dry basis)[b]						
		Landfill, onsite		Landfill, offsite				Recycled/reused
				Public		Private		
		Treated[c]	Untreated	Treated	Untreated	Treated	Untreated	Onsite and offsite
Acid sludges	38,300	6,200	. . .	3,700	900	20,000	7,900	. . .
Caustic and other sludges	15,400	. . .	. . .	. . .	. . .	. . .	. . .	15,400
Spent clay	20,190	1,900	. . .	4,100	1,000	6,500	6,600	. . .
Totals	74,300	8,100	. . .	7,800	1,900	26,500	14,500	15,400

[a]Reference 7
[b]Dry basis approximates wet basis since caustic sludges contain only a slight amount of moisture.
[c]Treated means acid neutralization by mixing with cement dust, lime, or other alkaline materials.

TABLE 17. SIC 2992 -- PETROLEUM REREFINING[a]

	Hazardous waste constituents								
Waste type	Constituents Mg/year, 1977 (dry basis)								
	Acid	Oils[b]	As	Ba	Cd	Cr	Cu	Pb	Zn
Acid sludges	11,600	13,000	2.4	37.8	0.8	0.4	3.8	581	81
Caustic and other sludges	. . .	5,600	0.8	15.5	0.4	0.6	1.9	232	32
Spent clay	. . .	4,000	. . .	. . .	. . .	. . .	. . .	85	. . .
Totals	11,600	22,600	3.2	53.3	1.2	1.0	4.7	898	113

[a]Reference 7
[b]Oils include petroleum oils, polymers, polar compounds, and asphalt.

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TABLE 18. SIC 30 -- RUBBER PRODUCTS[a]

Industrial hazardous waste quantities by disposal method

Waste type	Total hazardous waste Mg/year, 1977 (dry basis)	Onsite			Offsite		
		Landfill/dump	Landspreading	Interim storage	General purpose landfill[c]	Approved hazardous waste landfill[d]	Secure landfill[c]
Floor sweepings	9,500	450	. . .	. . .	9,000	. . .	Negligible
Air pollution control equipment dust	41,200	1,950	. . .	. . .	38,200	1,000	Negligible
Oily wastes	1,500	. . .	70	. . .	. . .	1,400	Negligible
Banbury mixer seal oils	100	. . .	. . .	100	. . .	. . .	. . .
Totals	52,300	2,400	70	100	47,200	2,400	Negligible

[a]Reference 8, 12, 13, 14, 15, and 19
[b]Dry basis = wet basis
[c]Believed to be largely public, ~80%
[d]Believed to be largely private, ~80%

TABLE 19. SIC 3111 -- LEATHER TANNING AND FINISHING[a]

Industrial hazardous waste quantities by disposal method
Mg/year, 1977 (wet basis)

Method	Quantities		
	Onsite	Offsite	
		Private	Public
Landfill[b]	4,800	51,200	45,800
Dumps[b]	1,900	2,100	38,500
Lagoons, trenches, pits, ponds[c]	5,300	6,200	7,300
Certified hazardous waste disposal facility[b]	. . .	9,700	. . .
Totals	12,000	69,200	91,600

Total leather tanning and finishing industry hazardous waste:
173,000 Mg/year, 1977 (wet basis)

[a]References 9, 14, 15, 17, 19, and 20
[b]Waste types disposed of by these methods include: trimmings
and shavings, finished and unfinished leather trim, buffing dust
finishing residues, wastewater screenings, and sewer sump and
dewatered wastewater or treatment sludges.
[c]These methods are primarily for sludges. Some other
waste types may intentionally or inadvertently be disposed of via
these methods.

Waste types are footnoted for particular disposal methods. Hazardous waste constituents are heavy metal compounds, principally chromium, lead, zinc, and copper.

Electronic Components, SIC 367 --

A significant portion of the hazardous wastes generated by the electronic components industry is disposed of (~44 percent) in municipal landfills (Table 20). A portion of all the wastes of this industry find their way to municipal landfills. Typical hazardous constituents composing these wastes are given in Table 21.

Batteries, SIC 3691/3692 --

Public disposal in general purpose landfills accounts for over 47,000 Mg of hazardous waste disposed of by this industry on an annual basis (Table 22). Waste types for particular processes within the industry are given in Table 23. The two waste types for this industry are wastewater effluent treatment sludges and rejected and scrap batteries/cells. Table 23 also gives amounts of hazardous

constituents for each waste type for each manufacturing process.

Industrial Hazardous Waste Municipally Disposed --

The following table summarizes the amount of industrial hazardous waste being disposed of in the municipal sector for those SIC codes included in our study. This table was developed from information included on Tables 7 through 22.

Type of municipal disposal facility	Industrial hazardous waste amount (Mg/year, 1977) (wet basis)
General purpose landfill	1,543,000
Dumps	38,500
Lagoons, trenches, pits, ponds	7,300
Approved hazardous waste landfills	500
Sewer	90
Total	1,589,000

TABLE 20. SIC 367 -- ELECTRONIC COMPONENTS[a]

Industrial hazardous waste quantities by disposal method

Waste type	Total hazardous waste Mg/year, 1977 (wet basis)	Disposal methods Mg/year, 1977 (wet basis)				
		Onsite		Offsite		
		Landfill	Incinerator[b]	Public landfill	Private	
					Landfill	Incinerator[a]
Nonreclaimable halogenated solvents and still bottoms	2,400	200	. . .	1,100	1,100	. . .
Nonreclainable nonhalogenated solvents and still bottoms	16,600	1,700	. . .	7,500	7,400	. . .
Wastewater treatment sludges	50,800	7,600	. . .	21,600	21,600	. . .
Lubricating and hydraulic oils	2,400	. . .	. . .	1,200	1,200	. . .
Paint wastes	200	. . .	6	200	10	6
Totals	72,500	9,500	6	31,600	31,310	6

[a]References 10, 14, and 19
[b]Resultant ash is disposed of either in onsite or offsite private secure landfills. It is estimated that this ash amounts to approximately 1 to 2 Mg and is contaminated with heavy metal oxides and salts.

TABLE 21. SIC 367 -- ELECTRONIC COMPONENTS[a]

Typical hazardous waste constituents

Nonreclaimable halogenated solvents and still bottoms

    Perchloroethylene
    Trichloroethane
    1,1,1-Trichloroethylene
    Freons
    Methylene chloride
    Still bottoms from reclamation of above solvents

Nonreclaimable nonhalogenated solvents and still bottoms

    Mixed solvents (halogenated and nonhalogenated)
    Methanol
    Acetone
    Alcohols
    Proprietary photoresists
    Xylene
    Still bottoms from reclamation of above solvents

Wastewater treatment sludges

    Particulate metals and oxides
    Chemically precipitated anions and cations
    Oils
    Solvents

Lubricating and hydraulic oils

    Water soluble oils
    Petroleum derived oils

    Paint wastes:

    Spray booth filters
    Cleanup rags
    Solvent/paint mixtures

[a]Reference 10

TABLE 22. SIC 3691/3692 -- BATTERIES[a]

Industrial hazardous waste quantities by disposal method
Mg/year, 1977 (wet basis)

| Method | Onsite | Offsite | |
		Public	Private
General purpose landfill[b]	45,200	47,200	47,200
Secured landfill[c]	12,300	. . .	12,300
Reclaimed/recovered/sold	10	. . .	. . .
Totals	57,510	47,200	59,500

Total batteries industry hazardous waste:
~164,000 Mg/year, 1977 (wet basis)

[a]References 11, 14, and 20
[b]This type of landfills accepts a wide variety of
wastes. There are usually no environmental
protection provisions for hazardous wastes such as
special containment, monitoring, or leachate
treatment. Exact classification can range from open
dump to sanitary landfill.
[c]This type of landfill employs environmental
protection provisions, is usually located in a
geologically and hydrologically suited area,
prohibits certain wastes, maintains records, and is
licensed or permitted by the state which it is in.

TABLE 23. SIC 3691/3692 -- BATTERIES[a]

SIC 3691: Waste types and typical hazardous waste constituents by process

Process	Waste types	Total hazardous waste Mg/year, 1977 (wet basis)	Constituents Mg/year, 1977 (dry basis)						
			Lead	Cadmium	Nickel	Silver	Zinc	Mercury	Miscellaneous
Lead-acid	Wastewater effluent treatment sludge	163,000	450[b]	. . .	. . .	. . .	. . .	. . .	. . .
Nickel-cadmium	Wastewater effluent treatment sludge	44	. . .	. . .	. . .	. . .	. . .	. . .	$Cd(OH)_2 = 12$ $Ni(OH)_2 = 3.7$
	Rejected and scrap cells	5	. . .	2.3	1.4	. . .	. . .	. . .	. . .
Other storage batteries		3[c]	. . .	0.044	. . .	0.13	0.014	0.0002	Water treatment sludges containing silver and cadmium = 1.2
Cadmium-silver oxide	Wastewater effluent treatment sludge	NA[d]	. . .	. . .	. . .	. . .	. . .	. . .	. . .
	Rejected and scrap cells	NA	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Zinc-silver oxide	Rejected and scrap Cells	NA	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Totals		~163,000	450	2.3	1.4	0.13	0.014	0.0002	. . .

SIC 3692

Process	Waste types	Total hazardous waste Mg/year, 1977 (wet basis)	Lead	Cadmium	Nickel	Silver	Zinc	Mercury	Miscellaneous
Carbon-zinc	Rejected and scrap batteries	1,100	0.03	0.03	. . .	. . .	380	0.67	$ZnCl_2 = 29$
Alkaline-manganese	Rejected and scrap batteries	165	. . .	. . .	. . .	. . .	27	1.3	. . .
Mercury	Rejected and scrap batteries	8	. . .	. . .	. . .	. . .	5	0.02	$HgO = 0.07$
Magnesium-carbon	Wastewater effluent treatment sludge	120	. . .	. . .	. . .	. . .	. . .	. . .	$Cr(OH)_2/CrCO_3$ sludge = 47.8
Zinc-silver oxide	Rejected and scrap batteries	6[a]	. . .	. . .	. . .	. . .	0.01	0.0007	$Ag_2O = 0.003$
Other Primary batteries									
Carbon-zinc air cell	Rejected and scrap batteries	55	. . .	. . .	. . .	. . .	2	0.007	. . .
Weston mercury cell	Rejected and scrap batteries	0.009	. . .	Neglig.	. . .	. . .	. . .	Neglig.	. . .
Magnesium reserve cell	Rejected and scrap batteries	NA[c,d]	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Lead-Acid reserve cell	Rejected and scrap batteries	25	14	. . .	8	. . .	. . .	. . .	. . .
	Wastewater effluent treatment sludge	0.6	. . .	. . .	. . .	. . .	. . .	. . .	Sludge containing nickel and lead = 0.2
Totals		~1,500	~14	0.03	8	. . .	~410	2.0	. . .

[a]Reference 11
[b]Lead equivalent of lead and lead compounds contained in sludge
[c]Reclaimed
[d]Not available

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ENCAPSULATION OF 55-GAL DRUMS HOLDING HAZARDOUS WASTES

H.R. Lubowitz, R.W. Telles, S.L. Unger
TRW Systems Group
Redondo Beach, CA. 90278

C.C. Wiles
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

ABSTRACT

Hazardous wastes in corroding 208 l (55-gal) metal drums present a serious potential threat to the well-being of man and his environment. To render drums secure and safe for transporting to and final deposit in a landfill, investigations were carried out to over-pack them with polyethylene (PE) encapsulates.

PE receivers, 6.35 mm (1/4-in.) thick wall and wide-mouth, and PE flat sheet, 6.35 mm (1/4-in.) thick, were employed for fabricating encapsulates. The receivers after insertion of corroding drums were weld sealed with sheet. Encapsulates so fabricated were expected to exhibit satisfactory performance. (In contrast, containers sealed conventionally, rather than welded, by use of lids and threads, gaskets, sealants and hoops were not expected to give rise to safe transportability of wastes and long-term stability of contaminants under landfill conditions.) The encapsulates provided a unique service because wide-mouth PE containers were not commercially available for securing 208 l (55-gal) drums and/or complying with Department of Transportation specifications governing containers for use in transporting hazardous wastes.

A prototype apparatus was designed and constructed to fabricate PE encapsulates by welding. The apparatus was analogous to that employed in commercial butt welding of PE pipe. Facilitating encapsulate fabrication was the findings that precision piece alignment and high surface regularity were not required. Furthermore, only minimal mechanical pressures were needed to form the welded joints. Differentiating encapsulate welding from pipe welding was moving of the heating element horizontally rather than vertically.

INTRODUCTION

The purpose of this work was to secure corroding 208 l (55-gal) drums holding hazardous wastes at the place where they reside. They would be encapsulated in polyethylene (PE) overpacks on an "as-is" basis, i.e., no isolation of their contents would be carried out. The encapsulated drums would comply with Department of Transportation (DOT) specifications governing containers employed in transportation of hazardous wastes. And they would be suitable for long-term, safe deposit in a landfill.

The work was an outgrowth of previous work carried out at TRW under sponsorship of the Environmental Protection Agency.[1,2,3] In previous work, hazardous, unconfined waste particulates, sludges and corroding small containers with contaminants were managed on a laboratory scale by encapsulating them in 63.5 mm (1/4-in.) thick, seam-free PE jackets. So encased, the wastes were found to exhibit unusual resistance to delocalization under severe mechanical stresses and harsh leaching waters which simulated extreme case

solutions that may be found in a landfill. When management of 208 1 (55-gal) drums was set forth, it was therefore proposed to encapsulate them also by jackets similar to those investigated.

Initial studies showed that encapsulating 208 1 (55-gal) drums with PE jackets may be carried out best by plastic welding, invoking particularly the art employed commercially for welding PE pipe.[4] Fabricating PE encapsulates by welding, however, was not state-of-the-art. Consequently, commercial apparatuses applicable to such an operation did not exist.

With pipe welding art as a guideline, the prototype apparatus described herein was constructed. The apparatus weld sealed PE receivers with PE flat sheet. Both receivers and flat sheet were items of commerce with the former being tailorable as required and being capable of production in commercial rotomolding operations.

MATERIALS

Polyolefins, particularly PE (but not excluding high impact polypropylenes and polyisobutylene), were selected for fabricating encapsulates because such materials were well characterized, mass-produced, low in cost, and provided a unique combination of properties: excellent chemical stability, flexibility and mechanical toughness. Prior laboratory studies showed PE encapsulates to have high performance heavy metal contaminant retension when subjected to aggressive leaching solutions.[3] Yet the resin can transmit gases, thus the encapsulates were self-venting when gas formed within as a result of chemical reactions.

Commercial PE containers were not available in size and in construction for securing 55-gal metal drums. The largest plastic vessel that may be transported with compliance to DOT regulations were 55-gal drum size fitted with bung holes. Widemouth drums did not qualify. Other PE vessels were not fitted with the means to effect secure closure. They were employed mainly as liners of steel and fiberglass reinforced vessels, or as free-standing receivers and holding tanks. Their value was particularly noteworthy in process and storage operations involving corrosive chemicals. There was great interest by plastics fabricators to make by rotomolding

large, free-standing chemical tanks from PE to replace plastic coated or glass lined steel tanks, stainless steel tanks, and fiberglass reinforced plastic tanks.

With consideration of commercial container art and the mechanics of encapsulate fabrication, rotomolded wide-mouth PE receivers, and PE flat sheet, were selected for use in making encapsulates. The receivers and flat stock were commercially available materials. Although on-the-shelf receivers were taller than desired, they were capable of being readily constructed to specifications when needed in significant numbers. The specifications of materials selected as suitable for encapsulate fabrication were:

Receptacles

● Rotomolded

● Medium density PE

● 6.35 mm (1/4-in.) thick walls

● Dimensions of 669 mm (26 11/32-in.) O.D. x 944 mm (37 3/16-in.) height

● Approximate weight of 20.4 kg (45 lb) (including cover)

● Capacity of 322 1 (85-gal)

Cover

● Cut from extruded flat stock

● High density PE

● 6.35 mm (1/4-in.) thick

The height and diameter of receptacles were selected for accommodation of 208 1 (55-gal) drums as shown in Figure 1. The free space between receptacle interior and 208 1 (55-gal) drum can be filled, if required, with low-cost filler materials such as foam to minimize drum movement during handling. Additionally, the free space allows encapsulation of distorted drums.

Figure 2 shows a side view of encapsulate. The upper "rim" or "flange" facilitates handling operations.
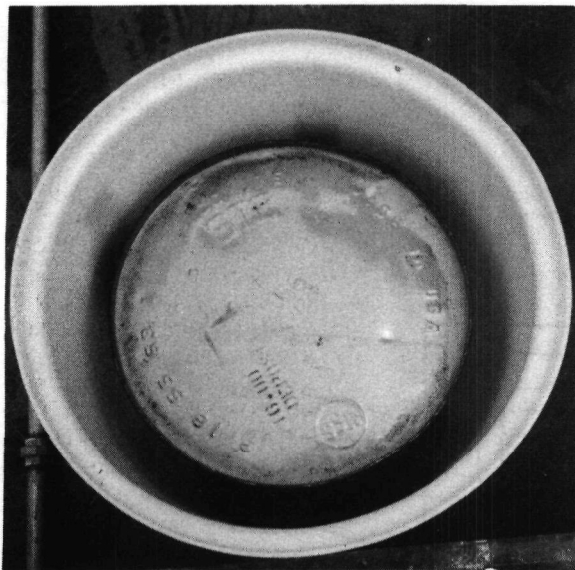
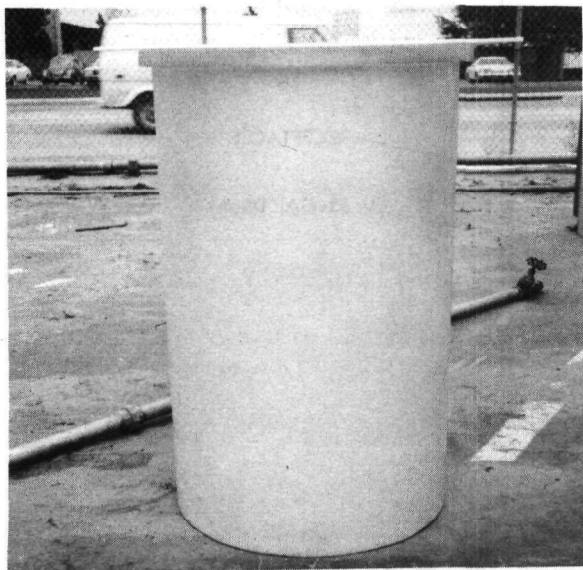Figure 1.   Receptacle holding 55-gal drum.

Figure 2.   Structure of encapsulate holding
            55-gal drum of hazardous waste.

WELDING APPARATUS

The welding apparatus was viewed as a container heat sealing device comparable to commercially employed polyethylene pipe welding devices.[5] The apparatus was fabricated with commercial components in the first cut for demonstration of proof-of-principle, i.e., 55-gal corroding drums holding hazardous wastes can be secured in plastic encapsulates fabricated by welding. And in the second cut (in a later program), the apparatus will be refined with custom made parts for efficient field operations. (We visualize the refined apparatus to be similar to the proof-of-principle one, but lighter in weight, particularly the frame.)

In order to get the purchased components into an encapsulate welding apparatus, additional pieces of equipment were required. These pieces were designed and custom fabricated. The pieces were geared to transmit pressure from the pump to point of welding and to apply heat to the weld areas.

The finished apparatus was novel although many of its features approximate features of commercial pipe welding apparatuses. The apparatus consisted of three major components: (1) the frame, (2) the hydraulic system and (3) the heater. Figure 3 gives a schematic of the apparatus and materials positioned for welding. The hydraulic system (pump, valves, cylinder, platen) and heater (with heater holder and circuitry) were attached to the frame; the apparatus was of modular construction thus allowing easy replacement and interchanging of components and simplifying shipping.

Frame

The frame (see Figure 4) was used to position both the plastic pieces for encapsulation and the other components of the apparatus. The frame employed in the prototype apparatus was an Enerpac 7531 H-frame, rated at 76,200 Kg (75-ton). Although this frame was oversized on a pressure capacity basis, this was the smallest frame which has the bed diameter needed. Because the receivers were approximately 762 mm (30-in.) diameter, the distance between the uprights of the H-frame must be approximately 889 mm (35-in.) so the receivers can be placed easily under the frame.

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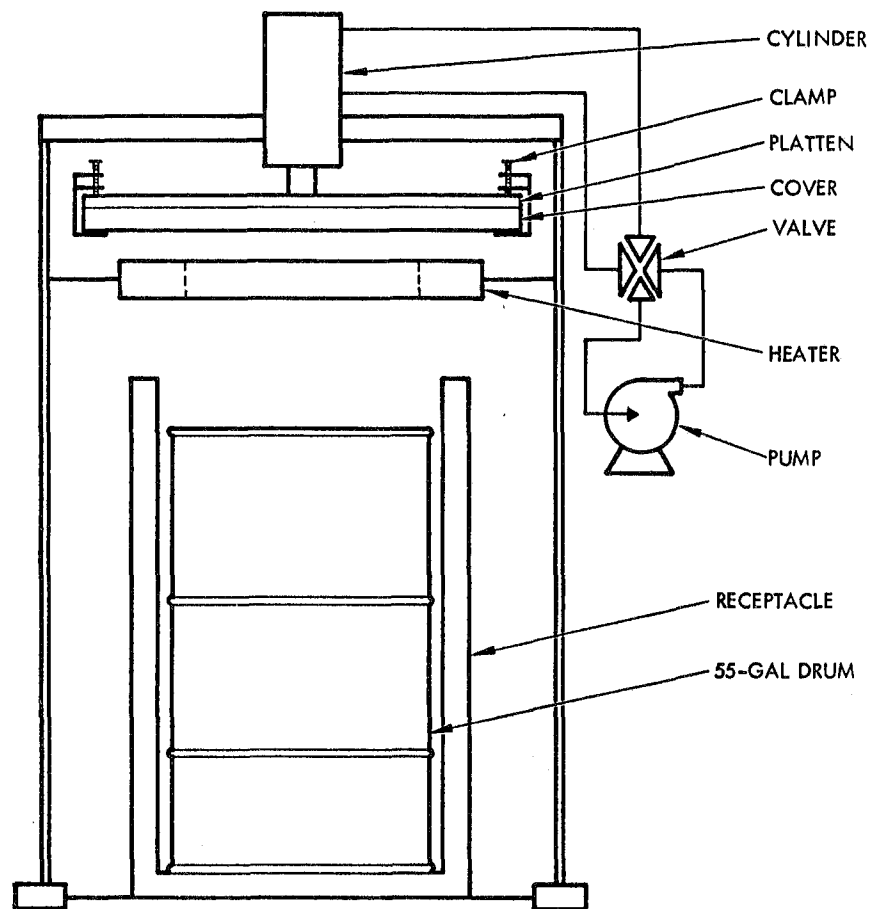
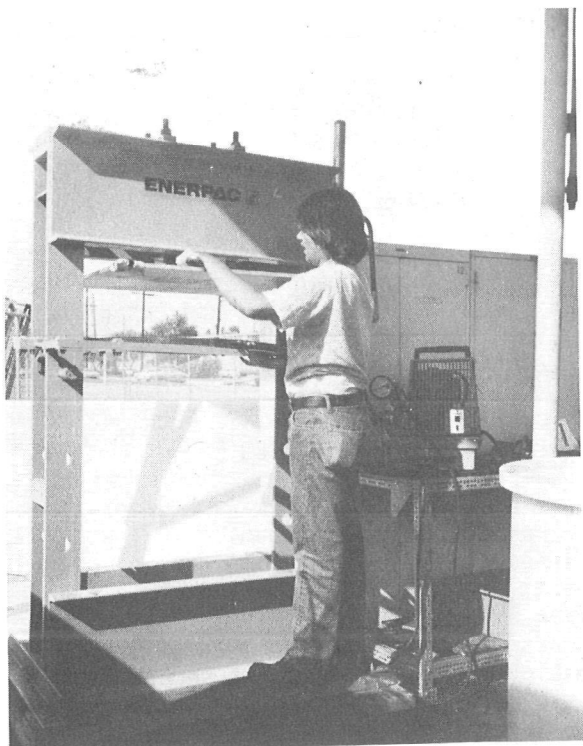Figure 3. Apparatus for encapsulating 55-gal drums.

Figure 4. Apparatus for encapsulating 55-gal drums holding hazardous wastes.

Hydraulic System

The hydraulic system consisted of a pump, a hydraulic cylinder, and the necessary valving. The hydraulic system was used to move the cover vertically so the heater can slide between the plastic pieces, and to apply the welding pressure necessary to achieve a leak-proof weld. The primary design criteria which the hydraulic system must meet were: (a) turnaround time less than 5-seconds and (b) pressurize the plastic pieces up to 300 psi. The first criterion, quick changeover, prevented "skinning", the formation of thin layer of polyethylene after the heater was removed from the polyethylene pieces. This criterion was met by using a high capacity, two stage, 1 1/2- H.P. electric pump and a double acting cylinder to move the platen to which the cover was clamped. The lid was first moved down to press against the heater. After heating, the cover was moved up, the heater removed, then the cover moved down and pressed against receiver. The cylinder was rated at 10-ton which

easily met the second design criterion. Pressure relief valves were utilized to prevent overpressurization. The components of the hydraulic system are shown in Figure 5.
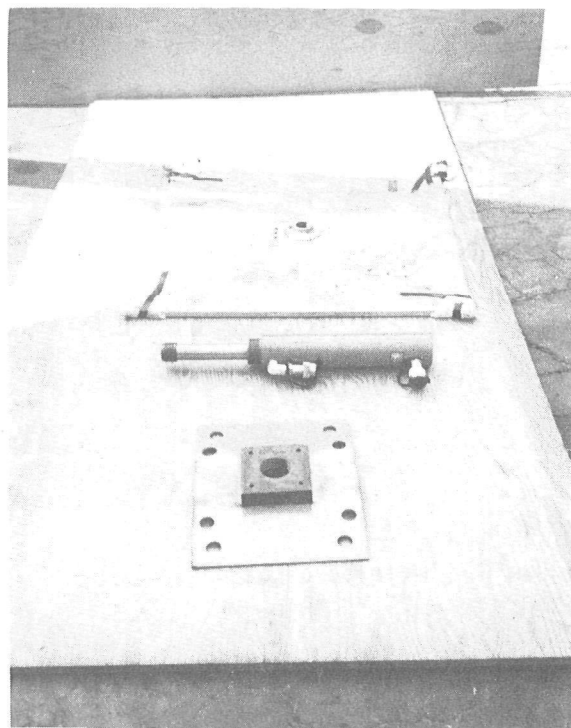
Figure 5. Hydraulic system components.

Heater

The heater was a ring heater designed to melt the lip of the receiver and a flat portion of the cover. The ring was 26-in. I.D., 30-in. O.D., and 1-in. thick. The heater was made from cast aluminum and was teflon coated to prevent the melted polyethylene from sticking to the heater. The heater was rated at 5.5 KW so that it can achieve a temperature of 450°F in 10 minutes. The heater was bolted to the heater holder. The heater holder was attached onto the H-frame. It was designed to allow vertical movement between the plastic pieces, as well as, horizontal swivel movement away from the welding area. The heater and heater holder are shown in Figure 6.

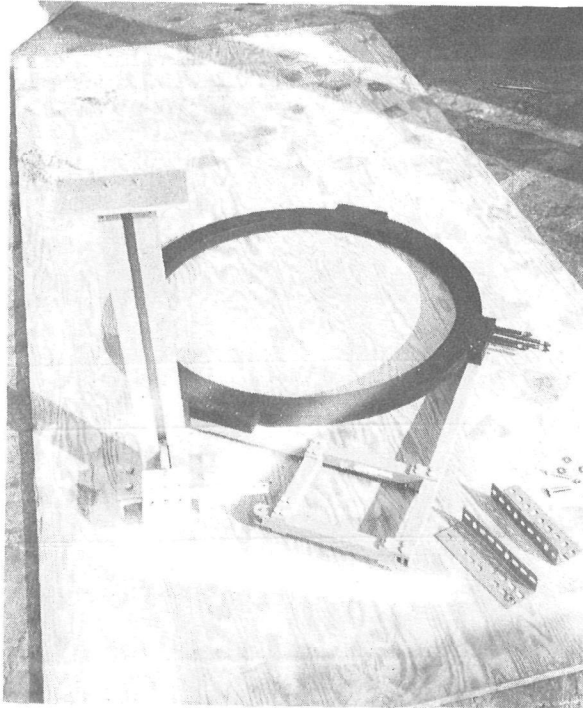The welding apparatus, shown in Figure 4 with the operator, functioned as follows:

Figure 6.   Heater and heater holder.

1. Receptacle (holding 55-gal drum) and cover are positioned for welding.

2. Heater, at temperature, was contacted onto surface areas of cover and receptacle geared for juncture.

3. Heater was removed from welding area.

4. Cover and receptacle contacted under pressure.

5. Welded joint cooled under pressure.

The following observations compare pipe welding to encapsulate fabrication:

● During welding pipes were positioned horizontally and end-to-end whereas receptacles were positioned in an upright position.

● Pipes with diameters comparable to receptacles used for encapsulation had much thicker walls, thus requiring manipulation of heavier pieces.

● Greater weights of pipe involved heavier duty machinery than that needed in encapsulation.

● Greater surface area of pipe required mechanical force at closure to be greater than that needed in welding lids to receptacles.

● Perhaps most important, closure of pipe required careful alignment to match rim to rim, whereas proper fitting of lid to rim of receptacle can be effected with lesser alignment sensivity.

NATURE OF PE ENCAPSULATES

Welded encapsulates were water-tight overpacks for 55-gal drums. They precluded contact of hazardous waste consignments with aggressive environmental waters even though the drums within may continue to corrode. Furthermore, encapsulates were anticipated to hold wastes secure under severe mechanical stresses that may arise in loading, transporting and landfill deposition.

Encapsulates were expected to provide appreciably greater service life than PE drums and pipe used in commercial operations because:

● Cyclical mechanical stresses or dynamic stresses would be essentially absent, thus mitigating plastic fatigue, a property that concerns users of PE drums and welded PE pipes.

● Reuse of encapsulates, in contrast to commercial plastic drums, was not contemplated, thus the absence of repeated impact.

● Deposit in a landfill shielded encapsulates from ultra-violet radiation.

Because they were subject to less stressful conditions, future encapsulates may be fabricated with scrap PE. And in addition, a simpler design may be employable than that required for commercial PE 55-gal drums.

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The major concern was stress due to single impact. Because encapsulates' contents were not homogeneous (due to 208 1 (55-gal) metal container inserts) encapsulates are subject to greater localized stress than that occurring in filled commercial plastic drums. However, the use of appropriate materials such as foam, if required, in the free space between encapsulate inner walls and metal drum, could mitigate the concentrated stress.

CONCLUSION

The work indicated that corroding 55-gal. drums can be managed in the field as follows:

1. Transport equipment and materials (materials can also be in the form of partially fabricated encapsulates) to the site where drums reside.

2. Encapsulate drums and transfer them to a landfill (encapsulates secure contents in case of mishaps in transportation).

3. Charge encapsulates into landfill according to accepted practice with respect to depositing containerized wastes.

ACKNOWLEDGMENT

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HAZARDOUS WASTE CONCENTRATION TECHNOLOGIES

Alan J. Shuckrow
Andrew P. Pajak
C. J. Touhill
Touhill, Shuckrow and Associates, Inc.
Pittsburgh, Pennsylvania 15237

ABSTRACT

This paper describes an ongoing program to evaluate and verify several selected concentration techniques for hazardous constituents of aqueous waste streams. The project has four phases of work. In Phase I, data was obtained regarding the performance of unit processes for concentrating the hazardous constituents. Applications are expected in the treatment of ground and surface waters affected by the disposal of hazardous wastes. In conjunction with gathering data on the unit processes, data were obtained on the composition of the waste streams to which the processes could be applied. In Phase II, technology profiles describing the pertinent unit processes are being prepared. These profiles are intended to describe applications of the processes, performance, and design criteria; both case studies and laboratory bench-scale and field pilot-scale work will be used to prepare the profiles. In Phase III, those unit processes believed to be most applicable will be further evaluated in laboratory treatability studies. Individual unit processes and process trains will be used. In Phase IV, field demonstration studies will be conducted. One site in Michigan has been selected for conduct of treatability and demonstration work. Other sites are being screened to select a second location for on-site studies.

INTRODUCTION

Indiscriminate past disposal practices - the implacement of waste chemicals in nonsecure ponds, lagoons, and landfills - have created serious environmental and public health problems. Indeed, as of June 1, 1979, 151 sites were under investigation. EPA has estimated that as many as 2000 disposal sites around the country may contain wastes that could pose health hazards and that more than 30,000 sites may contain hazardous wastes. In addition, EPA estimates that 80-90% of the approximately 35 million metric tons of hazardous wastes being produced annually in the United States is not being disposed of with adequate safeguards.

Recent incidents such as Love Canal and Valley of the Drums have aroused public attention and apprehension. Congressman Albert Gore, Jr. has described the hazardous waste disposal problem as "the most significant environmental health problem of this decade." The seriousness of the problem is evidenced by the fact that several pieces of legislation have been proposed to create a "superfund" to clean up uncontrolled waste sites and spills of oil and hazardous materials. Currently, responsibility for remedial action often devolves to state and local governments. This fund would enable EPA to provide legal and technical

assistance to local and state governments with regard to cleanup.

Because discontinuance of production and use of hazardous materials is infeasible economically, due to their benefits to society in terms of end-products and as raw materials, emphasis in environmental protection must focus on effective management. One such management step is preprocessing or concentration prior to detoxification or disposal.

This paper addresses a project, "Evaluation and Development of Techniques to Concentrate Hazardous Constituents of Municipal Waste Streams", currently being conducted for the U. S. Environmental Protection Agency.

The purpose of the project is to evaluate and verify several selected concentration techniques for hazardous constituents of aqueous waste streams. Existing concentration and pretreatment techniques are being identified, documented, researched, and evaluated for broad range effectiveness in placing hazardous materials in physical forms most amenable to ultimate disposal/detoxification. Concentration schemes are being selected for further development and subsequent field scale verification.

The project has the following four phases of work to be conducted over three years:

Phase I - Literature Search/ Data Acquisition, Program Approach Development

Phase II- Data/Process Analysis and Assessment

Phase III-Evaluation and Modification of Selected Processes and Techniques

Phase IV- Verification of Selected

Concentration
Technologies

In Phase I, data were obtained regarding the performance of unit processes for concentrating the hazardous constituents. Applications of the unit processes are expected in the treatment of leachates and ground and surface waters affected by the disposal of hazardous wastes. There are many well known examples of this type of problem: Love Canal, Rocky Mountain Arsenal, Redstone Arsenal, and Valley of the Drums, to name a few. In conjunction with gathering data on the unit processes, data were obtained on the composition of the waste streams to which the processes could be applied.

In Phase II, technology profiles describing pertinent unit processes are being prepared. These profiles are intended to describe applications of the processes, performance, and design criteria; both case studies and laboratory bench-scale and field pilot-scale work will be used to prepare the profiles.

In Phase III, those unit processes believed to be most applicable will be further evaluated in laboratory treatability studies. Individual unit processes and process trains will be used. In Phase IV, field demonstration studies will be conducted.

At the time of this writing, Phase I has been completed, Phase II of the project is well underway, and Phase III is commencing.

DATA ACQUISITION

The major thrust of Phase I efforts were twofold: 1) to collect and compile existing data on candidate technologies for concentration of hazardous constituents of aqueous wastes; and 2) to obtain and compile data on the composition of actual waste streams which may require or could benefit from treatment by the concentration technologies.

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Technologies included for initial consideration in the project were:

- Solvent Extraction
- Crystallization
- Evaporation
- Ion Exchange
- Distillation
- Reverse Osmosis
- Carbon Adsorption
- Resin Adsorption
- Chemical Precipitation
- Flocculation/Dissolved Air Flotation
- Density Separation
- Filtration
- Catalysis
- Molecular Sieves
- Centrifuging
- Dialysis/Electrodialysis
- Biological Treatment

Several hundred pertinent articles in the literature were identified as having potential usefulness. Of these, over 250 were reviewed and about 100 were summarized using an established literature review format.

Numerous contacts were made with governmental entities and companies involved in hazardous waste management and associated technology. These contacts consisted of telephone interviews, correspondence, personal interviews, and site visits for the purpose of obtaining data on candidate concentration technologies, information on known problems, and composition data on actual waste streams which could benefit from concentration technology.

Several important conclusions reached during data acquisition efforts directly impacted selection of an approach to technology screening and evaluation. Some of these were:

1) Only a limited number and range of unit operations have been applied in the treatment of hazardous aqueous wastes, even though concentration technologies have been used for other applications.

2) Activated carbon has been used almost exclusively for concentration of organics in the limited number of larger scale hazardous waste treatment operations.

3) Concentration technology performance and operating data for industrial process wastes containing a variety of pollutants usually are reported using a surrogate parameter such as TOC or COD. Specific compound data are available only for a very limited number of materials.

4) Limited specific information is available through vendors because much of their work is considered proprietary and/or confidential.

5) The current, biggest problem is contamination from waste disposal sites – generally leachates, and contaminated ground and surface waters.

6) There is no such thing as a "typical" hazardous waste problem – each site is unique.

7) Wastes encountered are diverse in terms of composition and concentration, often varying over time at any given site. Some wastes contain a broad spectrum of organic and inorganic compounds, while others have only a few constituents.

8) Actual or threatened legal proceedings almost invariably restrict the availability of data on the nature of the problem and effectiveness of cleanup operations.

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WASTE CATEGORIZATION/CLASSIFICATION

Composition data on leachates and contaminated ground and surface waters in the proximity of 27 sites containing hazardous wastes were obtained and summarized. In addition, data on 43 industrial disposal sites which were surveyed in a previous study by Geraghty and Miller[1] were examined.

A wide variation was found from site to site in the detail and completeness of the available data. Very few waste streams have been well characterized. In addition, it was noted that waste composition often is highly variable at any given site with respect to both time and location.

Because of the large number of chemicals and possible combinations and permutations of constituents in hazardous waste streams, it was deemed desirable to employ predictive techniques to forecast the behavior of chemicals present in such waste streams. Unfortunately, no proven method exists to accurately predict the removability of all of the potential chemical constituents of hazardous aqueous waste streams.

Nevertheless, some grouping or classification of waste streams and/or constituents is desirable to extend the usefulness of the data, facilitate the evaluation of concentration technology, and permit forecasting of treatment effectiveness in other situations. No one system is fully adequate to accomplish these purposes. Therefore, as a first attempt at grouping of waste streams and classification of chemical constituents, two schemes have been devised. Both provide insight into the problem and facilitate the technology evaluation. As the project proceeds, the utility of the grouping/classification systems will be more fully assessed and the systems will be modified as necessary to meet the objectives of this research.

The first attempt at grouping

pertains to waste streams and is based upon the concentration of the inorganic and organic constituents. A matrix has been devised as shown in Figure 1* which describes the concentration of the inorganic and organic constituents as high, medium, and low. In general, the working definitions of "high", "medium" and "low" are as follows:

	Hazardous Inorganic Constituent	Hazardous Organic Constituent
High	greater than 5 times water quality criteria#	greater than 400 ppb
Medium	from 2 to 5 times water quality criteria#	from 5 to 400 ppb
Low	less than water quality criteria#	less than 5 ppb

In addition, if a gross parameter such as BOD or TOC was reported in significant concentration (BOD$>$20mg/l TOC$>$10mg/l),the waste stream was considered to fall in the high organic category. Although this system is not rigorous, it does permit a useful grouping of the actual waste streams as shown in Figure 1.

In addition to the grouping of waste streams, a contaminant classification system was formulated (Table 1). All of the identified constituents of the 27 hazardous waste streams have been classified according to this system. The frequency of occurrence observed for compounds in each classification is summarized below:

*Each of the 27 sites for which composition data were summarized, were coded. The codes appear in the Figure 1 matrix.
#Water quality criteria derived from Quality Criteria for Water, US EPA, Washington, DC, July 1976.

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Figure 1
Waste Stream Categorization Matrix

ORGANICS CONCENTRATION	INORGANICS CONCENTRATION		
	High	Medium	Low
High	Sites 006 011	Site 010	Sites 001 002 003 005 021 023 024 025 026 027
Medium	Site 022		Sites 008 009 013
Low	Sites 004 012 014 015 016 018		

Alcohol 2
Aliphatic 4
Amine 2
Aromatic 8
Halocarbon 9
Metal 15
Miscellaneous 11
PCB 2
Pesticide 7
Phenol 7
Phthalate 2
Polynuclear
  Aromatics 5

Both the categorization matrix and the classification system were used in the selection of two actual waste streams for use in the technology screening described subsequently.

TECHNOLOGY SCREENING

The foregoing material has been used to formulate an approach to the screening and evaluation of concentration technologies. Subsequent to this screening and evaluation, selected technologies will be subjected to more detailed examination at the bench, and ultimately, pilot scale during later phases of the program.

Factors being considered in the technology evaluation include:

- state of development
- range of technology application
- process flexibility
- process reliability
- economic and engineering constraints in technology modification and application
- start-up requirements
- efficiency
- specific limitations
- energy requirements
- form of concentrated material (susceptibility to ultimate detoxification/disposal)
- environmental acceptability

The literature search format developed in Phase I was structured to categorize collected data in a manner to facilitate evaluation of the factors listed above.

Technologies are being evaluated in light of their applicability to treatment of hazardous waste streams identified in Phase I.

As a first step in the evaluation process, three stream compositions were chosen and sent to selected treatment equipment/product vendors. In addition, the vendors were supplied with: an estimated flowrate based upon data gathered on actual sites and a desired effluent quality based upon published standards whenever possible. The vendors were asked to provide their projections on the performance of their process or product in concentrating the hazardous constituents for the three selected waste streams. They also were requested to advise on any pretreatment or supplemental treatment they consider necessary for optimum performance. In addition, they were asked to estimate unit sizes, design criteria, operating requirements, and process economics. In the event that achievement of the desired effluent quality is extremely expensive, or

TABLE 1 CONTAMINANT CLASSIFICATION SYSTEM*

1.	Alcohols
2.	Aliphatics
3.	Amines
4.	Aromatics - nonhalogenated and halogenated aromatic compounds
5.	Ethers
6.	Halocarbons - halogenated aliphatic compounds
7.	Metals
8.	Miscellaneous - including selected priority pollutants, CN, pH, BOD, TOC, COD, chloride, sulfate, phosphate, and other parameters generally used to characterize wastewaters
9.	PCB'S
10.	Pesticides
11.	Phenols - including chloro and nitro phenols
12.	Phthalates
13.	Polynuclear Aromàtics

*Based on a classification system suggested by Dryden and Mayes.[2]

alternatively, cannot be met at all, the vendors were asked to define how well the process or product will perform in the competitive price range.

Eight vendors agreed to participate in the technology evaluation. However, responses received to date indicate that most of the vendors are unwilling or unable to make projections with regard to the performance of their technologies for treatment of the mixed composition waste streams.

The second step, pursued simultaneously with the vendor analyses, entails an independent desk-top analysis conducted by the project team using the same waste stream data.

Information generated by the project team on the selected waste streams will form the basis for the technology profiles. Thus, the profiles will extend beyond general characterizations for the more promising concentration techniques and will contain an evaluation of candidate process applicability to hazardous aqueous wastes which span a range of expected compositions. The resulting technology profiles will provide the basis for selection or rejection of candidate concentration technologies for/

from further consideration in Phases III and IV.

WASTE STREAM SELECTION

Inspection of the waste stream categorization matrix (Figure 1) reveals that most of the actual waste streams identified in Phase I fall into one of two categories: high organic-low inorganic or low organic-high inorganic. With regard to the latter category, concentration technology is essentially state-of-the-art. Moreover, inorganic constituents of concern are present in waste streams in other categories and will be examined as part of the overall treatment analysis for these waste streams. Therefore, low organic-high inorganic category is not being considered in the Phase II analysis.

Waste stream data from Site 026 in the high organic-low inorganic category was selected for the Phase II analysis for several reasons: the data set is one of the most comprehensive available; ongoing activity at the site foretells future supplemental data availability; the state has assumed responsibility for mitigation of contaminated groundwater problems; no litigation is involved; the state regulatory agency has been cooperative; and a strong possibility

existed for use of the actual waste in laboratory and pilot scale studies in Phases III and IV.

The second waste stream composition selected for the Phase II analysis was that of Site 010 in the high organic-medium inorganic category. Reasons for selection are similar to those given for Site 026. In addition, heavy metals are present in significant concentration. Thus, this waste stream is sufficiently different than that of Site 026 to provide a second case.

The third waste stream composition utilized in the Phase II technology screening is a hypothetical leachate postulated on the basis of data contained in another report[1]. Frequency of occurrence of the various classes of chemicals given previously also was considered in formulating the hypothetical leachate. The postulated leachate composition represents the high organic-high inorganic case. Reasons for selecting a hypothetical leachate include: (1) it provides a common basis for testing the appropriateness of various technologies, (2) it represents a reproducable "waste" composition for potential use in laboratory studies, (3) it contains a limited number of constituents representative of the broad range of materials found at actual sites, and (4) it is representative of "average" conditions at numerous sites.

Quantitative data describing the three waste streams of interest together with desired effluent objectives are given in Tables 2, 3, and 4.

BENCH SCALE STUDIES

Advantage will be taken of the ongoing Phase II analysis in selection of unit processes to be examined in the laboratory treatability studies. Although the Phase II effort is incomplete at the time of this writing, tentative selection of several unit processes for laboratory treatability

studies has been made as follows:

- Chemical Coagulation/ Precipitation
- Sedimentation
- Filtration
- Carbon Sorption
- Resin Sorption
- Reverse Osmosis
- Ultrafiltration
- Air/Steam Stripping
- Biological Treatment
- Combined Biological – Carbon

No one of these unit processes appears sufficient to achieve adequate treatment of the hazardous leachates and contaminated ground and surface waters identified in Phase I of the ongoing project. Therefore, the unit processes must be arranged in process trains. An initial selection of process trains to be examined in laboratory treatability studies will be accomplished as part of the ongoing Phase II activities.

In addition to removal of hazardous constituents from the aqueous phase, by-product streams will be examined in view of their ultimate detoxification, disposal, and environmental impacts.

Current plans call for conduct of the bench and subsequent pilot scale studies over an 18 month period at two field sites. One field site, site 026, has been selected. This site is the Ott/ Story Chemical Company site located in North Muskegon, Michigan. Selection of this site, which is now owned by Cordova Chemical Company, was based on several factors including availability of quantitative data describing problem nature and magnitude, absence of pending litigation which would limit information transfer, cooperative relationships between Cordova and Michigan Department of Natural Resources (DNR), and an ongoing feasibility study to identify and evaluate clean-up techniques which is being conducted by DNR.

Cordova Chemical Company has

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TABLE 2 WASTEWATER CHARACTERIZATION-SITE 010

Parameter	Raw Wastewater Quality Range	Effluent Quality Goal
pH	5.6 - 6.9	5 - 9
TOC	1800 - 4300 ppm	20 ppm
SOC	4200 ppm	20 ppm
COD	5900 - 11,500 ppm	50 ppm
Oil & Grease	90 ppm	10 ppm
SS	200 - 430 ppm	10 ppm
TDS	15,700 ppm	No increase
SO_4	240 ppm	250 ppm
Sulfide	< 0.1 ppm	0.3 ppm
Total P as P	< 0.1 - 3.2 ppm	0.1 ppm
PO_4 as P	< 0.1 ppm	0.1 ppm
TKN	5.4 ppm	NL
NH_4-N	0.65 ppm	0.5 ppm
NO_3-N	< 0.1 ppm	10 ppm
NO_2-N	< 0.1 ppm	
Na	1000 ppm	NL
Ca	2500 ppm	NL
Cl	9500 ppm	No increase
Fe	31 - 330 ppm	1 ppm
Hg*	< 0.5 -<1	20
Pb*	0.3 - 0.4 ppm	0.50 ppm
Sb*	2[a]	200
As*	130[a]	500
Cd*	11[a]	100
Cr*	270[a]	200
Cu*	540[a]	250
Ni*	240[a]	250
Se*	9[a]	100
Ag*	1[a]	20
Zn*	480[a]	2 ppm
CN⁻*	< 0.01[a]ppm	0.25 ppm
hexachlorobutadiene*	109[a]	10^3 reduction
1,2,4-trichlorobenzene*	23[a]	< 0.09
Aldrin*	<10a	< 1
heptachlor	573[a]	< 1
phenol*	30	500
phenols (total)*	3.5[a]ppm	NS
2,4-dichlorophenols*	10[a]	< 0.1
methylchloride*	180[a]	< 0.4
1,1-dichloroethylene*	28[a]	< 2.0
chloroform*	ND - 4550	10^3 reduction
trichloroethylene*	ND - 760	10^3 reduction
dibromochloromethane*	ND - 35	< 0.3
1,1,2,2-tetrachloroethylene	ND - 1000	see TOC
chlorobenzene*	1200[a]	10^3 reduction
methanol	42.4[a]ppm	see TOC limitation
ethanol	56.4[a]ppm	see TOC limitation
acetone	50.3[a]ppm	see TOC limitation
isopropyl alcohol	< 0.1[a]ppm	see TOC limitation
benzene*	ND - 3300	10^3 reduction
toluene*	ND - 31,000	10^3 reduction

(continued)

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TABLE 2 (continued)

Parameter	Raw Wastewater Quality Range	Effluent Quality Goal
1,1,1-trichloroethane*	ND - 225	⁻ 2
carbon tetrachloride*	92[a]	⁻ 4
hexachlorocyclohexane -		see TOC limitation
alpha isomer	ND - 600	
beta isomer	ND - 700	
gamma isomer	ND - 600	
delta isomer	ND - 120	

ND-Not Detected
NL-No Effluent Limitation
 a-denotes concentration following flow equalization and sand filtration
    processes
 *-A Priority Pollutant

TABLE 3 WASTEWATER CHARACTERIZATION-SITE 026

Parameter	Raw Wastewater Quality Range	Effluent Quality Goal
pH	11.5	5 - 9
COD	5400 ppm	50 ppm
TOC	1500 ppm	20 ppm
NH_3-N	64 ppm	0.5 ppm
organic N	110 ppm	NL
chloride	3800 ppm	No increase
conductivity	18,060 μmhos/CM	NL
SS	100 ppm	10 ppm
TDS	12,000 ppm	No increase
volatile organics:		
vinyl chloride*	140 - 32,500	10^3 reduction
methylene chloride*	<5 - 6570	10^3 reduction
1,1-dichloroethylene*	220 - 19,850	10^3 reduction
1,1-dichloroethane*	<5 - 14,280	10^3 reduction
1,2-dichloroethane*	350 - 8150	10^3 reduction
benzene*	6 - 7370	10^3 reduction
1,1,2-trichloroethane*	⁻5 - 790	10^3 reduction
1,1,2,2-tetrachloroethane*	⁻5 - 1590	10^3 reduction
toluene*	⁻5 - 5850	10^3 reduction
ethyl benzene*	⁻5 - 470	10^3 reduction
chlorobenzene*	⁻5 - 78	0.2
trichlorofluoromethane*	⁻5 - 18	2.0
acid extractable organics:		
o-chlorophenol*	<3 to 20	0.09
phenol*	<3 to 33	0.5 ppm
o-sec-butylphenol[b]	<3 to 83	see TOC limitation
p-isobutylanisol[b] or p-acetonylanisol[b]	<3 to 86	see TOC limitation

TABLE 3 (continued)

Parameter	Raw Wastewater Quality Range	Effluent Quality Goal
acid extractable organics: (cont.)		
p-sec-butylphenol[b]	<3 to 48	see TOC limitation
p-2-oxo-n-butylphenol	<3 to 1357	see TOC limitation
m-acetonylanisol[b]	<3 to 1546	see TOC limitation
isoprophylphenol[b]	<3 to 8	see TOC limitation
1-ethylpropylphenol	<3	see TOC limitation
dimethylphenol*	<3	0.01
benzoic acid	<3 to 12,311	see TOC limitation
base extractable organics:		
dichlorobenzene*	<10 to 172	10^3 reduction
dimethylaniline	<10 to 6940	see TOC limitation
m-ethylaniline	<10 to 7640	see TOC limitation
1,2,4-trichlorobenzene*	<10 to 28	0.09
napthalene*	<10 to 66	10^3 reduction
methylnapthalene	<10 to 290	see TOC limitation
camphor	<10 to 7571	see TOC limitation
chloroaniline	<10 to 86	see TOC limitation
benzylamine or o-toluidine	<10 to 471	see TOC limitation
phenanthrene* or anthracene*	<10 to 670	10^3 reduction

NL-No Effluent Limitation
 b-structure not validated by actual compound
 *-A Priority Pollutant

TABLE 4 WASTEWATER CHARACTERIZATION-SITE 000

Parameter	Raw Wastewater Quality Range	Effluent Quality Goal
TOC	500	20
BOD	1000	30
COD	1400	50
pH	5.0	5 - 9
Cl^-	285	No increase
NH_4^+	50	0.5
		(continued)

TABLE 4 (continued)

Parameter	Raw Wastewater Quality Range	Effluent Quality Goal
SS	50	10
TDS	350	No increase
Na	113	NL
Ca	110	NL
Mg	50	NL
K	10	NL
Fe^{+2}	10	1.0
$Mn_{+5}*$	1.0	1.0
$As^{+5}*$	20	0.5
$Ba_{+3}*$	2.0	1.0
$Cr^{+3}*$	0.5	0.2 (Total Cr)
Se*	0.5	0.1
Cu*	5.0	0.25
Ni*	0.5	0.25
Zn*	5.0	2.0
Cd*	1.0	0.1
Hg*	0.1	0.02
CN*	1.0	0.25
phenol*	10	0.5
trichloroethylene*	2.0	10^3 reduction
ethanol	50	see TOC limitation
acetone	100	see TOC limitation
benzene*	5.0	10^3 reduction
o-chlorobenzene*	1.0	10^3 reduction
o-nitrophenol*	2.0	10^3 reduction
endrin*	10 ppb	<1 ppb

NL-No Effluent Limitation
*-A Priority Pollutant

been very cooperative and a field office for conduct of the laboratory studies was established in Cordova facilities in mid December, 1979.

Although it is too early to fully detail the bench scale studies, the following processes appear to be most applicable at the Ott/Story site:

● Carbon Sorption
● Resin Sorption
● Biological
● Stripping
● Chemical Coagulation/ Precipitation

These processes alone and in combinations will be studied during the first four months at the Ott/Story site.

PILOT STUDIES

Based upon bench scale testing results at both field sites, pilot plant studies will be designed and conducted to verify and optimize process train performance. Pilot studies will be aimed at developing design criteria and scale-up factors for the design of full size systems. Pilot studies at approximately a 1 gpm scale will be conducted using up to three process trains for approximately nine months.

SUMMARY

Available data have been collected and compiled on technologies with potential for concentrating hazardous constituents of aqueous wastes. In addition, data have been obtained on the composition of waste streams which may require or could benefit from treatment by the concentration

technologies.

Only a limited number of concentration technologies have been applied to treatment of hazardous aqueous wastes. Activated carbon has been used almost exclusively for concentration of organic compounds in the limited number of larger scale hazardous waste treatment operations which were identified.

It was concluded that the biggest problem facing the public sector currently is contamination from waste disposal sites - generally leachates and contaminated ground and surface waters. Such wastes are diverse in terms of composition, often varing over time at any given site. Some wastes contain a broad spectrum of organic and inorganic compounds, while others have only a few constituents.

Two waste stream categorization/classification systems have been devised and applied to 27 hazardous aqueous waste streams for which composition data were obtained.

A desk-top analysis of the applicability of concentration technologies to treatment of characterized waste streams is nearing completion. On the basis of this analysis, technologies will be selected for experimental study on the bench scale and subsequently on the pilot scale.

The Ott/Story Chemical Company site has been selected for conduct of the on-site experimental studies which began in mid-December, 1979. Other sites are being screened and a second location for companion experimental studies will be selected shortly. Pilot scale studies will follow the bench scale studies at both locations.

ACKNOWLEDGEMENT

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INORGANIC HAZARDOUS WASTE TREATMENT

Warren J. Lyman
Arthur D. Little, Inc.
Cambridge, Mass. 02140

Gayaneh Contos
Versar, Inc.
Springfield, Va. 22151

ABSTRACT

This report describes an ongoing program being conducted for EPA's Solid and Hazardous Wastes Division of MERL, Cincinnati, Ohio. The objective of the program is to identify, develop, and demonstrate selected treatment techniques for hazardous wastes in the municipal sector. To some extent the program is focused on wastes containing heavy metals and, to a lesser extent, on wastes containing organic as well as inorganic components. Current plans include demonstration tests for three treatment techniques: (1) a solvent extraction process for the treatment of sludges containing both inorganic and organic components; (2) a magnetic separation process for the treatment of sludges containing ferromagnetic or paramagnetic solids; and (3) a novel precipitation-filtration-adsorption process for treating acidic mixed plating wastes (of very high ionic strength) for both heavy metal and organics removal.

INTRODUCTION

Arthur D. Little, Inc., along with Versar, Inc., as a subcontractor, is currently assisting the Solid and Hazardous Waste Division of MERL in an assessment of selected treatment technologies for inorganic hazardous wastes disposed of in the municipal sector. The term "municipal sector" is taken to include all areas outside the direct control of the generating industry and is not limited to publicly owned and operated treatment plants and disposal sites. The focus on the municipal sector does mean, however, that treatment technologies that are designed to operate principally on segregated waste streams within a generator's plant may be inappropriate in this case.

More often than not, the wastes in the municipal sector will be complex and varying mixtures of liquid and solid wastes that result from the comingling of compatible wastes from a variety of sources.

The degree of waste segregation that might be encountered in the municipal sector is shown schematically in Figure 1. Purely inorganic wastes may seldom exist, thus requiring one to consider the effect of various organics, including oils, on a treatment system designed for inorganics; the treatment system may, in fact, have to include a unit operation for the removal of the organic fraction. In addition, the prospects for material recovery from such wastes are significantly diminished from those associated with segregated waste streams. In spite of this, our program has actively sought to identify treatment systems that might, with certain waste streams, allow some material or energy recovery.

The objectives of any treatment system selected might involve volume reduction, detoxification, and/or material and energy recovery. No treatment system can avoid the problem of residuals generation, and thus it has been necessary to consider each

WORST
CASE

1ST LEVEL OF
SEGREGATION

2ND LEVEL OF
SEGREGATION

3RD LEVEL OF
SEGREGATION

(4) Potential for Material
Recovery

- Waste lube oils
- Chlorinated solvents
- Other valuable chem.

(2) Mixed Organics

- Contains little or
no water; burn for
heat value

(5) Easily Burned for Heat
Value

- Hydrocarbons

Probably not
required

(6) Those Needing Special
Detoxification or
Destruction Methods

- Some pesticides
- Complex sludges

(1) All Wastes Mixed

- Mixture of organic and
inorganic material in
form of dilute aqueous
sludge

(10) Need Special Treatment

- CN destruction
- Cr^{+6} reduction

(11) Treatable by General
Methods

- Leachate

(7) Aqueous Wastes

- Relatively low solids
content (e.g., leachate,
waste plating/rinse
baths)

(3) Mixed Inorganics

- Dilute aqueous sludge;
may contain small amount
of organic material

(12) Potential for Material
Recovery

- Contain only 1 or 2
valuable metals or
chem.

(8) Dilute Sludges

≤ 10% solids; need to
dewater

(9) Concentrated Sludges

≥ 25% solids; can use
fixation, etc., directly

(13) Contain Magnetic Metals

- Metals small % of to-
tal solids; remove
vial HGMS

(14) Contain Significant Or-
ganic Content

> 1% by vol.; use
asphalting/evaporation
or solvent extraction

(15) Bulk of Solids is Calcium-
Based

- Use pozzolanic cementa-
tion

(16) Solids Containing High
Fraction of Silicic
Material

- Use modified silicate
fixation

(17) All Others

Note: Degree of segregation will depend on volume and nature of wastes generated in the
area, the economics of various treatment and disposal options, public and regula-
tory pressures, as well as other factors.

FIGURE 1. Waste Categories That Might Be Kept
Segregated For Wastes Disposed Of
In The Municipal Sector

treatment technology in conjunction with
the basic disposal options available for
the residuals as compared with the disposal
options for the original raw waste. As
indicated in Figure 2, there may be signi-
ficant cost savings associated with some
treatment systems if the residuals going
to a secure (chemical) landfill can be sig-
nificantly reduced or eliminated. Not shown
in Figure 2 is the element of waste trans-
portation which should also be factored in.
At present, chemical landfills are few in
number and often receive hazardous wastes
that have been transported hundreds of
miles. The costs of such transport
(roughly 10¢/kkg/mi for tank trucks) can

obviously be significant. Figure 3 gives
two examples where transportation costs
are considered; the "treatment" in each
example is encapsulation in asphalt with
simultaneous evaporation of the water.
We have assumed in these two examples that
the encapsulated waste could legally be dis-
posed of in a nearby sanitary landfill.
Where a range of daily costs is shown, this
reflects the indicated range of costs for
secure landfill disposal which results
primarily from the annual capacity of the
landfill. The range shown in Figures 2
and 3 ($75-570/kkg) is associated with
landfills having an annual capacity of
50,000 m³/yr ($75/kkg) down to 1,000 m³/yr

~$75–570/KKG

Chemical Landfill

Leachate

Mixed
Hazardous
Wastes

~ $10/KKg

$20–300/KKg

Solids

Treatment
System(s)

(including
detoxification)

Sanitary Landfill

Liquids

Recovered Material ?

Construction Fill

P.O.T.W.

Sewer

$ (?)
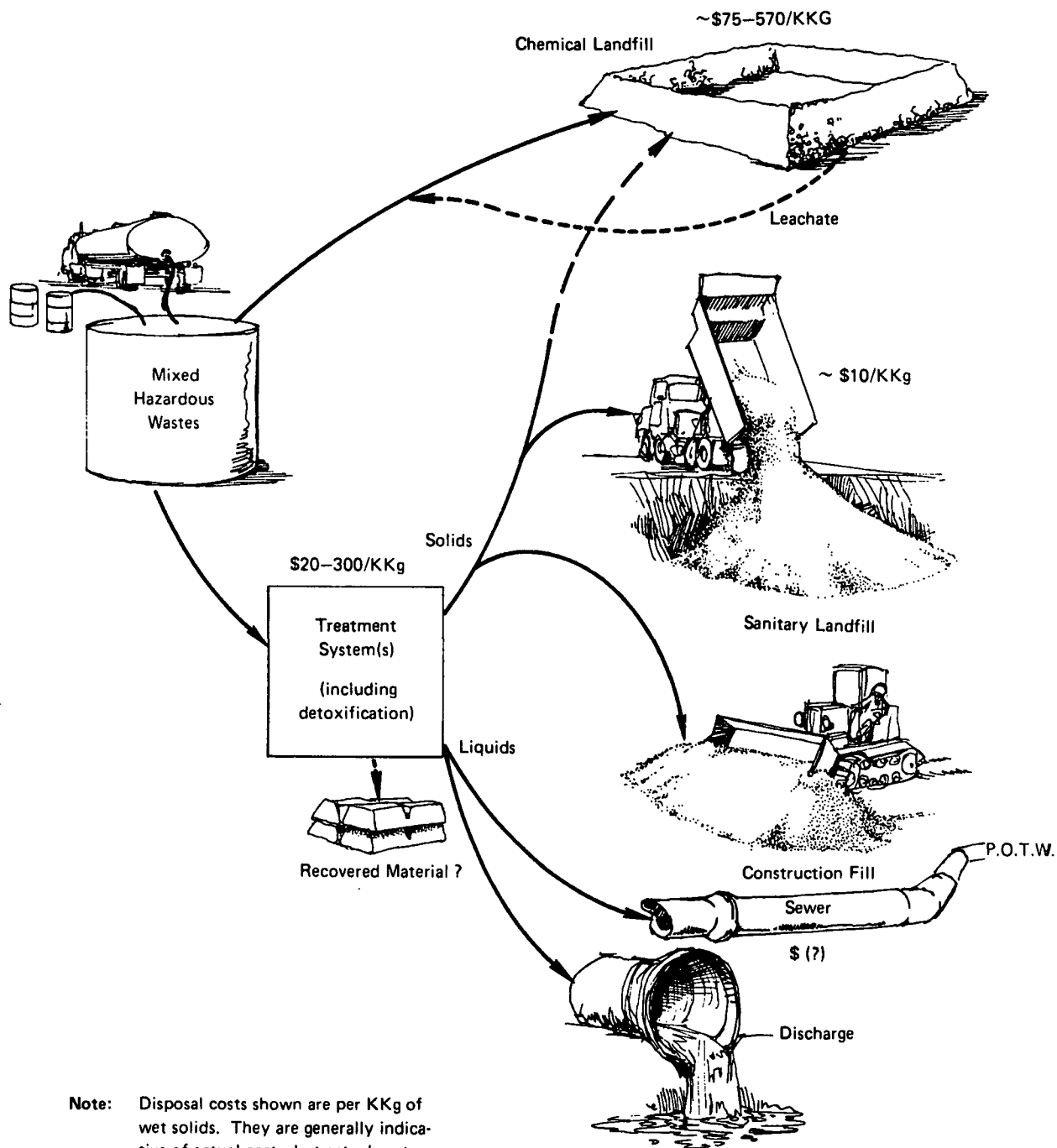
Discharge

Note: Disposal costs shown are per KKg of
wet solids. They are generally indica-
tive of actual costs, but actual costs
will vary significantly in some
situations.

Figure 2. Basic Disposal Options for Hazardous Inorganic Wastes Discharged to the Municipal Sector

($570/kkg).

The program of study being undertaken

by Arthur D. Little, Inc. and Versar is in
three phases. Phase I, completed in
January 1979, included a literature search

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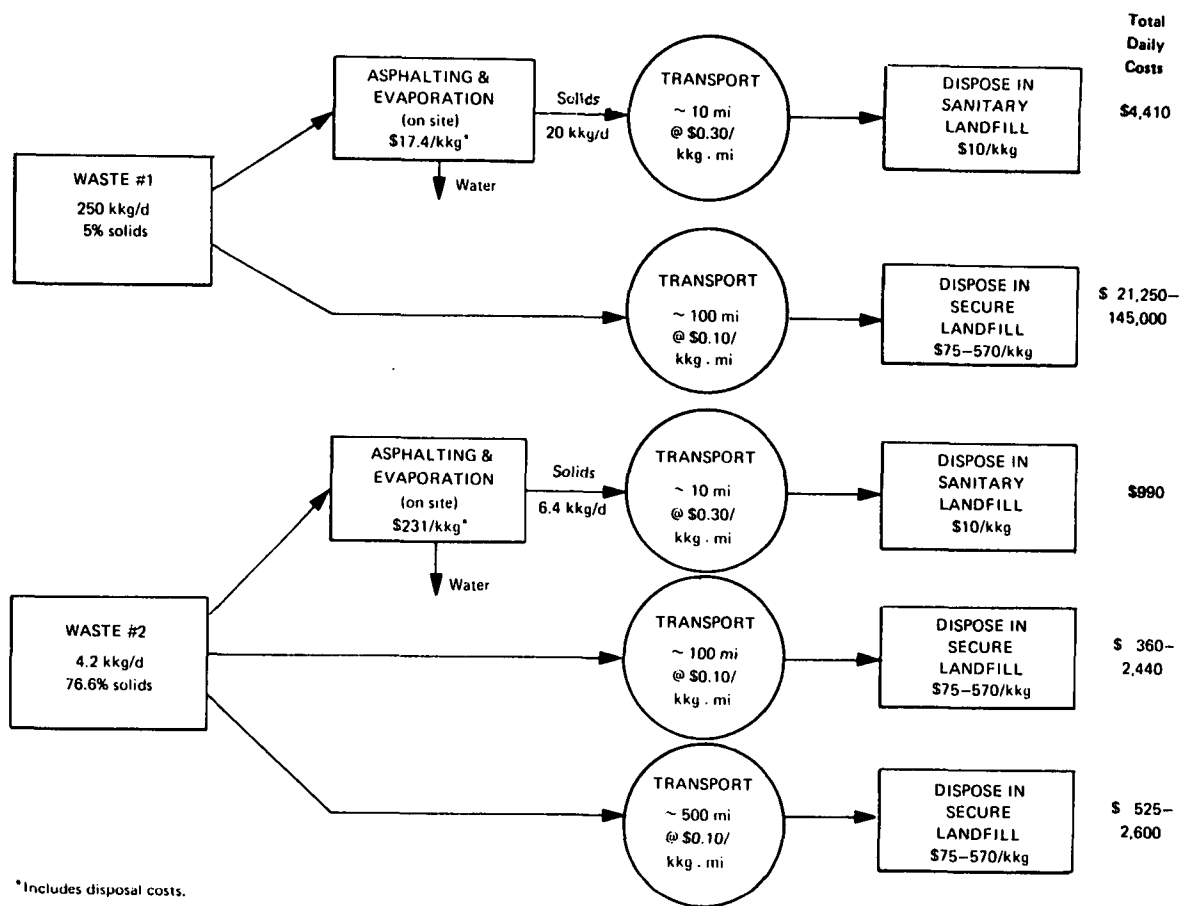
Figure 3. Asphalting/Evaporation vs. Secure Landfill Costs
Two Examples

and data acquisition program for an initial selection of waste streams and compatible treatment technologies. Phase II, completed in December 1979, included a more extensive analysis of the treatment technologies of interest and the eventual selection of three processes for future testing and/or demonstration. Phase III, to be conducted in 1980, will consist of laboratory and pilot-scale tests on the three selected processes. Results of these tests should be available late in 1980. The information below provides some details from the studies conducted in Phase I and II, and a brief description of the processes to be tested in Phase III.

PHASE I STUDIES

The results of three previous studies (Arthur D. Little, Inc.,[1] Versar, Inc.[2,3]) formed the basis for a significant portion of the Phase I review. This was supplemented by additional literature search efforts, contacts with several waste generators, and discussions with individuals knowledgeable in the area of hazardous waste treatment.

A total of 21 unit processes were eventually identified as being applicable to the treatment of inorganic hazardous wastes (Table 1). The unit processes are separated into three groups:

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A. Unit processes for the treatment
   of sludges;
B. Unit processes for the dewatering
   of sludges; and
C. Unit processes for the treatment of
   liquid wastes.

It is recognized that a complete treat-
ment system, consisting perhaps of several
unit operations, may be necessary for some
waste streams. A schematic diagram of
several generalized treatment process path-
ways (incorporating the unit operations of
Table 1) is shown in Figure 4.

TABLE 1. Summary List of Potentially
Applicable Unit Treatment Processes

Process	Category (see text)
A. Unit Processes for the Treatment of Sludges	
1. Fixation/ Encapsulation	III-IV
2. Asphalting/ Evaporation	IV
3. Calcination	IV
4. Fusion	III
5. High Gradient Magnetic Separation	III
6. Distillation	V
7. Dissolution	III
B. Unit Processes for Dewatering Sludges	
8. Filtration	V
9. Sedimentation	V
10. Centrifugation	V
11. Evaporation	IV-V
12. Vapor Compression Evaporation	III
13. Solvent Extraction	III
14. Ultrasonic Dewatering	II
C. Unit Processes for the Treatment of Liquid Wastes	
15. Precipitation	V
16. Neutralization	V
17. Flocculation	V
18. Adsorption	IV
19. Reverse Osmosis	IV
20. Ion Exchange	IV
21. Oxidation (of cyanide)	IV

Table 1 also identifies a process
"category" for each unit process according
to the following scheme:

No.	Category Description
II	Process might work in 5-10 years, but need research effort first.
III	Process appears to be useful for hazardous wastes, but needs developmental work.
IV	Process is developed for some applications but is not commonly used for hazardous wastes.
V	Process will be common to most industrial waste processors.

The assignment of a high category number
(IV or V) thus implies a relatively high
state of development for the process and a
moderate to high degree of usage for waste-
water treatment and/or other applications.
It cannot be taken to imply that the pro-
cess has been "demonstrated" (especially
for hazardous waste treatment) since this
term usually implies satisfactory applica-
bility to specific waste streams.

PHASE II STUDIES

The Phase II studies were aimed at
narrowing down the candidate list of treat-
ment processes with the intent to even-
tually select four for in-depth study.
Simultaneously we engaged in a search and
study program for waste streams in the
municipal sector that would be of particu-
lar interest to this program.

To assist us in the first item, the
screening of treatment processes, we
initially selected eleven surrogate waste
streams for study (Table 2). Nine of these
waste streams were inorganic hazardous
wastes generated by various segments of
the inorganic chemicals industry; these
waste streams had been previously investi-
gated by Versar.[3] A mixed metal hydroxide
sludge and landfill leachate (from sites
containing industrial wastes) were con-
sidered in addition. A twelfth waste
stream consisting of mixed (acidic) plating
wastes was subsequently added to this list.
Special studies on selected treatment
processes (e.g., alternative dewatering
and fixation processes) were also required
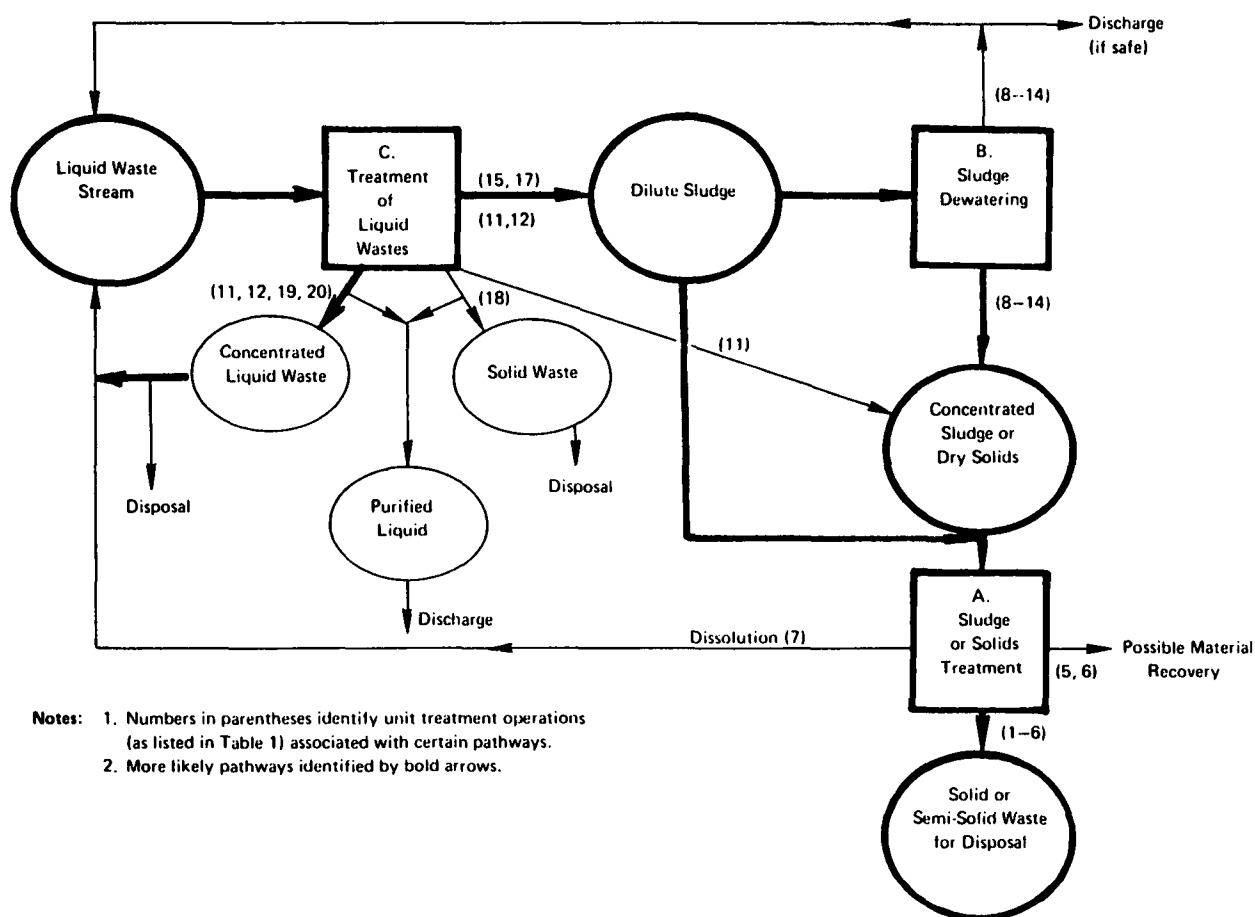
Figure 4. Schematic Diagram of Treatment Process Pathways for Inorganic Hazardous Wastes

Inside figure:

Discharge (if safe)

Liquid Waste Stream

C. Treatment of Liquid Wastes

(15, 17)
(11,12)

Dilute Sludge

B. Sludge Dewatering

(8--14)

(8--14)

(11, 12, 19, 20)

(18)

(11)

Concentrated Liquid Waste

Solid Waste

Concentrated Sludge or Dry Solids

Disposal

Disposal

Purified Liquid

Discharge

Dissolution (7)

A. Sludge or Solids Treatment

(5, 6)

Possible Material Recovery

(1—6)

Solid or Semi-Solid Waste for Disposal

Notes: 1. Numbers in parentheses identify unit treatment operations (as listed in Table 1) associated with certain pathways.
2. More likely pathways identified by bold arrows.

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to determine their specific applicability to the waste streams in question.

For each of the twelve waste streams being considered, one to three different treatment trains were proposed and evaluated. The treatment trains were designed to be complete treatment processes and, as such, contained between one and nine unit operations (see Table 1) in some defined sequence. The costs (capital and operating) of each treatment train were estimated and the relative merits compared. From this analysis it was shown that a relatively small number of unit operations could be considered as key operations for the treatment of inorganic hazardous wastes. Each key operation was then evaluated with respect to several factors including: (1) applicability to various waste streams (including the ability to handle wastes containing both inorganic

and organic chemicals), (2) effectiveness and technical feasibility, (3) potential for material or energy recovery, (4) capital and operating costs, (5) the need for further research and development (or demonstration) with the process, (6) the level (e.g., lab, bench, pilot) at which future R and D was most needed, (7) the availability of pilot plant equipment and waste streams for use in our Phase III program, (8) the environmental impacts associated with the use of each process, and (9) the need to avoid duplication of effort with other research efforts in this field.

The end result of our evaluation process was the selection of three treatment processes to be tested in Phase III:

(1) Solvent Extraction (B.E.S.T. process developed by Resources Conservation Co. for the treatment

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TABLE 2. Summary List of Waste Streams Considered

Waste Stream	Physical Form	% Solids	Nature of Hazardous Components	Hazardous Components As % of Total Dry Solids	Raw Waste: Typical Generation Rate Dry Basis (KKg/d)	Wet Basis (KKg/d)
1. [4*] Asbestos Separator Wastes, Diaphragm Cell	Sludge	70	Asbestos	12	1.5	2.2
2. [7a*] Solids from Wastewater Treatment, Titanium Dioxide Chloride Process, Rutile Ore	Sludge	25	$Cr(OH)_3$	0.5	27	110
3. [7b*] Solids from Wastewater Treatment, Titanium Dioxide Chloride Process, Ilmenite Ore	Sludge	25	$Cr(OH)_3$	0.09	140	560
4. [8*] Sludges from Wastewater Treatment, Chrome Color and Inorganic Pigment Manufacture	Sludge	77	Various heavy metals (Cr, Pb, Zn, Fe)	44	2.3	16
5. [14*] Chromate Contaminated Wastes, Chromate Manufacture	Muds and Sludges	75	$Cr(OH)_3$, chromate	0.02	150	200
6. [15*] Nickel Waste from Wastewater Treatment, $NiSO_4$ Manufacture	Sludge	50	$Ni(OH)_2$	0.14	0.5	1
7. [17*] Arsenic and Phosphorus Wastes, P_2S_5 Manufacture	Dry Residues and Dust	100	As_2S_3, P, and phosphorus sulfide	9	119	-
8. [18*] $AsCl_3$ Wastes from PCl_3 Manufacture	Dry Residues	100	$AsCl_5$	5	60	-
9. Mixed Metal Hydroxide Sludge from Pretreatment of Metal Finishing and Electroplating Wastewaters	Sludge	5	Heavy metal hydroxides (Cr, Ni, Zn, Fe, Al, Cu, Pb, Cd, Sn, Mn, others)	60	12.5	250
10. Landfill Leachate from Sites Containing Hazardous Industrial Wastes	Aqueous Stream	Very Small	Heavy metals, organics	< 0.1% of total aqueous flow	-	50-200
11. Mixed Industrial and Commercial Hazardous Wastes As Received in Municipal Sector**	Sludge	Dissolved: 6-18 Total: 12-73	Heavy metals, organics	Metals: 0.05 Organics: 8% of raw waste volume	.5-1200	50-2000

* Number in brackets is waste stream number from Versar's "Alternatives Report."

** Characteristics and flow rates listed are those for five class 1 landfills in the Los Angeles area that were recently investigated.

of municipal sludge). This process can operate on a mixed inorganic solids/organics waste stream and separate it into three output streams: aqueous stream, dry inorganic solids, and extracted organics.

(2) High Gradient Magnetic Separation (HGMS). The process can magnetically filter our ferromagnetic and paramagnetic solids (most heavy metals and their salts) from a waste stream that may contain a large amount of nonmagnetic (most presumably nonhazardous) material.

(3) Precipitation and Adsorption. A novel two-stage precipitation process incorporating carbon adsorption for organics removal was selected for the treatment of the acidic mixed plating wastes and leachate.

A fourth process based on simultaneous evaporation and encapsulation in asphalt was also ranked high in the final evaluation process and was studied in some detail. This process was, however, considered inappropriate for further tests in this program for a combination of reasons and thus will not be demonstrated in Phase III.

DESCRIPTION OF PROCESSES TO BE TESTED

Solvent Extraction

A novel process employing solvent extraction was recently developed by Resources Conservation Co. (Renton, Wash.) to remove essentially all of the water and oils from sludges containing both organic and inorganic material. The process, called Basic Extractive Sludge Treatment (B.E.S.T.), converts sludges with .05% to 60% solids to output streams of (1) very dry solids (4-5% moisture), (2) a clear aqueous effluent (will contain soluble inorganic salts) and (3) recovered oils. The process was initially designed for processing municipal sludges although it has been tested on some industrial sludges. The process train includes: (1) mixing the sludge with an aliphatic amine at low temperatures ($\sim$10°C) where the solvent, water and soluble oils form a single liquid phase; (2) removal of solids with a centrifuge followed by solids drying (and solvent recovery); (3) heating the solvent/water/oil mixture (to $\sim$50°C) to force phase separation (aqueous and organic); (4) steam stripping of the aqueous phase for solvent recovery; and (5) distillation of the solvent phase for oil recovery and solvent recycle. The use of heat exchangers minimizes the system's energy requirement, and the overall efficiency can be improved by mechanically dewatering the raw waste to at least 30% solids. The dry solids produced, if hazardous, could be disposed of as is in a secure landfill; the recovered oils could be burned for heat recovery. The aqueous effluent might need further treatment depending on the nature and concentration of soluble inorganics present.

The principal benefits derived from the use of such a process, besides its general applicability to most sludges, are extraction of dry solids free from oils, and the extraction of oils for reuse or heat value. The dry solids, if required, could be encapsulated prior to disposal with any of the common inorganic-chemical techniques. These fixation techniques are generally not operable on oil-containing sludges. The more important questions about this process relate to (1) the degree of treatment effectiveness on mixed hazardous wastes, (2) the complexity of the operation, (3) treatment costs (especially capital costs), and (4) energy requirements.

It is our intent to conduct a variety of tests on this process using a pilot plant owned by the Resources Conservation Co. Tests, using at least two different mixed wastes, will be designed to optimize the process and to answer the questions stated above.

High Gradient Magnetic Separation (HGMS)

HGMS is a relatively new technique for separating ferromagnetic and paramagnetic materials (down to colloidal particle size) from gas or liquid streams, on a large scale and at flow rates over one hundred times faster than the flow rates possible in ordinary filtration, and with lower cost and energy requirements. HGMS uses fine ferromagnetic material containing about 95% void space (felted or woven steel fabric, compressed steel wool, expanded metal, etc.), and magnets capable of generating high-intensity fields (up to 20,000 gauss) in large cavities. The magnetic impurities are collected on the filter by magnetic attraction as the feed stream passes through the unit. When the magnet is turned off, the filter matrix may be washed clean.

HGMS machines may be operated either as a cyclic or continuous operation, and both methods are in commercial use today primarily in the area of ore beneficiation. The principal current application in the United States is the beneficiation (whitening) of clay via the removal of a small magnetic fraction that imparts the unwanted color. Other units are used for iron ore beneficiation and for cleaning impurities out of the recycled cooling water in some power plants. The process has been tested on certain industrial waste waters and, in conjunction with the addition of magnetic seed material, on municipal waste waters. The process is being studied at present for coal desulfurization; a very large fraction of the pyritic sulfur can be removed from pulverized or liquified coal. There are no current applications to hazardous wastes.

A large fraction of the more common heavy metals encountered in hazardous wastes are either ferromagnetic or paramagnetic in the elemental form or in compounds. Included are Fe, Co, Ni, Cr, Cu, Ti, and Cs; not included are Pb, Hg, and Zn. In some instances it may be possible to remove nonmagnetic solids if they are associated in any way with the magnetic

material. Thus this process _may_ be applicable to a hazardous waste containing mixed metal compounds (e.g., No. 9 in Table 2) while it is certainly applicable to wastes whose principal hazardous components are known to be magnetic (e.g., Nos. 2, 3 and 6 in Table 2).

It is our intent to test HGMS on at least two waste streams to determine its applicability to hazardous sludges, one containing both magnetic and nonmagnetic compounds and one containing only magnetic impurities. The overall effectiveness of the process, costs, and energy requirements will be assessed. It should be clear that the end result of using HGMS on such wastes is (1) a nonmagnetic fraction which will presumably be sufficiently free of hazardous components and can be disposed of in a sanitary landfill, and (2) a magnetic fraction of relatively small volume which may be sent to a secure landfill or treated further for material recovery.

Precipitation/Adsorption

A treatment process involving precipitation and carbon adsorption, with subsequent filtration, has been proposed for the treatment of mixed acidic plating wastes that are collected by a hazardous waste hauler in the New England area. Waste from several generators is collected in a common tank prior to transport to a distant secure landfill. We have analyzed several different composites of such wastes and found them to be characterized by very low pH (0.5-3), high dissolved solids ($\sim$8,000 to 20,000 mg/L), high suspended solids ($\sim$2,000 to 10,000 mg/L), relatively low organic content ($\sim$100 to 500 mg/L oil and grease), and varying concentrations of a variety of metals (Fe, Al, Na, B, Cu, Pb, Sn, Zn, Cr and Ni). Anion analyses showed very high concentrations of Cl^-, $SO_4^=$, NO_3^-, F^-, and $PO_4^=$. Phenols and dichlorobenzenes accounted for about one half of the freon-extractable organics in one sample; the remainder was mostly hydrocarbons with smaller amounts of low molecular weight alkylated polynuclear aromatics, and an alkylbenzene-sulfonamide.

We decided that the primary treatment objectives for such a waste would be neutralization and removal of all hazardous components from the waste to the degree that the treated aqueous waste could be safely discharged to a publicly owned

treatment works (POTW). Neutralization of such a waste will, perforce, result in the precipitation of a large fraction of the heavy metals. The principal question is whether or not precipitation in such a waste can be effective enough given (1) a very high ionic strength which favors the formation of soluble ion pairs, and (2) chelating agents which will also tend to keep some metals in solution. To insure a very high removal efficiency for essentially all heavy metals we selected a two-step, batch precipitation scheme that operates as follows. Calcium hydroxide is used initially to slowly raise the pH while the waste is continuously filtered in a recycle loop, thus taking advantage of the minimum solubility of each metal over the pH range of 0.5 (or 2 for some wastes) to nearly 11. Above pH 8 a sulfide precipitating reagent (e.g., Na_2S) is added to reduce and precipitate any Cr^{+6} present, and to effect a higher degree of removal for the other heavy metals.

The process described above has been tested in our laboratory on a sample of mixed plating wastes. Very high removal efficiencies were achieved for all heavy metals of concern, and the final filtrate was found to have, with one slight exception, lower heavy metal concentrations than the maximums allowed by the EPA for electroplating plants discharging to POTWs. The anions F^- and $PO_4^=$ were also very efficiently removed while $SO_4^=$ was reduced about 90%.

We propose to use powdered activated carbon (on a throw-away basis) for the removal of hazardous organics from the waste. The carbon will be added at both acidic and basic pHs to increase removal efficiencies for various organics that tend to ionize in some pH ranges. The use of powdered carbon, with no subsequent regeneration, avoids the clogging problems (and the requirements for separate containers and associated pumps and piping, etc.) associated with fixed-bed granular carbon filters, and the significant problems often associated with carbon regeneration systems.

It is our intent to carry out additional laboratory tests on this process and then to construct a small pilot unit to use on batches as large as 100 liters. The treatment effectiveness for a number of different waste composites (from the hazardous waste hauler) will be determined. A

modified treatment process may subsequently
be used to treat samples of leachate that
have been contaminated by industrial wastes.

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THE REACTION OF PCB'S WITH SODIUM, OXYGEN, AND POLYETHYLENE GLYCOLS

Louis L. Pytlewski
Kenneth Krevitz
Arthur B. Smith
Edward J. Thorne
Chemistry and Biosciences Lab
Franklin Research Center
Phila., Pa. 19103
Frank J. Iaconianni
Chemistry Department
Drexel University
Phila., Pa. 19104

ABSTRACT

PCB's, as well as representative halogenated pesticides, were found to be rapidly and completely decomposed by the use of molten sodium metal dispersed in polyethylene glycols. The reaction was found to be exothermic and self-sustaining with the formation of NaCl, H_2, and polyhydroxylated biphenyls (in the case of PCB's) and other phenolic compounds. The reaction requires the presence of sodium and oxygen with the subsequent formation of a sizeable number of free radicals. A superoxide type of free radical was identified by the use of Electron Spin Resonance Spectroscopy and it is felt that dechlorination occurs by the reaction of a PCB molecule with a novel sodium-glycolate-superoxide radical. A reactive sodium-glycolate-oxygen solution can be made up beforehand, stored, and used effectively.

The experimental conditions are simple, open, and inexpensive. The reagents used are commonly known and available in commercial quantities. Cost estimates have been made for PCB's decomposition on a large scale and range between 10 to 32¢ per pound, without taking into account the salability of the reaction products.

INTRODUCTION

The enormous variety and amounts of toxic halogenated organic materials which have pervaded our environment during the past fifty years have left us with a major, crucial problem of disposal. Such a problem is very clearly delineated in a recent USEPA publication, "State-of-the-Art Report: Pesticide Disposal Research"[6].

To date, it appears that there are basically two methods used for large scale disposal of toxic materials such as PCB's: storage and incineration. When one realizes the enormous variety of toxic compounds that have been made and how many millions of pounds of these materials have been manufactured[6], it is impossible to believe that such methods of disposal are solving or ever will solve any environmental disposal problems. Incineration is not only extremely energy intensive, and becoming increasingly so each day, but the effluents are very corrosive and costly to remove. Chemical processes such as chlorolysis, catalytic dehydrochlorination, molten salt reactions, ozone reactions, alkali metal reduction in extremely dry "solvated electron" solvents all present entirely too many problems before and after reaction: severe limitations exist as to breadth of reactivity, expensive reagents, complex apparatus, energy intensiveness, complete absence of usable reaction products, extremely inert atmospheres, extensive temperature controls, etc. Furthermore, no present chemical methods have even the remotest chance of directly interfacing with an existing environmental pollution problem.

Our research was addressed to the well-known extreme chemical stability of chlorinated materials since these comprise the bulk of the problematic halogenated types. The resistance of the C-Cl bond to chemical attack is well documented in the literature of organic chemistry[3].

There are few published studies regarding chemical decomposition reactions of highly chlorinated materials[2,4]. Most chemical approaches are critically reviewed in reference 6. Chemical decomposition of highly chlorinated aromatic compounds such as PCBs and DDT have been achieved, in some cases only partially, using very strong reducing agents such as BH_4^-, and alkali metals dissolved in very dry, liquid NH_3, amines, HMPA, and more recently[4] the well known sodium-naphthalene reagent. However, such reductions require extremely anhydrous, air-free reaction systems and greatly reduced reaction temperatures ($0^\circ C$ and lower).

OBJECTIVE

The objective was to devise a reaction system which would result in the cleavage of the C-Cl bond. Further, the reaction should be quick, complete, exothermic, and thus self-sustaining; the reaction products should be usable, easily recovered, and also recyclable; the outlook should be good for developing commercial processes using inexpensive chemicals and equipment.

EXPERIMENTAL WORK AND RESULTS

The objectives of this research have already indicated the main thrust of our approach to the accomplishments of this program. We have discovered that molten sodium metal in the appropriate solvent medium can function as a broad based chemical reactant. This reactivity is governed by the primary mode of decomposition of the molecule of interest.

In our laboratories at FRC we had been investigating the use of Phase Transfer Catalysis[5] as a means for decomposing a large variety of very inert, toxic compounds, including PCBs. When it was found that PCBs were insensitive to Phase Transfer processes of several types (such as H^{-1} and BH_4^- transfer into alkane hydrocarbon solutions of PCBs), we decided that it would be in order to conduct a series of experiments whereby extremely reactive reagents would be added to neat and dissolved PCBs. Basically, it was felt that if we could get some type of

reaction "going" with PCBs, no matter how exotic or unorthodox, it would at least give us a "handle" with which to work.

We were able to devise a reaction medium at the start which instantly and completely decomposed large quantities of PCBs. The reaction was carried out in simple laboratory glassware, consisting of a 500 ml three neck round bottom flask equipped with a reflux condenser, a thermometer, and a neck sealed with a rubber septum.

The reacting solution was composed of 200 ml of polyethylene glycol 400 (average molecular weight = 400) [we later found that most glycols functioned as reactive solvents] dried over anhydrous Na_2SO_4 (which could also be present in the reaction mixture) and 2.3 grams of metallic sodium. At room temperature the solid metallic sodium in PEG 400 was unreactive with PCBs. However, when the temperature of the system was raised above the melting point of the metallic sodium ($97.28^\circ C$) and vigorously stirred to give a uniform dispersion, the reaction mixture took on a deep amber color. and the temperature of the system rose in a self-sustaining fashion to about $110^\circ C$. When the last of the liquid droplets of molten sodium on the solution surface disappeared, a 1 ml volume of PCB oil (Inerteen, Westinghouse) was added to the reaction mixture and the temperature of the system further rose to about $180^\circ C$. A gas chromatographic aliquot was taken 30 seconds after the addition of PCBs with the resultant chromatograms showing an approximate 95% decomposition of the PCB oil. The reaction of molten sodium with PEG 400 was accompanied by the evolution of large amounts of H_2 gas.

The reaction solution containing a small amount of residual sodium was quenched with methanol and water. Water soluble Cl^- was present and detected using a dilute HNO_3, silver nitrate solution. Cyclohexane was used to extract the organic components. Infrared and NMR spectra indicated that the PCB oil was converted to phenolic compounds (polyhydroxylated biphenyls and hydroxybenzenes). These compounds were also determined to be in the water layer as indicated by the classical $FeCl_3$-phenols qualitative tests. We also observed the precipitation of a white solid from the NaPEG 400-PCB system whose x-ray diffraction pattern matched that of NaCl.

Subsequent NaPEG 400 reactions were

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conducted using the following compounds in place of PCBs; hexachlorocyclohexane, hexachlorobenzene, tri- and tetrachlorobenzenes, pentachlorophenol, DDT, kepone, and chloroethylethylsulfide (a mustard gas simulant). Essentially all of these compounds were dechlorinated rapidly and completely--with the formation of NaCl and oxygenated products including Na_2S and ethanol in the case of chloroethylethylsulfide.

Importantly, we have determined that dechlorination did not occur using sodium treated under the following experimental conditions:

> a) in non-polar. low volatility liquids such as Nujol
> b) in glycolic solvents where both terminal hydroxyl groups are replaced with alkoxy groups.
> c) in glycols, including polyethylene glycols, in the absence of air (oxygen).

The melting of sodium in polyethylene glycol 400 was done in an oxygen free environment and it resulted in the formation of a clear solution (a very slight yellow tinge) with the evolution of hydrogen. When air was allowed into this system a vigorous reaction occurred with the formation of the expected deep red-amber colored solution.

The deeply colored sodium-PEG 400 solution was found to have a broad, intense ultraviolet absorption band centered at 250 nm, and produced a single, strong ESR absorption band located at 3391 gauss with a very narrow band width of 7 gauss. Dechlorination of PCBs occurred using this solution at elevated temperatures; measurably slow at $40^{\circ}C$ and too fast to collect rate data at $65^{\circ}C$. However, when these rate experiments were repeated under a dry N_2 atmosphere dechlorination did not occur.

In the presence of air (oxygen) molten sodium reacted with all glycolic solvents to produce deep amber colored solutions, excepting those having two terminal alkoxy groups-- e.g., diethylene glycol dimethyl ether was inert.

Furthermore, analysis of the reaction mixture (after treatment with methanol to decompose any small amount of residual sodium) by mass spectrometry in the chemical ionization negative ion mode showed the complete absence of chlorinated organic material.

DISCUSSION

Two ingredients are essential for dechlorination in polyethylene glycols-- sodium and oxygen. Oxygen is necessary for the formation of the free radical-containing amber colored NaPEG 400 solution, and also for its reaction with PCBs. The ESR absorption band of the NaPEG 400 solution is extremely narrow and this eliminates radicals of the types $\cdot OH$, $\cdot OR$, $Na\cdot$, and solvated electrons (as in Na-liquid NH_3 solutions. The ESR spectrum does match that observed for $O_2\cdot$, the superoxide ion, also written as O_2^-. However, even though the NaPEG 400 solution may contain the highly reactive O_2^- radical, this is not the principal reactive species for dechlorination of PCBs because a continuous supply of oxygen is required for this reaction.

It is well known in the literature of organic chemistry that ethers are readily susceptible to insertion reactions with O_2 to form explosive hydroperoxides[3]:
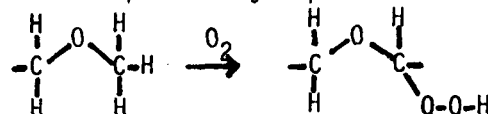
PEG 400 can also be classified as a polymeric ether, whose average molecular formula is $H-[-O-CH_2CH_2-]_n-O-H$, containing eight ether linkages. It is tempting to propose hydroperoxide groups at the carbon-ether linkages in PEG 400 but reaction does not readily occur with polyethylene glycol alone. This brings us to the importance of sodium in the reaction. It is necessary to propose that rapid oxygen uptake can occur at polyethylene glycol ether linkages only by insertion between sodium-carbon bonds. There is precedence for this type of bond and it has been described as occurring in reactions of sodium with high molecular weight glycols[1]. The initial reaction of sodium with PEG 400 produces a sodium glycolate and H_2. This reaction can be written as:
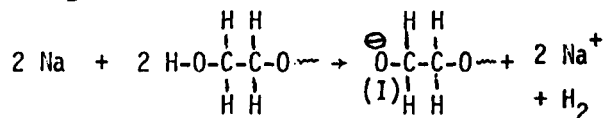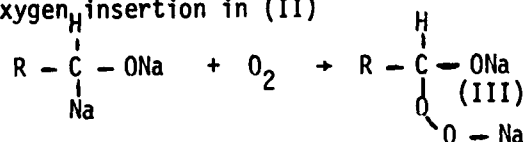

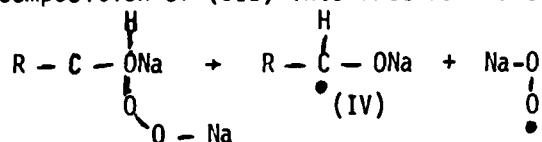The proposed mechanism for a PCBs reaction using (I) is as follows:

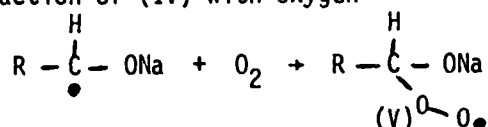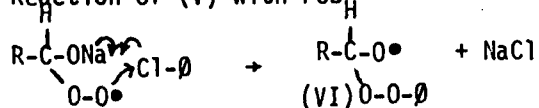A. Disproportionation of (I) - equilibrium system

B. Oxygen insertion in (II)
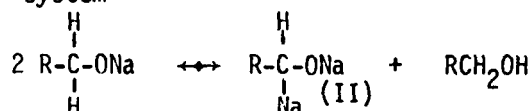
$$R - \underset{\underset{Na}{|}}{\overset{\overset{H}{|}}{C}} - ONa \;+\; O_2 \;\rightarrow\; R - \underset{\underset{O}{\overset{|}{}}\,\diagdown O - Na}{\overset{\overset{H}{|}}{C}} - ONa \quad (III)$$

C. Decomposition of (III) into free radicals

$$R - \underset{\underset{O}{\overset{|}{}}\,\diagdown O - Na}{\overset{\overset{H}{|}}{C}} - ONa \;\rightarrow\; R - \underset{\bullet}{\overset{\overset{H}{|}}{C}} - ONa \;+\; \underset{\overset{|}{O}\,\bullet}{Na - O} \quad (IV)$$

D. Reaction of (IV) with oxygen

$$R - \underset{\bullet}{\overset{\overset{H}{|}}{C}} - ONa \;+\; O_2 \;\rightarrow\; R - \underset{\diagdown O \bullet}{\overset{\overset{H}{|}}{C}} - ONa \quad (V)$$

E. Reaction of (V) with PCB

$$R - \underset{\diagdown O - O\bullet}{\overset{\overset{H}{|}}{C}} - ONa \underset{Cl-\emptyset}{\curvearrowright} \;\rightarrow\; R - \underset{O-O-\emptyset}{\overset{\overset{H}{|}}{C}} - O\bullet \;+\; NaCl \quad (VI)$$

(NOTE: Formation of NaCl is principal driving force for the overall reaction)

F. Reaction of (VI) with more sodium glycolate

$$R - \underset{\diagdown O-O-\emptyset}{\overset{\overset{H}{|}}{C}} - O\bullet \;+\; R - \underset{\underset{H}{|}}{\overset{\overset{H}{|}}{C}} - ONa \;\rightarrow\; R - \underset{O-O-\emptyset}{\overset{\overset{H}{|}}{C}} - ONa \;+\; R - \underset{\bullet}{\overset{\overset{H}{|}}{C}} - O \quad (VII)$$
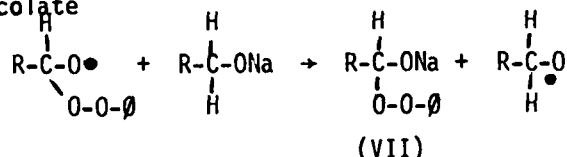
G. Decomposition of (VII)

$$\left(R - \underset{O-O-\emptyset}{\overset{\overset{H}{|}}{C}} - ONa \right) \;\rightarrow\; R - C \overset{\diagup ONa}{\diagdown_O} \;+\; OH-\emptyset$$
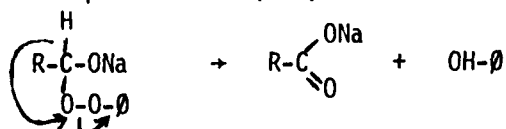
One can see that there are a variety of free radicals generated in this process. It is especially noteworthy that there are two steps that require molecular O_2: the first (B above) involves an insertion of O_2 between a Na-C bond by the disproportionation of the initial sodium glycolate product; the second (D above) results in the formation of a sodium glycolate superoxide complex radical. The second oxygen reaction is the one which is crucial for dechlorination to occur since the first reaction results only in the formation of a stable superoxide ion.

Currently, intensive kinetics studies are being conducted in order to further substantiate the reaction mechanism.

THE PRACTICALITY OF THE PROCESS

The Na-PEG process was submitted to our engineering group for a preliminary cost evaluation relative to chemical destruction of neat PCBs on a commercial scale. Working with the necessary assumptions, the uppermost of which were: 1) construction of a complete disposal facility; 2) Na metal currently selling for 41¢/lb; and 3) PEG 400 selling for 38¢/lb; they arrived at a cost of decomposition figure of about 32¢/lb of PCBs. Taking into account the recent wide fluctuation in the price of metallic sodium, reaching a minimum of about 21¢/lb, and the probable reduction in the cost of PEG 400 when used in very large quantities, it was estimated that the low side of the cost could easily reach 10¢/lb of PCBs. Furthermore, the recovery of products such as hydrogen gas, and the potential usefulness of polyhydroxylated biphenyls (polymers, antioxidants, novel chromatography column stationary phases, and solvents for very high temperature reactions) would certainly help to guarantee a lower cost figure (possibly making the whole process profitable).

Polyhydroxylated biphenyls have been synthesized containing as many as eight -OH groups. The melting points of these compounds are all above 300°C. Tri- and tetrahydroxybiphenyls are used as antioxidants in foods. However, current methods of synthesis are extremely expensive. Our process should yield useful commodities by the production of large quantities of polyhydroxylated biphenyls.

Of course the polyfunctionality of these compounds immediately suggests their use in the preparation of new classes of polymers, assuming that the polyfunctionality is not too high to preclude formation of polymeric structures with useful physical properties. The high melting points of the monomers would point toward the production of polymeric materials of very high thermal stability. There has always been a broad-based need for inexpensive polymers of these types. Condensation polymerization would produce highly crosslinked polymers either by the splitting out of H_2O from the monomer itself or by classical reactions with formaldehyde, terephthalic acid, ethylene diamine, etc. The crosslinking should also beneficially enhance the chemical and physical characteristics of the polymeric materials.

The evolution of hydrogen gas from any chemical process requires that commonsense safety measures be exercised in the complete avoidance of open flame, electrical sparking, and the use of electric heating elements. The melting point of sodium metal (97.28°C) permitted the use of steam as a means for initiation of the reaction. On a large scale the hydrogen gas can be drawn off and collected. As a valuable source of energy, it can contribute to the practicality of the process in several ways.

Also, with scale-up, large quantities of NaCl will be produced. Direct disposal of NaCl does not pose any special problems. It is within the realm of possibility that the recovered hydrogen gas could be used as a source of energy to melt the NaCl, and using electrolysis techniques reproduce sodium metal and chlorine gas. This would result in a recycling for the metallic sodium. The cost of this particular route would have to be determined.

CONCLUSION

The objectives of this research are clearly associated with a chemical process which converts toxic chemical products and wastes into useable materials, completely free of the need for external energy sources. The Na-PEG reaction is not only potentially applicable to conversion of all types of halogenated compounds to non-halogenated materials, but should be equally effective in reacting with any environmentally toxic compound which is capable of hydrolysis, such as the thiophosphoryl pesticides.

To date we know that the reaction proceeds by a complex free radical mechanism requiring oxygen for the activation of a sodium glycolate molecule and, most importantly, for dechlorination it is necessary for the production of a highly reactive complex glycolate-superoxide free radical.

A reactive sodium glycolate-free radical solution can be made up beforehand, stored for long periods of time, and made effective for dehalogenation, when needed, by the application of a little heat.

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EMERGING TECHNOLOGIES FOR THE DESTRUCTION OF HAZARDOUS WASTES
MOLTEN SALT COMBUSTION

Barbara H. Edwards and John N. Paullin
Ebon Research Systems
Washington, D. C. 20001

ABSTRACT

Ebon Research Systems is investigating new technologies for disposal of hazardous wastes. These methods are not state-of-the-art but involve new technologies or a novel variation of an established technology. Some of the processes that have been studied are: fluidized bed combustion, molten sodium combustion, high energy electron bombardment, ultraviolet radiation with hydrogen, molten salt combustion, and various combinations of ozonation, chlorinolysis, and ultraviolet radiation. Molten salt combustion is discussed in detail. Materials are incinerated, in the presence of oxygen, beneath or on the surface of a pool of molten salts. Alkali salts such as a mixture of sodium carbonate and sodium sulfate are usually used, but the salt in the melt can be varied to suit the properties of the waste. The operation of bench-scale and pilot-plant combustors is discussed. Pesticides, chemical warfare agents, PCBs, explosives, and propellants are some of the hazardous compounds which have been almost completely combusted using molten salts. Both high levels of particulates and undesirable emissions from organophosphorous and arsenical compounds cause problems in the process.

INTRODUCTION

The quantity of hazardous wastes generated in the United States exceeds the capacity of class 1, secured landfills. There are probably not enough environmentally sound facilities to accept the additional tonnages that are generated now and that will be generated in the future (Kiefer[16]).

Conventional incineration has been a popular alternative to landfills. However, most municipal and industrial incinerators do not reach a high enough temperature to completely destroy some compounds such as halogenated organics (Kiefer[16]).

Ebon Research Systems is investigating new technologies for hazardous waste disposal. These methods are not state-of-the-art but involve a new technique or a novel variation of an established technology. Methodology is analyzed and the degree of destruction assessed. Any associated problems are also noted.

The new technologies will be compared and ranked according to efficacy and cost. A survey of user needs will be the basis for the development of a matrix that will relate treatment techniques to specific pollutant problems.

EMERGING TECHNOLOGIES FOR HAZARDOUS WASTE DISPOSAL

Novel technologies proposed for hazardous waste disposal may not solve every hazardous waste problem. However, it is possible to highlight some of the more promising ones.

Fluidized Bed Combustion

The technique for fluidized bed systems was proposed by C. E. Robinson about a century ago. Catalytic reactions using fluid beds have been used in petroleum refining since the 1920s. Recently, hazardous wastes have been combusted in them.

If a fluid (either a gas or liquid)

flows upward through a bed of solid parti-
cles, the fluid exerts a frictional drag
on the particles with a corresponding pres-
sure drop across the bed. As long as the
force exerted by the fluid is less than
the weight of the bed, the particles will
remain esentially motionless, and the fluid
will flow through interstitial passages.
If the fluid velocity is raised, a point is
reached where the drag force just exactly
equals the bed weight. This is the point
of incipient fluidization. As fluid veloc-
ity is increased, the particles are bouyed
up, exhibit great mobility, and behave like
a fluid. The bed is then a fluidized bed
(Yerushalmi and Cankurt[29]).

A fluidized bed should provide an
ideal environment for thermal oxidation
of most organic waste materials. Waste
is rapidly and thoroughly mixed with the
fluid bed by the boiling-mixing action of
the bed itself. Contained water entering
with the waste rapidly evaporates. Com-
bustible solids and vapors intimately
contact air or oxygen and oxidize in the
presence of the fluidizing medium. Com-
plete combustion of the organic waste
occurs with a minimum of excess oxygen
and temperature because of the turbulent
action (Cheremisinoff et al.[4]).

After the waste is combusted, it
transfers heat back to the bed. Thus,
the process incorporates waste disposal
and energy recovery features. This fea-
ture has caused much recent interest in
fluidized bed technology as it relates to
electric power generation, coal gasifi-
cation and furnaces (Bliss and Williams[1]).
However, only a limited number of haz-
ardous wastes have been combusted.

Nuclear waste was one of the first
hazardous wastes which was treated by
using a fluidized bed. The process has
also been used in the destruction of oil
refinery wastes, carbon black, and spent
pulping liquor (Smithson[22]). More recent
applications of fluidized bed combustion
of hazardous wastes have resulted in the
almost complete destruction of materials
such as old munitions, (Carroll et al.[3]),
spent blasting abrasives containing
organotin (Ticker et al.[24]), an organic
dye water slurry (Nichols et al.[19]),
phenol and methylmethacrylates (Landreth
and Rogers[18]), and chlorinated hydrocar-
bons, (Eggers et al.[7], Kamino[15], Ragland
and Paul[21], Walker[26], Ziegler et al.[35]).

A relatively large number of fluid-
ized bed combustion studies on chlorin-
ated hydrocarbons (mainly polyvinyl
chloride, PVC) have shown that chlorine
can be neutralized by using a substance
such as dolomite for the bed material
(Ragland and Paul[21]). Chlorine neutral-
ization is enhanced if sodium carbonate
is used for the bed material and the
products of combustion are passed through
a static sodium carbonate bed (Ziegler
et al.[36]).

Chemical Decomposition By Molten Sodium

Dr. Lewis Pytlewski and associates
at the Franklin Research Center have
found that molten sodium metal, in the
appropriate solvent medium, can function
as a broad based chemical reactant.

Polyethylene glycol (any one of the
commercially available products with
molecular weight from 400-20,000) was
dried over anyhydrous sodium sulfate.
The dried polyethylene glycol was then
mixed with metallic sodium (97.28°C)
and stirred vigorously. The drying
agent can be present in the mixture.
After the dispersion was uniform, neat
PCB was added. This resulted in a high-
ly exothermic reaction where the temper-
ature of the reaction system quickly
reached 180°C. Gas chromatography
aliquots taken thirty seconds after the
addition of PCBs indicated that 95% of
the PCBs had been completely destroyed.
Further analyses showed that the PCBs
were completely converted to polyhydroxy-
lated biphenyls and that NaCl was formed.
(Pytlewski et al.[29]).

Subsequent tests resulted in the
complete dechlorination of hexachloro-
phene and 1,3,5-trichlorobenzene. The
reaction system is now being used to
study kepone destruction (Pytlewski
et al.[20]).

The investigators estimated that
commercial destruction of PCBs by the
molten sodium process would cost about
71 cents per kilogram in 1979. This
includes the cost of the disposal fac-
ility (Pytlewski et al.[20]).

High Energy Electron Treatment

Destruction of water-dissolved PCBs
and other toxic chemicals by electron

treatment was studied at MIT in water-lipid mixtures ranging from pure water to pure lipid. In pure water, a 10 kilorad dose produced almost complete PCB degradation. As the lipid concentration increased, the effectiveness of the treatment was severely inhibited. In pure hexane, 5 megarads produced 90% degradation. Monuron, a persistent herbicide of the urea type, was almost completely destroyed after treatment with 30 kilorads (Trump et al.[25]).

Dehalogenation With Ultraviolet Radiation in the Presence of Hydrogen

The Atlantic Research Corporation has developed a process for breaking and reducing carbon-halogen bonds in wastes. The compounds are dissolved in methanol and treated with UV radiation and hydrogen without any substantial amount of oxidizing agent. Carbon-halogen bonds are broken, halogen ions are formed, and the compound is reduced (Kitchens[17]).

The dehalogenation mechanisms are operative regardless of the structure of the compound or the presence of other molecular components such as nitrogen, oxygen, sulfur, or metals. The effect of these substituents is seen primarily in the energy of the C-halogen bond and can be compensated for by employing lower or higher UV radiation. The UV radiation ranged from 1800 to 4000A. The shorter wavelengths in the lower range (up to 2537A) are most effective because of the higher absorptivity of halogenated organic compounds at these wavelengths Kitchens[17]).

A high percentage of destruction was reported for kepone, tetrabromophthalic anhydride, and PCBs (Kitchens[17]).

Chlorinolysis

Chlorinolysis is another emerging technology for hazardous waste destruction. In this vapor phase reaction, chlorine is added to compounds such as DDT, agent orange, or PCB under high pressure and low temperature or high temperature and low pressure. A catalyst is not used in the process (SSM[23]).

If the waste consists of only carbon and chlorine atoms, the reaction product is carbon tetrachloride. If the molecule

contains oxygen or hydrogen, carbonyl chloride and hydrogen chloride are also produced (SSM[23]). These byproducts are undesirable and require clean-up before release to the environment. Also, 20 ppm sulfur will poison a chlorinolysis system (Landreth and Rogers[18]). The severe oxidizing and corrosive environment requires special materials for reactor construction (SSM[23]).

A process based on chlorinolysis catalyzed by ultraviolet light has been used to treat hydrazine, monomethyl hydrazine, and unsymmetrical dimethyl hydrazine found in dilute concentrations in waste water. No undesirable products were found in the waste water at the end of the treatment process. However, significant amounts of chlorinated contaminants remained in waste water which was processed by chlorinolysis without UV radiation (Fochtman and Koch[10]).

Ozonation

In an ozonation process developed by Wong et. al.[28]), 60-70% TCDD degradation was obtained in 12 hours. A relatively low dose (0.4 mg/min) was used. When the TCDD solution was ozonated and irradiated with UV light (300-400 nm) simultaneously, a 10-15% increase in the rate of degradation was observed. An increase in ozone dosage to 2.5 mg/min resulted in 40-50% degradation after 40 minutes. The effect of UV light on the reaction with higher ozone levels is not clear.

A procedure for evaluating chemical compounds susceptible to ozone oxidation was developed by Fochtman and Dobbs[9]. Water in a 12-liter baffled cylindridal stirred tank was saturated with ozone. Ability of the ozone to strip the compound and the chemical reaction of the compound with the ozone-saturated water were evaluated. Concentrated extracts of the test solution were analyzed by high performance liquid chromatography and an ultraviolet absorption detector.

Chemical Degradation

A new class of chloroiodides was used to degrade 2,3,7,8,-tetrachlorodibenzoparadioxin (TCDD) without light. The chloroiodides were prepared by treating aqueous solutions of quaternary ammonium salt surfactants with gaseous chlorine in a slight excess of iodine. The water solubility of

the new chloroiodides was increased by using micellar solutions. The micellar solutions were prepared from the same type of surfactants used to make chloroiodides. Depending on the chloroiodide used, degradation of TCDD varied from 71-91% Botre et al.[2]).

A study on the degradation of diazinon by sodium hypochlorite demonstrates some of the hazards that are associated with degradation studies (Dennis et al.[5]). Hypochlorite oxidation degrades diazinon with a common and relatively inexpensive reagent. However, the first step in the degradation forms diazoxon under acidic conditions. This compound has a cholinesterase inhibiting activity 4000 times greater than diazinon. Trichloroacetate and chloroform may also be formed in the degradation sequence.

Molten Salt Combustion

Theoretical Summary--

Various pollutant species, especially hydrocarbon derivatives, react with oxygen at relatively high energies of activation. Conventional methods used for industrial incineration of these wastes require relatively high temperatures. Molten salts can function as catalysts to permit almost complete oxidation at temperatures below those of normal combustion. There are substantial decreases in the unburned hydrocarbon products (Greenberg[12], and Greenberg and Whitaker[13]).

Most non-charged materials are soluble in molten salts. This solubility is probably related to the crystal structure of salts in the molten state. Data from x-rays taken at temperatures above their melting point indicate that molten salts still retain a quasi-lattice structure. The solubility of the inert material (solute) in the molten salt is based on the theory that the solute assumes an electronic charge in the semi-crystalline melt. This charge gives the solute an electrostatic orientation similar to the ionic component of the molten salt. The process of polarizing or orienting the normally neutral species results in a reduction of the energy required to initiate and sustain chemical reactions. Under these conditions, the solute, when exposed to oxygen, will oxidize at temperatures lower than those normally

required for oxidation. Because molten salts dissolve most neutral species and lower their oxidation temperature, molten salt combustion is used to destroy hazardous wastes (Greenberg and Whitaker[13]).

Melts Suitable for the Process--

Molten salts used for the combustion of hazardous wastes should be stable at temperatures required for combustion of the given hazardous substance. A single salt or mixture of salts may be employed. Eutectic mixtures are often used as they provide the greatest efficiency of operation at lower temperatures (Greenberg[12], and Greenberg and Whitaker[13]). In a eutectic mixture, two or more salts are combined in a ratio where the mixture melts at a lower point than do either of the single salts (Findlay[8]).

The types and combinations of salts that can be employed in molten salt combustion allow the process to operate at a large range of temperatures and under varied conditions of oxygen availability.

Active or neutral salts or a mixture of both can be used in molten salt combustion. Neutral salts require an external oxygen source and do not react chemically with the solute (waste) (Greenberg[12]).

Metallic halides with melting points in the 50-600°C range are neutral salts that can be used in molten salt combustion. The eutectic points of various combinations of these salts have been determined, and it is possible to chose from a wide range of salt combinations in order to obtain a temperature that is optimal for the destruction of a given waste. Any metallic halide with a melting point of 600°C can be used by itself. (Greenberg[12]). Alkali carbonates, alone or as a eutectic mixture, are also used as neutral salts (Yosim et al.[30]).

Chemically active oxidizing salts are used to increase the oxygen pressure both at the surface and within the melt. These salts donate nascent oxygen and take in ambient oxygen. An equilibrium pressure which facilitates oxidation is maintained. Typical active salts are the metallic nitrates, nitrites, sulfates, hydroxides, oxides, and chlorates. These are usually used in combinations that give the lowest melting point (Greenberg[12]).

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Oxidizing salt mixtures produce baths with lower melting temperatures than those of neutral salt mixtures. It is possible to further lower the temperature of the melt by the addition of a lithium salt. Lithium sulfate rather than the carbonate is recommended as the sulfate forms a stable monohydrate that does not continuously absorb water (Greenberg[12]).

Combinations of active salts improve the oxygen-releasing properties of the salts. If a nitrate salt is mixed with a nitrite, the nitrate will more readily release its oxygen. While neutral salt baths are normally used at temperatures immediately above their melting points, oxidizing baths are commonly used about 93°C above their melting point in order to facilitate oxygen release. The lower range of the bath temperature is limited only by the melting point of the salt (or mixture of salts). A temperature of 50°C can be achieved if a mixture of 50M% thallium nitrate and 50 M% silver nitrate is used in the molten salt bath (Greenberg[12] and Whitaker[13]).

Oxidizing baths are in a neutral or inert state at temperatures below 93°C, yet they still can be used within the inert range in order to avoid extreme temperature rises which may occur when highly flammable material is added to the melt. Because molten neutral salt baths operate at higher temperatures, the use of an inert oxidizing melt permits operation at temperatures where exothermic reactions are not as likely to cause undesirable explosions (Greenberg[12]).

Active salts can be combined with neutral salts in molten salt combustion of hazardous wastes. Sodium carbonate is used with 1-25 wt% sodium sulfate in partial pyrolysis conditions. In the process, sodium sulfate is regenerated by the following reactions:

$$Na_2SO + 2C \longrightarrow Na_2S + 2CO \quad \text{(endothermic)}$$

$$Na_2S + O \longrightarrow Na_2SO_4 \quad \text{(exothermic)}$$
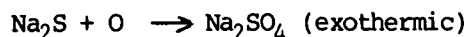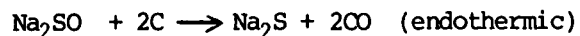
where C represents the carbonaceous portion of the waste (Yosim et al.[31]).

Hazardous wastes have been combusted at Rockwell International Corporation,

Canoga Park, CA., and at Anti-Pollution Systems, Inc. (APS), Peasantville, NJ.

Molten Salt Combustion of Hazardous Wastes at Rockwell International Corporation—

In the Rockwell International process, combustible material and an oxygen source, usually air, are continuously introduced beneath the surface of a molten salt bath. Sodium carbonate containing approximately 10% sodium sulfate is usually used as the melt. The molten salt is maintained at temperatures ranging from 800-1000°C (Yosim et al.[33,34]).

The method of waste addition is designed to force any gas formed during combustion to pass through the melt before it is emitted into the atmosphere. The system is engineered to render any gaseous emission into relatively innocuous substances. Theoretically, the intimate contact of the waste, melt and air causes a high heat transfer to the waste and results in its rapid and complete destruction (Yosim et al.[34]).

The chemical reactions of the waste with molten salt and air depend on the waste composition. Carbon and hydrogen molecules are converted to carbon dioxide and steam. Halogens form corresponding sodium halide salts. Sulfur, arsenic, phosphorous, and silicon form sodium sulfate, sodium arsenate, sodium phosphate, and sodium silicate, respectively. Any iron present (from containers) forms ferric oxide. Small quantities of nitrogen oxides are formed by fixation of nitrogen in the air. Ideally, the off-gas should contain carbon dioxide, steam, nitrogen, and unreacted oxygen. If any particulates or inorganic salts are present in the off-gas, they are removed by a scrubber or by passing through a baghouse (Yosim et al.[34,33]).

Rockwell International Corporation has carried out most of their hazardous waste destruction studies in four combustion facilities. Two of these units are bench-scale combustors with feed rates of 0.25-1 kg/h. They are used for feasibility and optimization studies. A pilot plant unit has a feed rate of 25-100 kg/h. The fourth combustor is portable and is used for disposal of empty pesticide containers (Yosim et al.[34]) Rockwell has also built a

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Department of Energy-Funded coal gas-
ification process development unit that
has a throughput of 1,000 kg/h of coal
(Grantham et al.[11]). Most of the haz-
ardous waste combustion studies were
carried out in the bench-scale molten
salt combustors.

The bench-scale combustor contains
about 5.5 kg of molten salt in a 15-cm
internal diameter, 90-cm high alumina
tube. The tube is placed in a stainless
steel vessel which is in turn contained
in a 20-cm internal diameter, four heat-
ing zone furnace. A 3.7 cm internal di-
ameter alumina feed tube is adjusted so
its tip is immersed approximately 1 cm
above the bottom of the combustor. The
waste air mix is forced in a downward
path through the feed tube, outward at
the bottom, finally circulating upward
through about 14 cm of the molten salt
(Yosim et al.[34]).

One of the bench-scale units has
been modified for the incineration of
very hazardous waste. The combustor is
located in a walk-in, controlled access
hood. All controls are located outside
the door, and gas from the room is scrub-
bed in an activated charcoal absorber
(Yosim et al.33,34).

The unit can accomodate liquids,
solids, and mixtures of liquid and solid
wastes. Methods for feeding hazardous
wastes into the bench-scale combustor,
as well as a description of the other
combustors, are detailed in Yosim
et al.34).

After a combustion test, the off-
gas is passed through a filter to remove
particulates. The particulate-free gas
is then analyzed for nitrous oxides,
carbon monoxide, oxygen, nitrogen, and
unburned hydrocarbons (Yosim et al.34).

Many different kinds of hazardous
wastes have been combusted in the Rock-
well International bench-scale molten
salt unit. Typical liquid wastes combus-
ted were chemical warfare agents, PCBs,
tributyl phosphate, chloroform, trichlor-
oethane, monoethanol amine, malathion,
and 2,4,-D. Solids tested were ion
exchange resins, DDT, and para-arsan-
ilic acid. Chemical warfare agents
mixed with container dunnage, a high
sulfur waste refinery sludge, and

perchloroethylene-containing waste are
examples of waste slurries combusted by
molten salts (Dustin et al.[6], Grantham
et al.[11], Yosim et al.30, 31, 32, 33, 34).

Molten Salt Combustion of Hazardous
Wastes at Anti-Pollution Systems—

Anti-Pollution Systems (APS) has devel-
oped an alternative molten salt process.
The system consists of a box within a
box. The inner box (trough) floats on
a 7.6 cm of salt. The floating inner
trough makes ash removal simple and is
designed to preclude problems when water
is introduced directly into the melt.
Liquids (containing water in any concen-
tration or solids are introduced into
the center box and exposed to a flame.
As the waste combusts, the generated
heat is transferred to the salt bed
beneath the combustion chamber. If the
heat of combustion is sufficiently
large, and enough waste is burned, it is
not necessary to premelt the salt bed.
The generated heat maintains the bottom
portion of the combustion chamber at the
melting point of the salt. The exhaust
gases from combustion are pulled through
a series of baffles and bubbled through
the melt before exiting. This provides
a second incineration for toxic, vol-
atile substances and traps particulates
in the melt (Wilkinson[27], Greenberg[14]).

Suction is supplied by an induced
draft fan which creates a negative pres-
sure on the baffle closest to the exit
side of the system. This causes a rise
in the liquid level with an accompany-
ing drop in the melt level on the exit
side of the baffle. The exhaust gases
impinge on the liquid front created by
the suction. Carbon particulates and
inert materials are removed by a mesh,
stainless steel screen (Wilkinson[27],
Greenberg[14]).

There are currently (1979) three
molten salt units at APS. One is port-
able and can be fueled with propane.
This system has combusted tannery wastes
so that chromium metal could be recover-
ed. The combustor also scrubbed HCl and
raw halogens generated from the combus-
tion of aluminum chlorohydrate (Personal
communication to B. Edwards from J.
Greenberg, July, 1979). In another ap-
plication of the APS process, textile
manufacturing wastes containing acrylic

residue were purified in a melt consisting of the nitrates of potassium and calcium. The APS molten salt combustion process uses a wider range of melts than those employed by Rockwell International (Greenberg and Whitaker[13]).

An Assessment of Molten Salt Combustion for the Destruction of Hazardous Wastes—

A wide range of hazardous substances have been almost completely destroyed by molten salt combustion. If a suitable melt is used, the emission of most gaseous pollutants in significant quantities is eliminated. However, in studies conducted on the destruction of nerve gases at Edgewood Arsenal, intolerable levels of HCl were reported. The possiblity of metal volatility from organometallic metal-based substances during combustion may also be a problem (Dustin et al.[6]).

The emission of particulates presents a problem which requires the use of a trap, filter, or scrubber. These additions add to the cost of the process. Arsenic and phosphorus containing wastes may emit particulates composed of harmful pentoxides and arsenates of these elements. Particulate levels were lower than those from conventional incinerators (Dustin et al.[6]).

Wastes with higher than 20% ash are undesirable since ash levels of this magnitude may destroy melt fluidity. This necessitates frequent melt changes. (Yosim et al.[34]).

In order to prevent excessive corrosion, the Rockwell International combustors are lined with alumina rather than with less expensive steel. Added protection from corrosion comes from the film of sodium aluminate formed during combustion (Yosim et al.[34]). In tests on materials for construction of combustors, it was learned that corrosion in a stainless steel combustor is reduced if the melt is kept in the 750-800°C range. "Exotic coatings" which can reduce corrosion are also being investigated. The alumina combustors that are

employed have a "long life" except when used to combust wastes with a high fluoride content (Personal communication to B. Edwards from Rockwell International, August, 1979).

In the molten salt combustion, water in the waste is converted into steam. If the waste contains a large quantity of water, the efficiency of the Rockwell International process is reduced. In some cases, combustion could be supported by the addition of methanol or some cheaper material (crank case oil), but the process is not considered to be suitable for the disposal of weak acids (Personal communication to B. Edwards from Rockwell International, August, 1979.

Although molten salt combustion is a reliable, efficient process for the destruction of most hazardous wastes at the bench-scale level, little is known about its potential to process large amounts of material over an extended period of time. Estimates have been made for building molten salt combustion demonstration units, but no hard figures are currently available for the cost of operation.

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Holding and Evaporation of Pesticide Wastes

Charles V. Hall - Project Coordinator
Department of Horticulture
Iowa State University

About ten years ago, a new Horticulture Research Center was developed near Ames, Iowa, including all new facilities. Fortunately, a unique facility was designed and constructed for storage of all pesticides and application equipment, weighing and mixing, and with an attached waste disposal pit. All excess wash water and dilute pesticides generated from spraying operations and from the mixing room are discharged into the disposal pit. Details of the total system are illustrated by slides.

Several years earlier, a more simplified system, which included only an excavated pit lined with plastic and filled with soil, was established at the Agronomy Agricultural Engineering Center at Ames. This pit had not provided complete containment and overflow was evident in surrounding areas.

No detailed research had been done to determine the effectiveness of either system as to leakage, chemical buildup, or biological activity.

In 1976, a joint five-year study was initiated between the U.S. Environmental Protection Agency and faculty members from the Department of Agronomy, Agricultural Engineering, Bacteriology, Botany, Energy and Mineral Resources-Research Institute, Entomology and Horticulture to determine the environmental effects of the systems and chemical-biological activity within each. In addition, a series of micro-pits were established to look at similar factors, but on a much more extensive scale and with selected compounds. I have served as coordinator of this research project and as liasion official between Iowa State and the E.P.A.

As of October 31, 1979, we will complete the third year of research and we are programmed for two years of demonstration of the research findings. A research report summarizing the first three years' data will be submitted to E.P.A. for publication as of November, 1979. However, we were informed on October 5 that the project would not be funded in 1980 the final two years.

During the first three years, modifications were developed and incorporated into the systems. These will be included in the guidelines for future users. The intent is to provide suggested guidelines for research and development stations, commercial applicators, farmers, nurserymen, greenhouses, etc., to the extent necessary to provide appropriate safe systems without specific details.

Our results to date can be summarized as follows:

1. The concrete pit, along with pesticide handling systems at the Horticultural Research Center, has not created any environmental problems and has been an effective system for disposal. There has been no overflow leakage and it contains highly active bacterial populations. This pit is 12' wide x 30' long, 3' deep on one end and 4' deep on the other. It is filled to within approximately eight inches from the top with a layer of gravel, a layer of soil, and another layer of gravel. The top is mobile and activated to close by rain. Approximately 36 inches of liquid was evaporated from this pit between May 1 and October 15, 1979.

2. The old plastic lined pit without a cover did not provide containment and would not, as constructed, provide adequate protection of the surrounding environment.

A similar plastic lined pit, with a shed cover, was constructed in 1977. This system is being studied and to date, no recommendations can be made. It appears that there is subsurface leakage, but the extent is unknown.

3. The following two years are scheduled to be devoted to demonstration and further testing of the improved systems as well as container cleanup and disposal.

General Summary:

1. Containment with evaporation of dilute liquid wastes has been a safe method of disposal at Iowa State University.

2. With soil and gravel stratified within the concrete pit, there is biological activity and degradation.

3. Chemical degradation occurs in mixtures of various pesticides.

4. Any such disposal pit should have a protective cover.

5. Pit size can be estimated based on climatological data for the region.

Systems illustrated with slides.
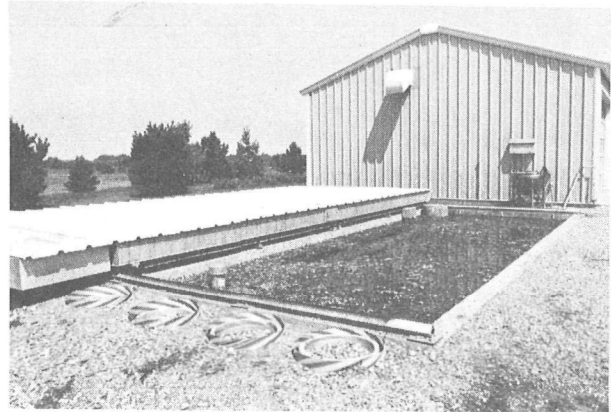
Disposal system at the Horticultural Station.
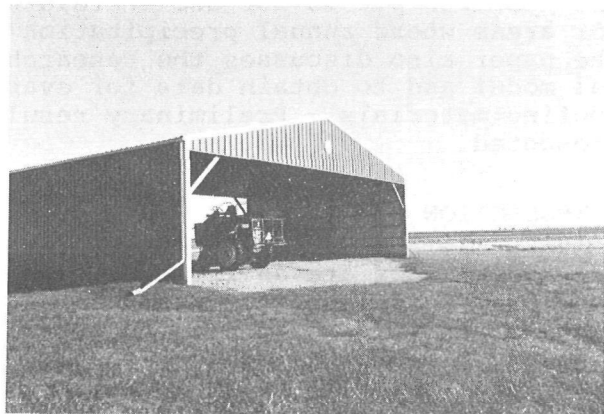
Disposal pit at the Agronomy-Agricultural Engineering Station. This pit is plastic lined.

DESIGN OF EVAPORATIVE PITS FOR WASTE PESTICIDE SOLUTION DISPOSAL

Model Development and Progress

Richard P. Egg and Donald L. Reddell
Agricultural Engineering Department
Texas A&M University
College Station, Texas 77843

ABSTRACT

Commercial aerial applicators of agricultural chemicals generate a dilute chemical waste by flushing the aircraft spray system and washing their aircraft. Traditionally this waste has been dumped on the aircraft wash pad or runway resulting in a pollution threat to surface and ground waters. This paper presents a model for design of evaporative pits for disposal of this waste. The model considers both roofed and unroofed evaporative pits. The unroofed pit is for use in relatively dry areas while the roofed pit is for areas where annual precipitation equals or exceeds annual evaporation. The paper also discusses the research being conducted to test the mathematical model and to obtain data for evaporation rates under various types of roofing materials. Preliminary results of roofing material evaluation are presented.

INTRODUCTION

Pesticides are an integral component of food and fiber production. These pesticides are generally applied by professional applicators, particularly aerial applicators. These applicators generate dilute pesticide wastes from several sources (Avant[1]). Spray plane systems generally hold a residual of 0.02-0.04 m^3 (5-10 gallons) of dilute pesticide solution after the pump starts drawing air. When the type of pesticide is changed, or at the end of the day, the pesticide in the system is dumped, and the system is flushed with water. This process usually requires from 0.04 - 0.11 m^3 (10-30 gal) of water depending on the system. Also, the plane is occasionally washed which uses between 0.04 and 0.08 m^3 (10 and 20 gal) of water per plane. Thus, it can be seen that from 0.02 to 0.23 m^3 (5-60 gal) of waste pesticide solution can be generated per plane per application day.

Disposal of these wastes presents a serious problem to pesticide applicators across the nation. Of the many possible systems for waste disposal available, the evaporative pit appears to be the most practical in terms of cost, safety, and effectiveness. Figure 1 shows an evaporative pit system. With this system, waste pesticides are dumped onto a wash pad and drained into a pit with an impervious liner. The liquid is then allowed to evaporate.

Two types of evaporative pits can be used depending upon the climate of the area. In dry areas, an open top pit is recommended. For areas in which annual precipitation equals or exceeds annual evaporation, a transparent roof is needed to prevent rainfall from entering the pit while allowing maximum solar radiation to penetrate.
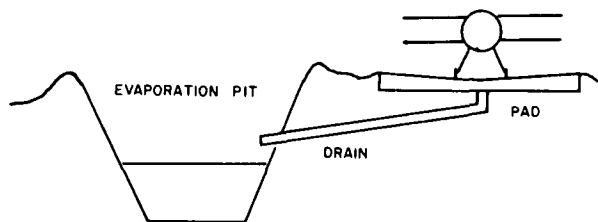
Figure 1. Schematic of typical
evaporation pit

Design of an open evaporative
pit is a relatively simple process.
Sweeten and Price[2] developed design
charts for open evaporative pits on
the Texas High Plains for disposal of
cattle dip solutions at feedlots.
However, very little information is
available on evaporation rates as
affected by transparent roofing mat-
erials.

The Agricultural Engineering
Department at Texas A&M University
is currently conducting research to
develop design parameters for the
design of roofed and unroofed evapo-
rative pits for disposal of the
waste pesticides generated by commer-
cial applicators. Transparent mater-
ials are also being evaluated for
effectiveness as roofing materials
for roofed evaporative pits.

Objectives

The objectives of this paper
are:
1. Present a mathematical model
of roofed and unroofed evapora-
tive pits for waste pesticide
disposal.

2. Discuss the scope and objec-
tives of the current research
project for testing the design
model.

3. Present results of a study
to evaluate the evaporation
rate under various types of
transparent roofing materials.

The mathematical description of
an evaporative pit is complicated.
However, certain assumptions and
approximations were used to simplify
this description resulting in a work-
able design procedure. A simple vol-
ume balance was used to show the
basic operation of the system. The
model was developed for an annual
time period. Daily liquid level
fluctuations in the pond reflecting
daily changes in storage were ig-
nored. The annual change in the
storage of the pit was assumed zero.
Thus, the volume of fluid put into
the pit must equal the volume of
fluid removed. Since the ponds are
lined, the percolation is zero.

Open Pits

For an uncovered evaporative pit,

$$Q_w + Q_p = Q_e , \qquad (1)$$

where Q_w = volume of waste pesticide
put into the pond (m^3), Q_p = volume
of precipitation (m^3), and Q_e = vol-
ume of waste evaporated (m^3).

The volume of waste pesticide is
calculated by

$$Q_w = N_a W D_a , \qquad (2)$$

where N_a = the number of aircraft,
W = the daily volume of waste dis-
charged from each aircraft (m^3/day),
and D_a = the number of operating
days.

The volume of precipitation added
is calculated by

$$Q_p = \frac{q_p A_t D}{(100)(365)} = \frac{q_p A_t D}{36500} , \qquad (3)$$

where q_p = the average annual pre-
cipitation rate (cm/yr), A_t = top
area of pit (m^2), and D = total time
elapsed in period under considera-
tion (days).

The volume of waste evaporated
is calculated by

$$Q_p = \frac{q_e A_{fa} D}{(100)(365)} = \frac{q_e A_{fa} D}{36500} , \quad (4)$$

where q_e = the average annual evaporation rate (cm/yr), A_{fa} = the average surface area of fluid in the pit (m^2), and D = the total elapsed time in period under consideration (days).

Substituting Equations 2, 3, and 4 into Equation 1 yields the following relationship:

$$N_a W D_a + \frac{q_p A_t D}{36500} - \frac{q_e A_{fa} D}{36500} = 0 , \quad (5)$$

This is the basic equation used to design an evaporative pit. For vertical walled pits $A_t = A_{fa}$ and Equation 5 can be rearranged to calcalate the required area of the pit by

$$A_t = \frac{36500 \; N_a W D_a}{(q_e - q_p) \; D} , \quad (6)$$

Equation 7 is only good when $q_e > q_p$. To obtain the proper size vertical walled pit, set D = 365 days.

When designing a pit with sloping sides, $A_{fa} \neq A_t$. Consequently, A_{fa} and A_t must be evaluated using an iterative solution for Equation 5. A_t should be at least 0.6 m above the maximum fluid level to insure the facility can contain a 10-year, 24-hour storm and/or wave action. By assuming the pits are square, A_t can be determined from A_{fa} by

$$A_t = [\sqrt{A_{fa}} + 2 \, H/S]^2 , \quad (7)$$

where H = the height of the pit above A_{fa} (m) and S = the side slope of the pit (rise/run). The area of the pit's base is calculated from

$$A_b = [\sqrt{A_{fa}} - 2 \, d/S]^2 , \quad (8)$$

where A_b = the area of the pit's base (m^2) and d = the depth of the fluid in the pit (m). The fluid depth, d, should be greater than 0.3 m.

Using Equations 5, 7, and 8 and an iterative solution technique, A_t can be obtained for different side slopes. Values of A_{fa} and A_t are substituted into Equation 5 and the volume of fluid on hand at the end of the application season ($D = D_a$) is computed. The first term in Equation 5 is then set equal to zero and D is set equal to $365 - D_a$ to calculate the volume of fluid removed in the non-application season. If this quantity of fluid is less than the volume on hand at the end of the application season, a larger pit should be selected. An iterative process is needed to obtain the proper pit size.

Next, the volume contained below the maximum fluid level A_f is determined from

$$V = (d/3)(A_f + \sqrt{A_f A_b} + A_b) , \quad (9)$$

where V = volume of pit (m^3) below the fluid level. This volume should be greater than or equal to the volume on hand at the end of the application season. Assume that the base of the pit is at a reasonable depth below the maximum fluid level ($d \geq 0.3$ m). If the volume below the fluid level is less than the volume on hand at the end of the application season, select a greater depth and recalculate the volume to determine the proper pit depth.

Roofed Pits

In areas of high precipitation and low evaporation, the above design procedure cannot be used since inflow will be greater than outflow. Therefore, the pit must be covered by a transparent roof to prevent precipitation from entering the pit. The above procedure for designing the open pits can be modified to design roofed evaporation pits by setting $q_p = 0$ and reducing q_e by a factor R to account for the reduction of solar radiation caused by the transparent roof. Preliminary results from field evaporation models indicate that the evaporation reduction for most transparent materials is about 25 percent.

PROJECT OBJECTIVES AND SCOPE

The overall scope of the on-going evaporation project at Texas A&M University is to quantify the evaporation of waste pesticide solutions from evaporative pits, both roofed and unroofed, for climatic conditions that range from high evaporation - low precipitation to low evaporation - high precipitation. From this, guidelines will be developed for designing effective evaporative pits for waste pesticide disposal.

Objectives

Specific objectives of the project are:

1. Develop a model for designing evaporative pits used to dispose of waste pesticide solutions,

2. Field test the recommended design from the model,

3. Evaluate several transparent materials under field conditions for use as roofing material for evaporative pits, and

4. Prepare final guidelines for designing evaporative pit to dispose of waste pesticides from aerial applicators.

Methods

There are essentially three phases to this research. The first phase which has been completed was to evaluate transparent materials under field conditions for their effectiveness as roofing materials. Seven materials were tested as roofs over evaporation pans, and the evaporation rate under each roof was compared with the evaporate rate from an uncovered pan. One of the covered evaporation pans is shown in Figure 2. From the results of this study, two roofing materials were selected for further testing in the second phase of the project.

The second phase of the project is a physical model study to evaluate
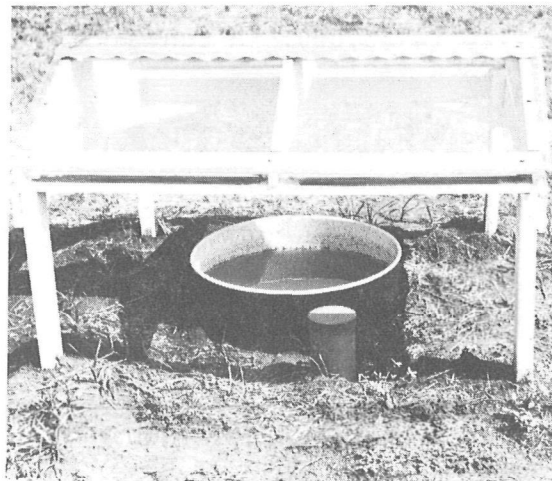
Figure 2. Physical model evaporation pan and roof.

the two most promising transparent roofing materials and to develop data on evaporation under transparent roofs. This phase of the project is currently underway. The same type of evaporation pans as used in the first phase of the project are being used. This phase of the study consists of two treatments. The first treatment consists of four roofing materials, (1) no roof, (2) corrugated steel, (3) corrugated fiberglass, and (4) a polyethylene film. The second treatment consists of three types of fluid, (1) clear water, (2) a pesticide solution, and (3) muddy water only in the "no roof" treatment.

The third phase of the project includes a prototype study at two locations. One location is a high rainfall - low evaporation area (Beaumont, Texas) and the other location is a low rainfall - high evaporation area (Vernon, Texas). Evaporation pits will be constructed at an aerial applicator's facilities in these two areas.

In the Beaumont area, only a covered pit will be constructed since rainfall exceeds evaporation in that area. At Vernon, both a covered and uncovered pit will be constructed. The Vernon facility is currently under construction.

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The estimated cost for the Vernon facility is $5,000. A schematic for the Vernon facility is shown in Figure 3.
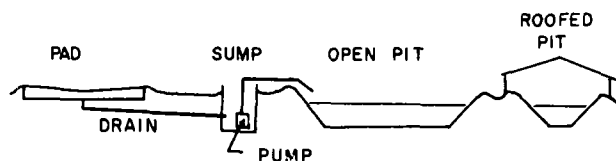

Figure 3. Schematic of Vernon prototype facility.

The evaporation pits will be lined with a reinforced hypalon liner to prevent percolation. Measurements will be made of daily precipitation, fluid level in the pits, and volume of waste added to the pits.

This phase of the project will be used to verify the design model presented in this paper. The evaporation data from the evaporation pans in the physical model study will be compared with the evaporation data from the prototype pits to determine the correlation between the pan data and the full scale pit data.

After developing and verifying the final mathematical model, final guidelines will be developed for designing evaporation pits to dispose of waste pesticides from aerial applicators. Although guidelines will be based on data obtained under climatic conditions in Texas, they will be applicable in other areas of the United States. They could be easily modified to reflect the local needs of individual states.

TRANSPARENT MATERIAL EVALUATION

In the first phase of the project seven transparent materials were evaluated for their effectiveness as roofing materials for evaporative pits. These materials were then used to construct roofs over evaporation pans. Evaporation data were collected from the pans under the different roofing materials and from an uncovered pan. Data were collected from 9 June - 29 August, 1979.

Evaporation data for the different transparent materials is shown in Table 1, along with the approximate cost and life expectancy of the different roofing materials. Overall, the evaporation rate was reduced by about 20 to 30 percent from the uncovered pan for the various materials tested, with little difference among most of the materials. Over the course of the study the evaporation reduction gradually increased for all the roofing materials. This was apparently due to a gradual accumulation of dust on the roofs which tended to decrease the solar radiation transmittance. Although the data presented was taken over a relatively short period of time, it appears that an evaporation reduction of 25 to 30 percent would be valid for use in designing a roofed evaporative pit.

Based on the data presented in Table 1, two materials were selected

TABLE 1. EVAPORATION CHARACTERISTICS OF TRANSPARENT ROOFING MATERIALS

Roof Type	Approximate Cost ($/m^2)	Expected Life (yr)	Average Daily [a] Evaporation (cm)	Evaporation [b] Reduction (%)
No Cover	---	---	0.668	0.0
Flexigard [c]	4.09	10	0.546	18.3
Acrylic	16.47	Indefinite	0.511	23.6
Polycarbonate	6.88	Indefinite	0.498	25.5
Polyethylene Film	0.43	3	0.480	28.1
Flat Fiberglass	4.84	20	0.475	28.9
Corrugated Fiberglass	4.95	20	0.472	29.3
Corrugated Fiberglass (Tedlar Coated)	6.03	20	0.457	31.6

a. Evaporation data is for period 9 June - 29 August, 1979.
b. Percentage evaporation was reduced from the "no cover" evaporation rate.
c. Flexigard is a composite polyester and acrylic film manufactured by 3M Company.

for additional testing in the second phase of the project. The polyethylene film was selected essentially for its low cost. Although it has a life expectancy of only three years, a facility could be roofed for a relatively low initial cost. The facility could be re-roofed several times before the cost would approach that of any of the other more durable materials. Polyethylene film is also widely available from companies selling greenhouse supplies.

The second material selected for further testing was the corrugated fiberglass. This was selected for durability, ease of construction, and availability. It was felt that these two materials would offer aerial applicators a choice between a low cost roof requiring periodic maintenance and a more expensive but durable roof that is essentially maintenance-free. Either type of structure would be simple to construct.

SUMMARY

A mathematical model was developed for designing evaporative pits for disposal of waste pesticide solutions generated by aerial applicators. The model can be used for designing both roofed and unroofed systems. Research being conducted to verify the model and to evaluate transparent materials for use as roofs over evaporative pits was described. Preliminary results indicate that the evaporation rate under a transparent roof is about 25-30 percent less than evaporation from open water.

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DETOXIFICATION OF CAPTAN-TREATED SEED CORN*

Joel R. Coats and Paul A. Dahm
Department of Entomology, Iowa State University
Ames, Iowa 50011

ABSTRACT

The development of a process for removal and degradation of captan from seed corn is presented. An alkaline aqueous solution was utilized to exploit the instability of captan in a basic medium. Addition of detergents improved the efficiency of removal by increasing solubilization of the captan. Optimization of conditions is discussed for various parameters: strength of base, concentration of detergent, time, volume, lasting capacity, agitation methods. The fate of captan in the detreatment bath was investigated.

INTRODUCTION

The disposal of pesticide-treated seed corn has presented a problem for over 25 years. The fungicide captan has been widely used as a seed protectant but has caused difficulties in disposing of leftover seed corn. As the result of overproduction, obsolete hybrids, or decreased viability, two million bushels of seed corn are earmarked for disposal annually. Because of the captan treatment, the leftover corn cannot be fed to livestock nor burned for fuel. Landfill is currently the only legal recourse for its disposal. In an attempt to recover a valuable resource, this project was launched to develop a captan detreatment process for leftover seed corn.

Although captan is not acutely toxic, it has been shown to be mutagenic (Marshall[4] et al. 1976; DeBartoldi[2] et al. 1978), carcinogenic (Bishun[1] et al. 1978), and teratogenic (Martin[5] et al. 1978) in certain organisms.

The instability of captan in an alkaline medium is well established (Wolfe[6] et al. 1976). The present study attempts to exploit that susceptibility to hydrolysis in a basic solution to degrade the chemical and markedly reduce residues on the seed corn. The procedure uses inexpensive reagents and is effective in removing 99.9 percent of the captan on the seed.

MATERIALS AND METHODS

Pioneer Hybrids of Johnston, Iowa, provided: technical captan (92.5%); captan 5001 Seed Protectant Slurry (32% a.i.); treated seed corn. Ortho division of Chevron Chemical Company (Richmond, California) provided: analytical grade captan (99+%); technical grade captan (96%); Orthocide 75W Seed Treater (75%) with rhodamine dye. Standards of 4-cyclohexene-1,2-dicarboximide and 4-cyclohexene-1,2-dicarboxylic acid were purchased from Aldrich (Milwaukee, Wisconsin) and Chem Services (West Chester, Pennsylvania), respectively.

The analytical method used for the detection of high concentrations of captan was modified from the Kittleson[3] (1952) colorimetric method. The procedure required that captan be extracted from the corn (using reagent grade benzene) and the seed be decolorized using a mixture of charcoal, celite, and anhydrous sodium sulfate. The extract and resorcinol were heated in a 135° C oil bath. Acetic acid was added to the residue and, when cool, was read at 425 millimicrons.

For low-level residues a gas-liquid chromatography method was adapted from that of Wolfe[6] et al. (1976) using a Varian 3700 series GLC equipped with a [63]Ni-electron capture detector. The column was 137 cm long with a 4-mm ID and was

packed with 3% SE-30 on 80/100 mesh Supel-coport. The temperatures of operation were: injection port, 170° C; column oven, 160° C; detector, 230° C. The carrier gas, prepurified nitrogen, was utilized at a flow rate of 25 cc/minute. The limit of detection for captan was 15 picograms; for the imide and acid degradation products, it was approximately 50 nanograms.

Extractions used reagent grade benzene for the colorimetric assay and nanograde benzene for the GLC analyses.

Teflon®-coated stirring bars and Lab-line's® Multi-magnestir provided the needed agitation for corn samples (25 g) in beakers containing 50 ml alkaline solution. A rolling technique was developed, using a jar roller to simulate an auger more closely than a magnetic stirring unit might.

All data are means of 6 replicates except where indicated otherwise.

Each detreatment was followed by a 5-minute rinse in 50 ml of clean water.

RESULTS

Base and Base Strength

Three bases, KOH, NaOH, and $NaHCO_3$, were compared for efficiency of captan detreatment at alkaline strengths of 0.1 N and 1 N. A 5-minute 0.1 N wash of 25 g treated seed corn in 50 ml of alkaline solution resulted in low levels of captan remaining after hydroxide wash while the bicarbonate wash removed less of the fungicide (Table 1). The pH of the wash solution dropped only slightly in each case. The 1 N hydroxide baths produced quite low levels while the bicarbonate

again was less efficient and the pH's were again only slightly depreciated (Table 2).

Effect of Time

Preliminary experiments with alkaline washes were carried out for several time intervals: 5, 10, 20, and 30 minutes, in 0.1 NaOH, KOH, and $NaHCO_3$ as well as 1 N $NaHCO_3$. The 5-minute wash yielded residues nearly as low as the other washes.

An alkaline wash using 1 N NaOH for various time intervals also was run. The washes of 1 and 2 minutes gave high results. (3.17, 1.64 ppm) while the differences in the remaining time trials probably were not significant (Table 3).

A wash of 0.5 N NaOH and 0.05% Dreft was tested at different times. A 10-minute wash still was found to provide residues reliably below 1 ppm, while 5-minute and 2-minute washes did not always give acceptable residues (Table 4).

Effect of Detergents

The effect of detergents was determined by adding them to the alkaline bath as well as adding them to a water bath. The 1 N hydroxide bath produced low levels while the water was less efficient. The detergents improved removal/degradation of captan by 4.8- to 15-fold (Table 5).

To find the most efficient wash, further testing was conducted by varying the percentage detergent or the normality of NaOH. The normality of NaOH was held constant at 0.5 N, and the percentage of detergent was varied as shown in Figure 1. Conversely, the concentration of detergent was held constant at 0.05% (Dreft®), and
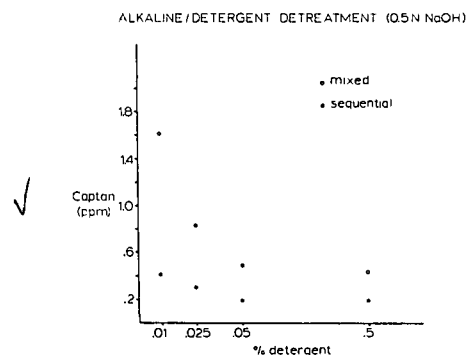

Figure 1. Influence of detergent concentration on the detreating efficiency of a 0.5 N alkaline bath.
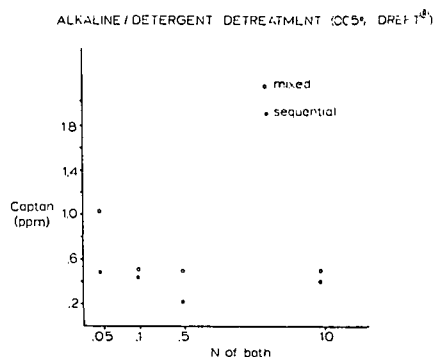

Figure 2. Influence of normality on the detreating efficiency of a 0.05% detergent/ alkaline bath.

the strength of alkalinity was varied as shown in Figure 2. Detergent and NaOH were applied either sequentially (detergent solution first) or as a mixture of 50 ml to 25-g corn samples.

On the basis of these results, a mixture of 0.5 N NaOH and 0.05% Dreft was chosen as the most efficient wash for further study.

Effect of Bath Volume

Bath volume was another variable to be optimized. Comparison of 50-, 100-, 150-, and 200-ml volumes resulted in no significant differences in captan residues left, so the 50-ml volume was considered optimal.

Lasting Capacity of Bath

The lasting capacity of the selected alkaline wash was tested in a scaled-up experiment using a larger sample size and greater volume than usual (Table 6).

Effect of Agitation

A rolling technique was developed, using a jar roller to simulate an auger more closely than the magnetic stirring unit did. Rolling resulted in higher residues than stirring. Variation in rolling speed resulted in improved detreatment as agitation was increased (Table 7).

Detreatment with no agitation for various times and normalities of NaOH resulted in a decrease of residues the longer the agitation took place (Table 8).

Degradation Products in Bath

Captan was degraded rapidly to 4-cyclohexene dicarboximide, which was slowly degraded further (Table 9). The corresponding acid, 4-cyclohexene dicarboxylic acid, may be a relatively stable degradation product. Quantification of this acid was less than satisfactory by our extraction and GLC methods, but it was confirmed to be present in the 24-hour analysis of the bath.

TABLE 1. DETOXIFICATION EFFECT OF 5-MINUTE WASH
WITH 0.1 N SOLUTIONS OF THREE BASES

Base	Captan residue (ppm)	Beginning pH of wash	Final pH of wash
KOH	6.7	12.6	12.5
NaOH	3.8	12.6	12.5
$NaHCO_3$	23.8	8.2	8.0

TABLE 2. DETOXIFICATION EFFECT OF 5-MINUTE WASH
WITH 1 N SOLUTIONS OF THREE BASES

Base	Captan residue (ppm)	Beginning of pH of wash	pH of base after wash
KOH	1.9	13.8	13.7
NaOH	1.8	13.6	13.6
$NaHCO_3$	14.5	8.5	8.6

TABLE 3.   EFFECT OF TIME IN BATH

Captan residues (ppm) after washing 25-g corn samples
with 50 ml 1.0 N NaOH for indicated time.

Time (minutes)	Residue
1	3.17
2	1.64
5	.94
10	.44
15	.94
20	.96

TABLE 4.   EFFECT OF TIME IN BATH

Captan residues (ppm) after stirring 25-g corn samples
with 50 ml of a solution of 0.05% Dreft in 0.5 N NaOH
for indicated time (means of 3 trials).

Time (minutes)	Residue
0.5	2.30
1	1.96
2	.95
5	1.12
10	.56

TABLE 5.   EFFECT OF DETERGENTS OR EMULSIFIERS

Captan residues (ppm) after washing 25-g corn samples
for 10 minutes with 50-ml of solutions.

	in H_2O	in 1 N NaOH
1% Tide	3.6	.34
1% Dreft	2.0	.42
1% Triton X-100	3.6	.24

TABLE 6. LASTING CAPACITY OF BATH

Captan residues (ppm) and pH of alkaline bath after
consecutive 10-minute stirrings of 100 g of corn in
400 ml of a solution of 0.05% Dreft in 0.5 N NaOH
(means of 4 replicates).

Batch	Residue	pH of base after wash
1	.06	13.4
2	.11	13.4
3	.15	13.1
4	.29	13.0
5	.27	12.9
6	.31	12.9
7	.41	12.9
8	.40	12.6
9	1.0	12.5
10	.85	12.2
11	1.9	11.9
12	2.9	11.5

TABLE 7. EFFECT OF ROLLING VS. STIRRING

Captan residues (ppm) after washing 25-g corn samples
for 10 minutes with 50 ml of a solution of 0.05% Dreft
in 0.5 N NaOH by stirring and by rolling.

Method	Residue
Stirring	.15
Rolling (speed)	
5	1.80
7	1.20
10	1.00

TABLE 8. EFFECT OF NO AGITATION

Captan residues (ppm) after washing 25-g corn samples for
various times with 50 ml of 0.5 N NaOH (means for 3
samples).

Time (min)	Captan (ppm)		
	0.5 N	1 N	2 N
15	5.0	1.2	.82
30	.95	.12	.37
60	.31	<.10	<.10

TABLE 9

Time-course study of concentrations (ppm) of captan and
4-cyclohexene dicarboximide, in a detergent alkaline
bath (10-minute detreatment).

Time	Captan	Imide
1 min	7.2	551
2 min	7.2	442
5 min	7.2	340
10 min	7.2	274
30 min	6.9	279
60 min	1.9	162
4 hour	.1	77
24 hour	.1	80

DISCUSSION

This research has determined that
captan can be removed from seed corn and
degrades rapidly in the alkali/detergent
solution. The optimizing of conditions
for the detreatment process indicated that
a strong base (e.g., sodium hydroxide) is
more efficient than sodium bicarbonate at
removal/degradation. Addition of deter-
gent enhanced the detreatment efficacy
considerably. The conditions chosen as
optimal were 0.5 N NaOH with 0.05% laundry
detergent. Agitation improved efficiency
of detreatment as well. The optimal
removal/degradation conditions resulted in
0.1 to 0.2 ppm captan residue remaining on
the corn. It was possible to make up for
reductions in agitation by using longer
times in the detreatment bath. Likewise,

the weaker base was effective when used at
greater strengths.

The primary breakdown product of cap-
tan was 4-cyclohexene-1,2-dicarboximide.
It was slowly degraded further as the
alkaline solution was allowed to stand for
24 hours.

The method is suitable for detoxifica-
tion of captan-treated seed corn; the
disposal of the spent bath should present
no problem from toxic products, although
adjustment to a neutral pH would be
advisable; the materials employed are in-
expensive and easily obtainable. It is
hoped that this research will allow for
the recovery and use of leftover seed
corn or, at least, alleviate the disposal
problem.

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STUDY OF CURRENT LABEL STATEMENTS
ON PESTICIDE DISPOSAL AND STORAGE

Janet Brambley and Dimitrios Kollias
Systems Research Company
Philadelphia, PA   19104

ABSTRACT

As part of an EPA contract to develop data requirements and testing protocols for better evaluation of specific disposal and storage recommendations on labels of pesticide products, to develop new and improved label directions for proper storage and disposal of excess pesticides and pesticide containers, and to identify label statements that will be readily understood by applicators, a survey was undertaken to determine what information and instructions are currently given on pesticide labels for the storage of the pesticide and the disposal of the container and excess pesticide. The information was obtained from pesticide labels, specimen labels or product manuals supplied by pesticide manufacturers. This report provides a summary of storage and container and excess pesticide disposal recommendations for 241 single pesticide formulations and 143 mixed formulations.

INTRODUCTION

The introduction of pesticides into the environment can result in adverse effects on man and other non-target species. When pesticides are used safely, the problems of safe storage and the disposal of empty containers remain. The USEPA under 40-CFR-162 has proposed guidelines for registering pesticides in the United States. The guidelines state the conditions under which specific data would be required to support the registration of a product, specify the standards for acceptable testing, provide references to test protocols in the scientific literature, and describe the format for reporting data. Under CFR Section 162.62-13 environmental chemistry data are required to support pesticide label statements on disposal and storage of registered manufacturing use products and all formulated products. The object of this contract is to generate data requirements and testing protocols for better evaluation of specific disposal and storage recommendations, with particular attention being paid to the development of improved label directions for proper storage and disposal of excess pesticides, controlled release pesticides, and pesticide containers.

METHODS

In January 1979, the authors contacted 98 pesticide manufacturers either by phone or by letter, requesting sample labels from their pesticides or their technical manuals. By 15 March 1979, we had received replies from 58 manufacturers. Of these, 49 manufacturers supplied labels or product or technical manuals for their pesticides. The remaining 9 manufacturers reported that they were no longer manufacturing pesticides or were unable to supply label information at this time.

The pesticides were categorized into seven groups, following the classification developed by Lawless, Ferguson and Meiners in "Guidelines for the Disposal of Small Quantities

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of Unused Pesticides". The seven groups are: I-Inorganic and Metallo-organic Pesticides, II-Phosphorus-containing Pesticides, III-Nitrogen-containing Pesticides, IV-Halogen-containing Pesticides, V-Sulfur-containing Pesticides, VI-Botanical and Microbiological Pesticides, and VII-Organic Pesticides Not Elsewhere Classified. This report analyzes the disposal recommendations for containers and for excess pesticides, and recommendations for storage based on the labels of the responding manufacturers.

RESULTS

Information was obtained for 241 single compounds. These were categorized into the seven groups as follows:

Group I	27
Group II	45
Group III	109
Group IV	37
Group V	2
Group VI	3
Group VII	18

Information was also obtained for 143 mixed formulations, containing two or more pesticides from the same or different groups.

Disposal

Pesticide Containers -

Table 1 is a presentation of the container disposal recommendations by pesticide group. Many of the pesticide labels have recommendations for disposal by more than one method; others have none. Container disposal recommendations were recorded for 236 pesticides. The label recommendations are written as they appear on the labels, as given by the manufacturers.

Burial, usually specifying in a safe place away from water supplies, is the most frequently recommended disposal method, for a total of 174 or 73.7% of the pesticides for which information was offered. It is also the most recommended method for each group of pesticides with the excep-

tion of Group VII pesticides; the most recommended method for this group is destruction. Destruction is the second most frequently recommended method, given for 91 pesticides, 38.6% of the total.

Burning is recommended for 79 pesticides or 33.5%, while incineration is recommended for only 19 or 8.05%. Landfill disposal, either sanitary or specifically for pesticides, is recommended for 43 or 18.2% of the containers. The other destructive methods, disposal with trash, and discarding with no other instructions, account for 8 and 38 recommendations, respectively, or 3.39% and 16.1%. "Discard" frequently includes the instruction "in a safe place".

The non-destructive methods - reconditioning, use for scrap steel, recycling, and returning to the manufacturer - are recommended for 36, 2, 24, and 3 containers respectively, or 15%, 0.85%, 10.2%, and 1.27%. Approved procedures, with no other details given, are recommended for 8 containers, or 3.39%, always as a choice among other methods.

As for the single compounds, the labels for the mixtures may recommend more than one disposal method, or none. The recommended methods for disposal of containers that held mixtures of pesticides and their frequency are as follows: bury 72, destroy 46, recondition 25, burn 24, discard 17, landfill 14, trash 5, incinerate 5, return to manufacturer 4, and recycle 3.

Excess Pesticides -

Figure 1 summarizes the disposal recommendations for excess pesticides. Again, many of the pesticide labels have recommendations for disposal by more than one method and others have none. The recommendations given are based on information given for 98 pesticides. Fewer than half of the pesticide labels give any information for disposal of excess pesticides.

As with containers, burial is the most frequently recommended disposal method; it is recommended

TABLE 1.   PESTICIDE CONTAINER DISPOSAL RECOMMENDATIONS
TAKEN FROM LABELS OR PRODUCT MANUALS

Pesticide Grouping	Burn	Bury	Incinerate	Recondition	Return to Manufacturer	Landfill
I Inorganic and Metalloorganic	9	18	...	3	...	...
II Phosphorus -Containing	18	42	1	7	...	6
III Nitrogen -Containing	36	73	13	14	1	22
IV Halogen -Containing	11	30	4	10	1	11
V Sulfur -Containing	...	2	...	1	...	1
VI Botanical and Microbiological	1	1	...	...	...	1
VII Organic Not Elsewhere Classified	4	8	1	1	1	2
TOTAL	79	174	19	36	3	43

(continued)

TABLE 1. (CONTINUED)

Pesticide Grouping	Discard	Trash	Destroy	Scrap Steel	Approved Procedure	Recycle
I Inorganic and Metalloorganic	10	...	9	...	3	...
II Phosphorus -Containing	9	3	12	1	...	4
III Nitrogen -Containing	6	3	40	1	2	10
IV Halogen -Containing	8	1	18	...	3	9
V Sulfur -Containing	...	...	1	...	...	1
VI Botanical and Microbiological	1	...	2	...	...	...
VII Organic Not Elsewhere Classified	4	1	9	...	...	...
TOTAL	38	8	91	2	8	24

for 87 pesticides, or 88.8% of the pesticides examined giving information. Disposal of excess pesticides in a landfill is recommended for 33 pesticides, or 33.7%. Incineration is recommended for only 3 pesticides or 3.06%, and burning for 1 or 1.02%. Chemical reprocessing and returning to the manufacturer account for 27 and 1 of the recommendations, respectively, or 27.5% and 1.02%. Approved procedures with no other details given, are recommended for 3 pesticides, or 3.06%.

There are only three methods recommended for the disposal of excess pesticide mixtures, burial, chemical reprocessing and landfill disposal. Each method is recommended for 37, 9, and 10 pesticides, respectively, as shown in Figure 2. Only 38 or 26.6% of the labels give any

information for disposal of excess pesticides.

Storage

The storage recommendations and precautions by pesticide group are summarized in Table 2. Storage information was recorded for 194 pesticides. The six most frequently occurring instructions - away from heat, fire and sparks; away from seeds, feeds and foodstuffs; away from seeds, feeds, fertilizers, insecticides and fungicides; above 32°F; cool dry place; and dry - are given 100, 86, 42, 44, 34, and 26 times, respectively.

The numbers of pesticide labels providing temperature requirements or restrictions are shown in Table 3. Twenty different levels were record-
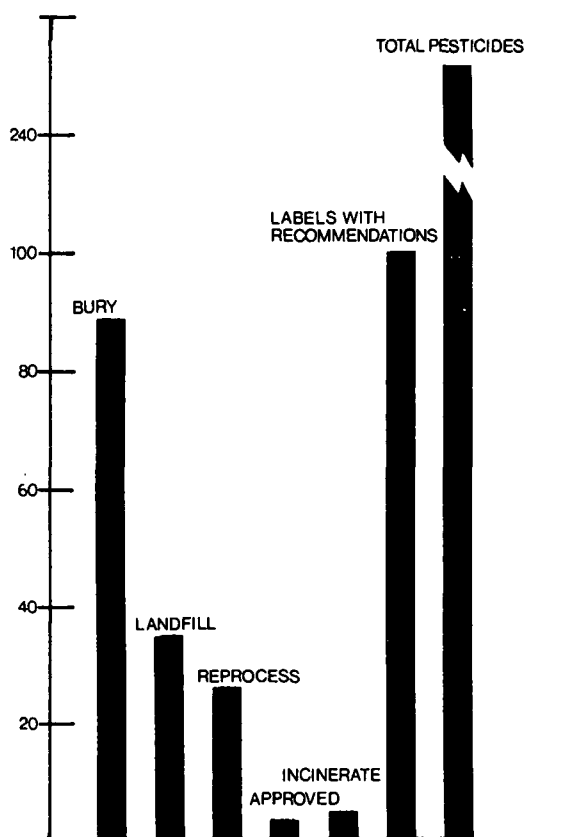
Figure 1. Disposal of excess pesticides - recommendations
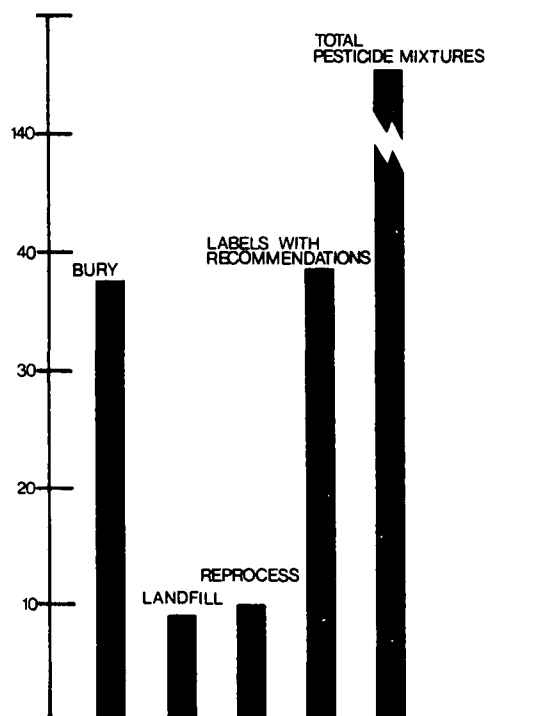
Figure 2. Disposal of excess pesticide mixtures - recommendations

ed, 14 being for the lowest permissible temperature, 6 for the highest.

Instructions occurring less frequently are: keep in original container, 13; away from herbicides, 9; away from toys, dishes, cosmetics, clothing and furniture, 7; in a ventilated area, 7; and maximum of two containers per pallet, three pallets high, 2. The remaining instructions occur once only: away from drafts; away from food, medicine and household cleaning materials; not in tightly sealed containers; and away from combustible containers. Almost one fifth, 19.5% of the pesticides had no storage recommendations or precautions.

Storage recommendations for pesticide mixtures are comparable with those for individual pesticides. Table 4 shows the frequency of each recommendation: away from heat, fire and sparks, 61; away from seeds, feeds and foodstuffs, 34; away from foods, feeds, insecticides and fungi-

cides, 23; above 32°F, 7; keep cool and dry, 23; dry, 13; keep in original container, 7.

Fewer temperature restrictions are given for the pesticide mixtures than for individual pesticides. Those that are given are shown in Table 5. No storage information was given for 23, or 16.1% of the pesticide mixtures.

DISCUSSION

Disposal of Pesticide Containers

A great variety of pesticide containers are in use, ranging in size from 55 gallon drums to containers of a few ounces or less, and made of metal, plastic, paper and glass. This range is reflected in the number of disposal methods recommended.

Burial of pesticide containers, as the most freqently indicated means of disposal, has distinct advantages.

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TABLE 2. MOST FREQUENTLY SUGGESTED STORAGE CONDITIONS FOR PESTICIDES

Pesticide Grouping	Away from Heat, Fire and Sparks	Away from Seeds, Feeds, and Foodstuffs	Away from Seeds, Feeds Fertilizers, Insecticides Fungicides	Above 32°F	Cool and Dry	Dry
I Inorganic and Metalloorganic	6	5	1	2	2	1
II Phosphorus -Containing	31	20	5	5	11	5
III Nitrogen -Containing	36	36	20	24	16	18
IV Halogen -Containing	22	19	16	10	4	...
V Sulfur -Containing	1	1	...	...	...	2
VI Botanical and Microbiological	...	1	...	...	1	...
VII Organic Not Elsewhere Classified	4	4	...	3	...	...
TOTAL	100	86	42	44	34	26

It requires no special equipment or chemicals, no trip by the user to a collection point, and is without the immediate pollution hazards of burning. Its disadvantages are long term, in that containers always contain some residual pesticide. Triple rinse procedures reduce this amount, but the rinse instructions are not always given. The long term risk is to water supplies. Most of the labels recognize this hazard, and suggest burial away from water supplies.

The smoke and fumes from burning containers and the pesticide residue present hazards to the person supervising the burning and to surrounding wildlife and plants. The labels routinely warn the user to stay out of the smoke and fumes. Increased restrictions on open burning raise further doubts about the continued use of this method.

A number of studies of the incineration of pesticides and their containers has shown its feasibility for a variety of pesticides. Most of the studies have involved small-scale or pilot-level incinerators, and the results cannot necessarily be extrapolated to a full scale incinerator.

TABLE 3. TEMPERATURE CONDITIONS FOR THE STORAGE OF PESTICIDES

				Not Below °F			
	-60.0	-50.0	-40.0	-30.0	-20.0	0.0	3.0
Total Pesticides	1	1	1	1	1	5	1

				Not Below °F			
	10.0	20.0	32.0	40.0	50.0	55.0	65.0
Total Pesticides	3	10	44	9	2	1	2

				Not Above °F		
	90.0	100	110	120	130	140
Total Pesticides	5	2	1	1	1	3

Precautions must be taken to deal with toxic gases and ash produced in the process. The costs of and hazards involved in shipping containers to suitably equipped incinerators may inhibit their use.

Reconditioning has the advantages of reuse of the pesticide containers, but the disadvantages of shipping. It is, however, recommended for 15.2% of the containers, and this percentage could probably be increased. The same advantages and disadvantages apply to returning containers to the manufacturer, sending the containers for scrap steel, or recycling with no subse-

quent use specified.

Landfill disposal is recommended for only 18.2% of the pesticide containers. Provided that metal containers are rinsed prior to disposal, that the landfill is properly sited and maintained, and that adequate safety measures are taken to protect both the pesticide operator and the landfill personnel, this would seem to be a safe means of disposal for containers of the less hazardous pesticides.

Discard and destroy are recommended for 15.9% and 36.4% of the pesticide containers, even though

TABLE 4. MOST FREQUENTLY SUGGESTED STORAGE CONDITIONS FOR PESTICIDE MIXTURES

Away from heat, fire and Sparks	Away from Seeds, Feeds and Foodstuffs	Away from Foods, feeds Insecticides Fugnicides	Above 32°F	Cool and Dry	Dry	In Original Container
61	34	23	7	23	13	7

these are vague terms. Even when qualified by "in a safe place" there is room for considerable judgement and interpretation of what constitutes a suitable disposal site.

Disposal with trash is suitable only for, and is generally only recommended for, small containers of pesticides intended for household use.

When approved procedures are recommended it is as the last choice of several methods. They are recommended only eight times, three of which are for the Group I pesticides, which pose the greatest detoxification problems.

The container disposal methods for pesticide mixtures are comparable with those for single compounds, with the exception of reconditioning, recommended more frequently, and landfill and discard, recommended less frequently. Thirteen of the 143 pesticide mixtures gave no instructions for the disposal of containers.

Disposal of Excess Pesticides

Burial of excess pesticides, the most recommended method, usually adds the caution to avoid water supplies. The effectiveness of this disposal method depends on several factors, including pesticide degradation by soil microorganisms, soil texture,

TABLE 5. TEMPERATURE CONDITIONS FOR THE STORAGE OF PESTICIDE MIXTURES

	Not Below °F					Not Above °F	
	10.0	20.0	32.0	40.0	50.0	130	140
Total Pesticide Mixtutes	1	1	7	3	1	5	1

temperature, water and organic matter content, and the concentration of the pesticide. The interrelationships of some of these factors have been studied for a limited number of pesticides.

Landfill disposal of pesticides requires that the landfill be sited safely, and that safety precautions are taken to protect the landfill operators and those involved in the transport of the pesticide.

Chemical reprocessing may be applicable to more pesticides than the 27 for which it is recommended. It is a method which involves the hazards of repacking and shipping. Only one pesticide, currently for experimental use only, gives specific directions for its return to the manufacturer.

Incineration, perhaps the most promising method for disposal of large quantities of pesticides, is recommended for only three. Work on the incineration of pesticides is mainly at the scale model or pilot-scale stages, although there are a few incinerators active, handling large amounts of pesticides.

As with the containers, approved procedures are suggested as one of a choice of methods for the disposal of excess pesticides.

Chemical reprocessing and land-fill disposal of excess pesticides when they are recommended, are always given as alternatives to burial. The chemical reprocessing of mixed pesticides may not be practical for many mixtures; each mixture will have to be evaluated individually. Almost all research to date has involved single compounds evaluated separately.

Storage of Pesticides

Because of the variety of pesticide containers, different storage conditions are suggested for the same pesticide. The variety of pesticide formulations using the same active ingredient with different inert ingredients increases the number of storage recommendations.

The majority of pesticides are organic compounds and are to greater or lesser degree flammable and the formulations frequently include a flammable organic solvent. These factors are recognized in that the greatest number of recommendations are for pesticides to be stored away from heat, fire and sparks.

Keeping pesticides away from seeds, feeds and foodstuffs, and away from seeds, feeds, fertilizers, insecticides and fungicides so as to avoid contamination, are recommended 86 and 42 times, respectively. These recommendations also mention avoidance of transport of pesticides with these same materials.

Storage temperature is an important factor in the safe storage of pesticides, and a total of 94 pesticides give an indication of maximum and/or minimum tolerable temperature. Very few pesticides indicate an acceptable temperature range. Keeping pesticides above freezing is the most frequently recommended condition, with fewer recommendations towards the temperature extremes.

The instruction to keep the pesticide cool was invariably associated with "dry" and was recorded in this form, a total of 34 times, while "dry" alone occurred 26 times.

The instruction of keeping the pesticide in its original container addresses a number of problems - the hazard of putting the pesticide into an unlabeled container, of putting the pesticide into an inappropriate container, i.e., one unsuitable for the pesticide or a soft drink container, and the presumed loss of instructions, precautions and safety information. However, it only occurs 13 times among the 194 pesticides.

The less frequent instructions deal with the specific properties of the individual pesticide.

CONCLUSIONS

Pesticide Containers

The great variety of pesticide containers currently in use requires

a number of different methods of disposal. For specific instructions, the type of container and the nature of the pesticide must be considered. Specific, positive instructions are necessary; five of the 241 pesticides surveyed had no instructions for the disposal of containers.

For the large metal containers which have potential for reuse as containers or as scrap metal it should be possible to balance the factors involved to make some re-cycling worthwhile. The factors involved are safe transport to a recycling or pick-up center, detoxi-fication of the drums, acceptability for reuse, and sufficient economic incentives at each stage.

As air pollution controls tighten, open burning should and will become a more limited option for the disposal of flammable containers. This option will be taken over by incineration, with the incinerators being appropri-ately modified to control toxic gases.

Landfill and burial options should remain available, subject to precautions against water pollution.

Disposal in the trash is probably the only disposal method likely to be followed by householders using small amounts of pesticides intended for home use.

Excess Pesticides

Only 98 of the 241 pesticides surveyed had any instructions for the disposal of excess pesticide. Ideally, the user will estimate how much pesticide is required, purchase that amount and use it up. Because ideal conditions are seldom achieved, some specific, positive recommendations for the disposal of excess pesticide should be included on the label.

Chemical reprocessing should be investigated for more pesticides, both as a means of pesticide detoxi-fication, and as a means of resource conservation.

Incineration should be made more readily available to dispose of those

pesticides which are unsuited for chemical reprocessing.

Landfills can safely be used for the disposal of the less toxic pesticides.

Burial, following appropriate precautions to prevent contamination of water supplies, continues to be a practical disposal method, particu-larly for use strength pesticides.

The lack of research on the safe disposal of mixtures would suggest that until the necessary research is done, the mixture should be disposed on the basis of the most toxic and/or most refractory materials contained in the formulation.

Storage

The variety of pesticides and their containers requires a variety of different storage instructions. Specific instructions are necessary depending on the nature of the pesticide, the inert ingredient and the container. Currently, 47 of 241, or 19.5% of the pesticides have no storage instructions. The safe temperature range for storage instead of only a maximum or minimum should be used.

Pesticide mixtures require specific storage instructions appro-priate to the mixture; 23 of 143, or 16.1% have no instructions what-soever.

The survey was based on the labels and product manuals of the manufacturers who responded to our request for information. The basis for the disposal and storage instruc-tions is not known and they may be present because of mandatory require-ments rather than being environmen-tally sound practices. Different manufacturers give different disposal or storage instructions for essential-ly the same pesticide and container. This may reflect the use of different inert ingredients or different ratios of active to inert ingredients, but it is clear that some labels are much more informative than others.

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WINDMILLS, INCINERATORS AND SITING

Frank C. Whitmore
Versar Inc.
Springfield, Virginia 22151

Richard A. Carnes
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

ABSTRACT

The public reaction to proposals for the siting of hazardous waste disposal facilities results largely from fear and from distrust of technologists. Several case histories are presented with inferences drawn as to possible future actions to reduce the problem.

INTRODUCTION

It is our purpose here today to discuss some of the problems that are associated with the siting of a hazardous waste disposal facility and to illustrate some of these difficulties in terms of our personal experience in attempting to site an experimental facility. It is unfortunate that we cannot offer a prescription for success, but perhaps by revealing some of the pitfalls into which we have strayed our experience might help others in the future.

In order to obtain a data base sufficient to allow the establishment of reasonable and safe standards for the incineration of a number of industrial waste streams, the Environmental Protection Agency awarded Versar a contract to conduct a series of test burns. The system to be used, which includes a rotary kiln and afterburner with appropriate air pollution control equipment, is probably the most heavily instrumented incinerator in the world. It was planned that the system be located in the middle of a large area west of Washington, D.C., that has been for years zoned for research and light manufacturing. The total area, encompassing some 350 acres, is surrounded by fencing and has very limited access.

Even though the feed rate and the nature of the proposed operations are such that permitting was not required, application for a permit in Virginia was made. The permit was issued without alteration to the plan but with the admonition that it would not be necessary to contact the county officials since the proposed site was already zoned for research. After several months, during which the needed facilities modifications and leasing arrangements were being made, there was a request from the County Commissioners for an informal, non-public meeting with the principals of the program. This meeting was devoted to the very reasonable request for information about the possible impact of the research program on available county resources—fire, police, and medical. The meeting was very amicable, and the program went forward. Somehow, however, there developed an undercurrent of public concern that led the Commissioners to request a formal meeting in executive session.

The "executive session" was, in fact, an unannounced public meeting which was attended by the press. Since there had been no prewarning that there would be press coverage, no preparations had been made to brief the press properly. The

upshot of that meeting was a series of newspaper articles that presented a very distorted picture of the proposed operations. Examples of some of the headlines are shown in (the next several slides) Figures 1 and 2.

These rather inflamatory headlines and the accompanying text served to create considerable public reaction. The nature of this reaction is best shown by the hand-lettered sign that appeared in a local chain grocery store as shown in (the next slide) Figure 3. In view of this reaction, the lessor, in order to maintain his local good image, withdrew the lease. The program has still not been successfully sited at this writing.

It is the purpose of this paper to attempt to analyze the above situation and to determine, if possible, what course of action might have been taken to avoid such an outcome.

THE PUBLIC HEARING

In the common understanding of the democratic process, it is essential that there be a suitable forum for the expression of shades of opinion on any matter that affects, or that is preceived to affect, the common welfare of the community. It is in this spirit that most political jurisdictions have instituted the public hearing process when faced with making a decision that could have wide influence on the community. In particular, this mechanism is widely used in matters that concern the local zoning laws. For example, when considering the siting of a new shopping mall or an extension of the interstate highway system, the public is invited to express its opinions as to the probable impact of the new mall. In large measure, this is a natural result of an evolutionary process brought about by the complexity of the decisions that public officials are required to make. In order to dilute the ultimate responsibility, the public is invited to share in the decision-making process.

The quasi-judicial public hearing process has then been developed as a mechanism by which parties with opposing views may come together in an orderly fashion to present their individual views, to discuss their differences, and to reach a concensus. The petitioner is expected

to present his case for the facility, including the costs and the benefits to the community. The public participants, who are not infrequently opposed to the proposal, are expected to listen and understand the case presented by the petitioner and then to present their position on the matter. In the dialogue that should follow, the points of differences should be accurately defined and subsequently resolved by compromise. There is a necessity for mutual respect and understanding based on a common language if agreement is to be reached through public hearings.

The difficulties that are inherent in this process are well illustrated by the problem that arises when the petitioner is presenting the case for a new or modified chemical waste disposal facility. He is expected to present his case in terms of the technical details of the operation of the proposed facility and the provisions that will be taken to reduce the hazard associated with transport to the facility and of accidents within the facility. In addition, he is expected to discuss the nature of the procedures to be instituted for dealing with an accident. The public reaction to such a proposal is generally negative since the possible benefits are completely overshadowed by the possible deleterious effects of an accident, however improbable that eventuality might be. In view of the general lack of accurate information on the part of the general public and the very general distrust of technologists, there is no real possibility of dialog and thus no possibility of compromise.

TECHNICAL LANGUAGE AND TECHNOLOGY

A major deterrent to essential communication arises from the very specialized vocabulary characteristic of most of modern technology. This language, which is specific to each of the disciplines involved, serves a very important function in that it allows very precise communication among practitioners. Even when used in the manner for which it was created, the very nature of this language serves to confuse and therefore frighten the general public. Many examples of this problem might be cited; the arcane distinction between hazardous and toxic will serve to illustrate the point. The precise distinctions are often lost on the lay public

WEDNESDAY JULY 25, 1979

Poisonous Chemicals
To Be Burned Here

By DAVE ROMAN
JM Staff Writer

Officials Say Toxic Tests To Be Harmless

By DAVE ROMAN
JM Staff Writer

FIGURE 1
NEWSPAPER HEADLINES AFTER INITIAL HEARING

Residents Protesting Burning

OFFICIAL SAYS

Burning of Toxic Waste Could Be Permanent

SUPERVISORS...

...Receptive to Versar Protestors
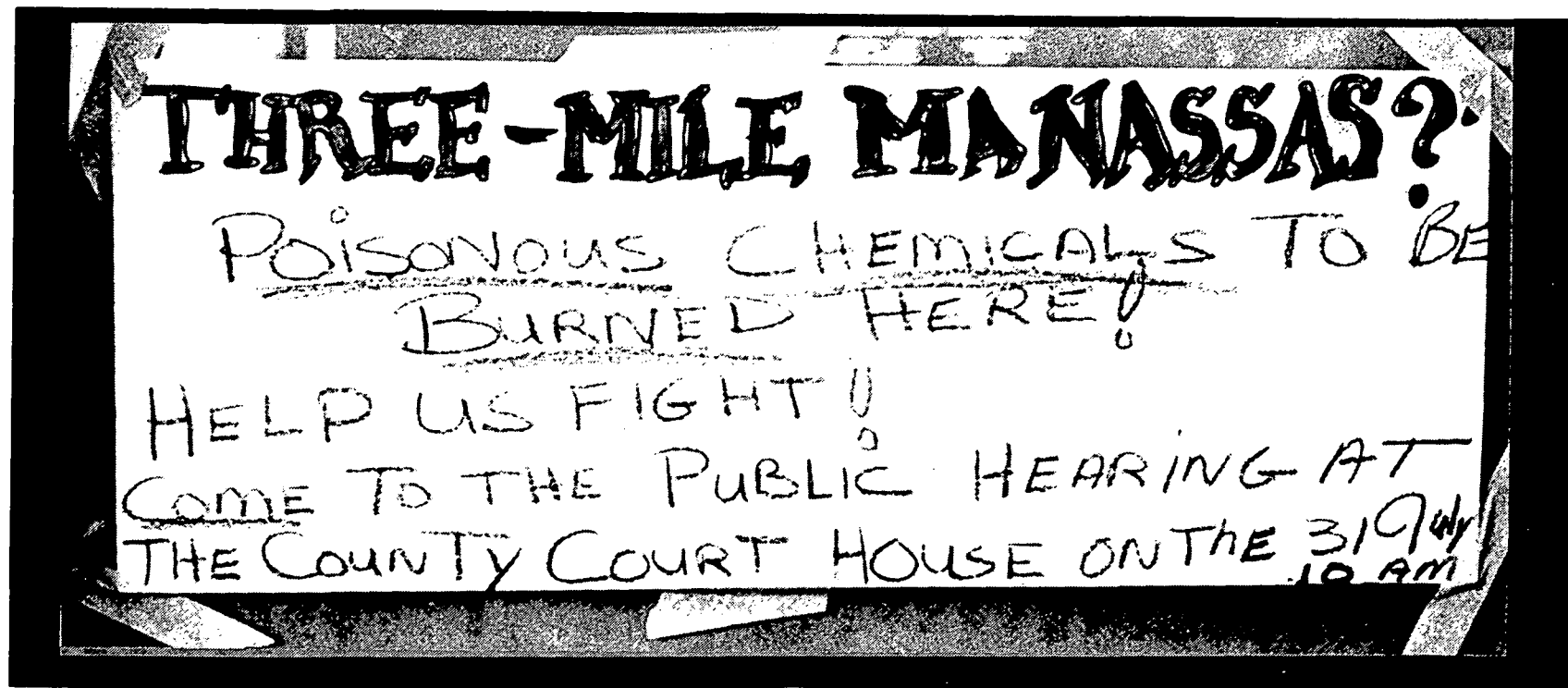
FIGURE 2
NEWSPAPER HEADLINES AFTER PUBLIC REACTION

FIGURE 3

with the result that there is no common language so that consensus, based on mutual understanding, is actually not possible.

A second problem that has arisen in the use of the technical jargon can be illustrated by a quotation from Orwell[1] taken from his essay, "Politics and the English Language." A quote from Ecclesiastes is as follows:

"I returned and saw under the sun, that the race is not to the swift, nor the battle to the strong, neither yet bread to the wise, nor yet riches to men of understanding, nor yet favour to men of skill; but time and chance happeneth to them all."

Here it is in modern English:

"Objective consideration of contemporary phenomena compels the conclusion that success or failure in competitive activities exhibits no tendency to be commensurate with innate capacity, but that a considerable element of the unpredictable must invariably be taken into account."

Although the "modern English" version is something of a parody, we are all very familiar with many examples of this kind of turgid writing by which the author succeeds in completely obscuring his meaning and intent. The very general tendency of technical writers to use complicated syntax coupled with highly specialized terminology tends to render technical literature inaccessible to even the interested lay reader.

Further examples of poor communication are those given in the recent award of the "1979 Doublespeak Award"[2] to the Nuclear Regulatory Commission for its explanations during the Three Mile Island incident, Figure 4. Clearly, these examples represent a deliberate attempt to confuse the public by the use of obscure technical euphemisms to describe real physical events. Such a use of the language serves to further erode the credibility of technology and of technologists.

When the case for the safety of a proposed waste disposal facility is discussed in a public hearing, the emphasis is always on the nature of the monitoring and on-line safety equipment that will be used. Tacit in the discussion is the

assumption that the operators will be responsible and that they actually know of what they speak. The public perception of this is not always what we technologists would have it be. The point can again be illustrated by the Three Mile Island incident. All too often in the past, nuclear technologists have blandly assured the public that there are no dangers in their technology, and since all is under their control in their very capable hands, there is no cause for alarm. The recent events at Three Mile Island clearly showed that all was not well, that things were not in control, and that there were, indeed, unforseen dangers. The net result of these lapses has been a general erosion of public confidence, not so much in technology but rather in technologists.

PUBLIC INFORMATION

A second aspect of the complexities of technical language is the fact that, because of the many disciplines that are involved in problems of the environmental effects of chemical wastes, the technical literature is simply not available to the concerned lay public. In view of this fact, the only viable source of information is through the media. Unfortunately, most of the media presentations in the past have been of poor practices. Many, if not most, of the media presentations tend to the spectacular with gross oversimplification. Few of the commentators are sufficiently knowledgeable in chemical or toxicological technology to adequately appraise the actual situation. This fact, coupled with the short attention span of both writers and readers, leads to the use of buzz words rather than the more unfamiliar technical terms. Examples of this effect are shown in Figure 5 (next slide).

It would appear that at least some of the more vocal members of the general public have reacted to such sources of information by perceiving a chemical waste disposal facility somewhat as Don Quixote in Cervantes[3] perceived the windmill:

"Engaged in this discourse, they came in sight of thirty or forty windmills which are in that plain; and, as soon as Don Quixote espied them, he said to his squire, 'Fortune disposes our affairs better than

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EXPLOSION = ENERGETIC DISASSEMBLY

FIRE = RAPID OXIDATION

ACCIDENT = NORMAL ABERATION OR PLANT TRANSIENT

THE REACTOR VESSEL IS CONTAMINATED WITH PLUTONIUM =
 PLUTONIUM HAS TAKEN UP RESIDENCE IN THE REACTOR VESSEL

FIGURE 4
DOUBLESPEAK - AN EXAMPLE OF TECHNOLOGICAL LANGUAGE[2]

TOXIC	POISONOUS
HAZARDOUS	EXPLOSIVE
WASTE	POISONOUS
REMOTE	ARIZONA
ISOLATED	ARIZONA (UTAH)
EXPERIMENTAL FACILITY	PERMANENT INSTALLATION
LIMITED OPERATION	CONTINUOUS OPERATION
FAIL-SAFE	DANGEROUS
EMISSIONS	BILLOWING CLOUDS
EMISSION STANDARDS	CONTAMINATED NEIGHBORHOOD
NON-HAZARDOUS	GASOLINE, PROPANE, ETC.

FIGURE 5
VOLABULARY

we ourselves could have desired; look yonder, friend Sancho Panza, where thou mayest discover somewhat more than thirty monstrous giants, whom I intend to encounter and slay and with their spoils we will begin to enrich ourselves; for it is lawful war, and doing God's good service to remove so wicked a generation from off the face of the earth."

The mere mention of the possibility that a chemical waste disposal facility is contemplated in their vicinity seems to evoke images of the turn of the century industrial city. Great belching stacks filling the skies with rolling billows of greasy black smoke, obscuring the bright blue skies, killing the vegetation for miles around, causing happy children to choke and to be convulsed with pain, causing the good citizens to die like flies from the noxious fumes--these are the visions conjured up by the mention of an incinerator. The mention of a secure landfill site evokes the vision of a vast desert covered with rusting drums and abandoned industrial equipment; here and there are foul pools of oily water and over all hangs a miasma of poisonous fumes. In view of such visions of the nature of the chemical waste disposal facilities, it is indeed "a lawful war, and doing God good service to remove so wicked a generation from off the face of the earth."

APPLICATION TO VERSAR SITING HEARING

The gap between languages became apparent in the case of the above mentioned public hearing in questions dealing with the nature and magnitude of possible emissions. When it was explained that the only source of emissions would be the stack and that the latter would be monitored on a continuous basis during each and every experiment, the response was, "If there will be no emissions, why is it necessary to monitor the stack?" It was further pointed out that there would be a network of ambient air monitors and high volume monitors in operation, again the question, "Why, if there will be no emissions?" Attempts were made to explain that only by monitoring could one be assured that there were no emissions; these uniformly failed. It was also observed that, because of the fact that the only hard information available to the protesting public was from the media, there seemed to be no sense of trying to hear

and understand our case; "Why bother, our minds are made up!"

What became abundantly clear during the hearing was the fact that, by the use of common buzz words, the press had stirred up emotions and fear. The business of rejecting this abomination became, in the minds of a small but vocal minority, "doing God good service." Clearly, by the time of the hearing, the technical staff of the program had so little credibility, there was no possibility of a dialog. The damage had been done before the hearing.

FUTURE COURSE

Not all recent attempts to site waste disposal facilities or to carry out test burns have failed because of public reaction. It will be instructive to examine one such successful attempt in order to determine the factors that led to success. In the aftermath of the kepone disaster in Virginia, it was decided that co-incineration offered the best approach to the disposal of the contaminated sludge that was stored in the Hopewell lagoon. A facility available in Toledo, Ohio, appeared to be the most conveniently arranged for a series of test burns to establish the necessary conditions for a large scale disposal operation.

After a number of private meetings with concerned local, state, and regional officials in Ohio, a comprehensive publicity and public information program was prepared. Specifically, a very detailed Kepone Fact Sheet[4] was prepared for the purpose of briefing the interested press (and other media) in as detailed and factual a manner as possible. All terms that might lead to substitutions of buzz words carefully defined. In addition, the precise details of the proposed experiments were spelled out, as were the safety precautions to be taken. This information was made widely available some six months before the proposed start date of the test burns. The principals of the technical staff were on call to answer any questions that arose during the pre-burn period.

The availability of accurate, detailed information enabled all media to present a knowledgeable explanation of the proposed experiments. There was no concerted public outcry, and the experiments were carried out in an atmosphere of candor and

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public acceptance. (It should perhaps be pointed out that the experiments were carried out in the dead of winter, a factor that perhaps dampened the ardor of persons who otherwise might have been tempted to protest more vigorously.)

Every attempt to site a facility that is rejected by public reaction serves to harden position on future attempts. This chain reaction effect makes it imperative that there be a national program to assist every attempt at siting. What is urgently required is a careful examination of the present situation with respect to waste disposal and the development of an adequate and candid discussion of past mistakes, both of commission and of omission. When such an appraisal has been completed it will then be essential that an educational program be undertaken to upgrade the general understanding of the problem of hazardous industrial wastes, their sources, and the safe and effective means for dealing with them. Only in terms of an enlightened public can the necessary steps be taken to avoid future Love Canals.

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HIGH TEMPERATURE DECOMPOSITION OF
ORGANIC HAZARDOUS WASTE

D. S. Duvall, W. A. Rubey, and J. A. Mescher
University of Dayton Research Institute
300 College Park
Dayton, Ohio 45469

ABSTRACT

A sophisticated laboratory system has been designed and assembled with the objective being to provide fundamental thermal decomposition data on a wide variety of organic materials. This thermal decomposition analytical system (TDAS) is a closed system consisting of a versatile, highly instrumented thermal decomposition unit which is connected to a gas chromatograph-mass spectrometer-computer. With the TDAS, gases, liquids, and solids (including polymers) can be subjected to thermal decomposition studies.

Thermal decomposition tests were conducted with the TDAS on polychlorinated biphenyls (PCBs), and on "Hex" wastes. The PCBs were found to have high thermal stability in air. Furthermore, in oxygen-deficient atmospheres their thermal stability is increased by at least 200°C over that experienced in air. "Hex" wastes also demonstrated a high degree of thermal stability. Several chlorinated, aromatic compounds were still present after exposure to 800°C. Further increases in temperature to 1000°C decomposed all compounds except for low levels of hexachlorobenzene.

INTRODUCTION

The safe disposal of highly toxic organic wastes is a very serious problem in many parts of the world. One of the best methods for permanent disposal of these wastes is high-temperature incineration. However, in the interest of safety, it is necessary that knowledge of the thermal decomposition properties of a toxic organic substance be attained before large-scale incineration is conducted.

In response to this need, a sophisticated laboratory system has been designed and assembled by the University of Dayton Research Institute (UDRI). This thermal decomposition analytical system (TDAS) is a closed, continuous system which consists of a versatile thermal decomposition unit followed in-line by a dedicated gas chromatograph-mass spectrometer-computer (GC-MS-COMP). The objective of this laboratory system is to provide fundamental thermal decomposition data on a wide variety of organic materials.

In the TDAS, precisely controlled thermal exposures are conducted in a narrow-bore, quartz tube reactor. Subsequently, products of thermal decomposition are collected in an adsorptive, cryogenic trap. The products are thermally desorbed; subjected to high-resolution, gas chromatographic separation; and then identified by mass spectrometric analysis. A dedicated minicomputer is utilized for reducing the analytical data. Product analyses conducted at a selected series of temperature exposures can provide a profile of the thermal decomposition properties of an organic substance.

This paper presents experimental data determined by the UDRI on two major types of hazardous wastes, polychlorinated biphenyls (PCBs) and "Hex" wastes. The introduction of PCBs to the world market was made in 1929. Now the problem of global environmental contamination by PCBs has

been well documented. Comprehensive reviews have reported the existence of significant quantities of PCBs in atmosphere, soil, water, sediment, fish, wildlife, and even in samples of human blood and tissue.[6] "Hex" wastes, a mixture of industrial wastes containing chlorinated organic compounds, have been major contributors to environmental pollution. In addition to the Love Canal tragedy where "Hex" wastes were a part of the problem, an illegal dumping of these wastes in Louisville, Kentucky in March, 1977 forced the closing of their sewage treatment plant.[3] Subsequently, untreated sewage was dumped into the Ohio River for about four months, while cleanup and reactivation of the sewage treatment system was performed.

CONCEPT AND BASIC DESIGN OF TDAS

The rationale behind the design concept of the TDAS has basically not changed from that of the earlier discontinuous system.[5] The sample is still inserted into the system, and then gradually vaporized in a flowing carrier gas. The vaporized compounds are subsequently subjected to a controlled high-temperature exposure. The components that emerge from the high-temperature environment are then collected and analyzed by instrumental techniques. With respect to the TDAS, this same thermal analysis format has been employed; however, each operation within the system is much more sophisticated, thereby producing greatly increased experimental versatility.

The major design changes over the earlier system are centered around the design of the reactor, the closed continuous system concept, and also the vastly increased analytical capability which is now provided by an in-line gas chromatograph-mass spectrometer-dedicated computer (GC-MS-COMP). Numerous refinements have also been designed into the TDAS, and these are detailed elsewhere.[7]

There were many design objectives associated with the development of the TDAS. This system must be capable of conducting precise thermal decomposition tests. More precisely, it should be capable of experimentally determining the effects of the five prominent thermal decomposition variables, which are listed in Table 1.

TABLE 1. THERMAL DECOMPOSITION VARIABLES

THERMAL DECOMPOSITION VARIABLES
EXPOSURE TEMPERATURE
COMPOSITION OF ATMOSPHERE
PRESSURE
MEAN RESIDENCE TIME
RESIDENCE TIME DISTRIBUTION

In addition, the TDAS should be able to accommodate almost any type of organic material; it should be capable of analyzing the thermal decomposition effluent products; and it should be capable of dealing with toxic materials. Finally, the TDAS should be capable of generating data on a quick response basis. Figure 1 shows a block diagram, and Figure 2, a conceptual drawing of the TDAS.
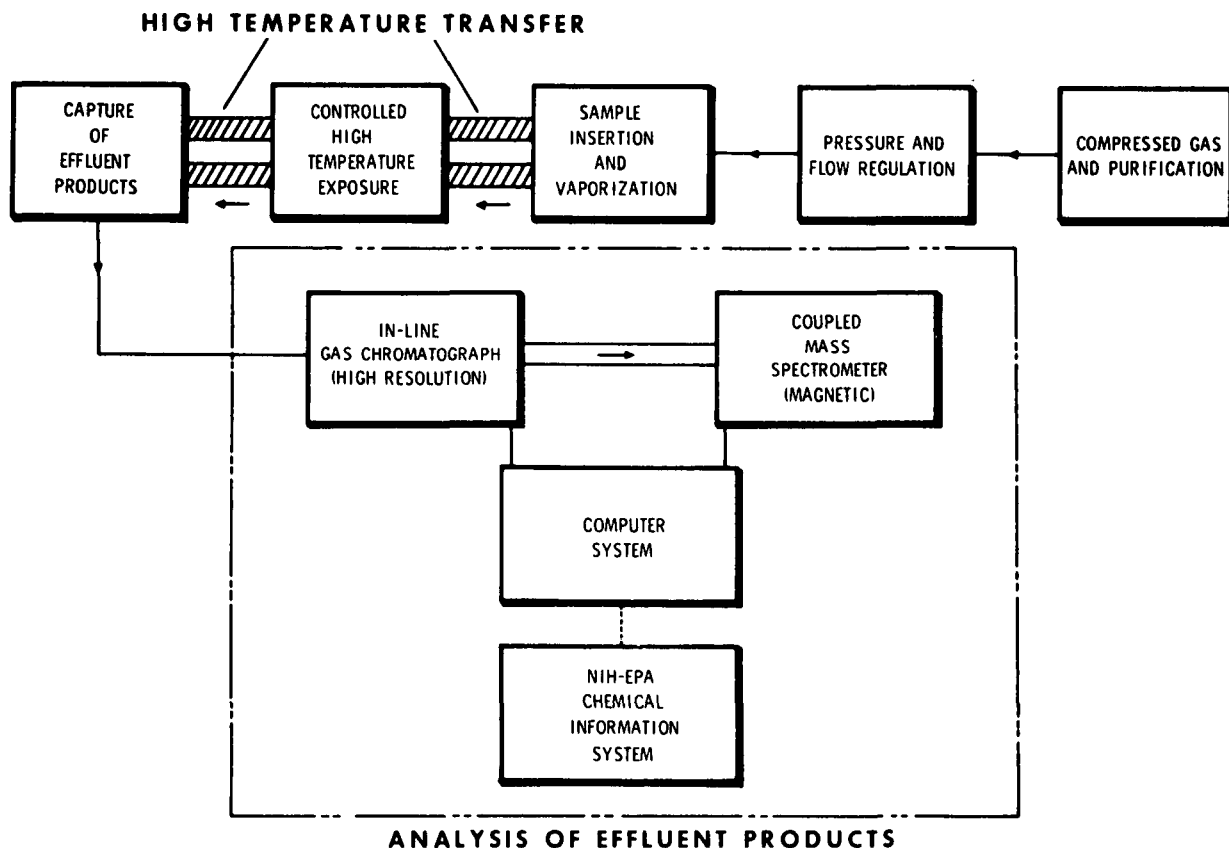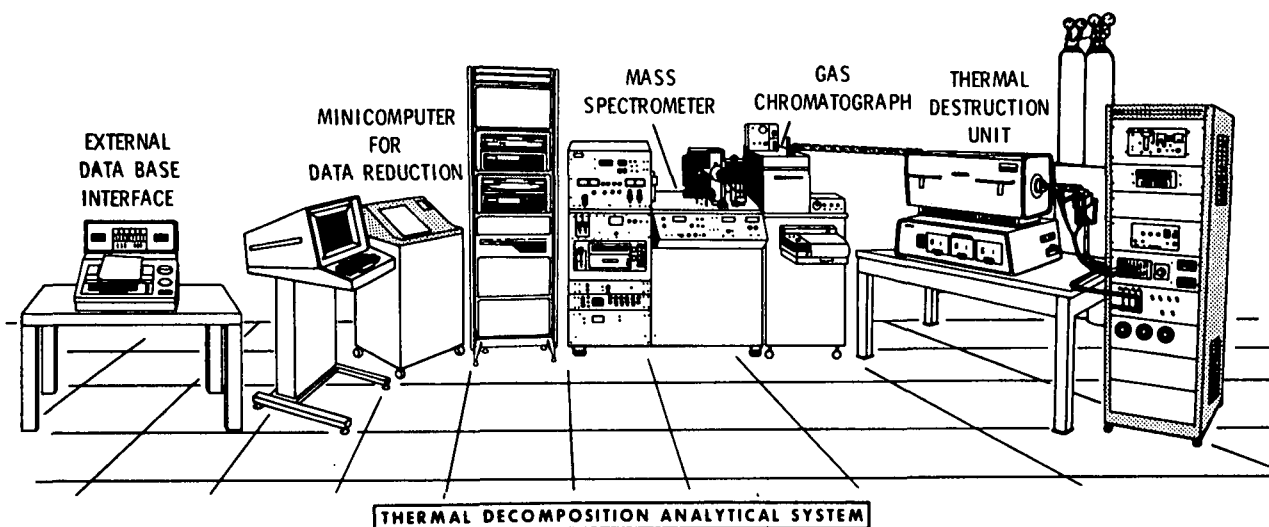
HIGH TEMPERATURE TRANSFER

ANALYSIS OF EFFLUENT PRODUCTS

Figure 1. Block diagram of TDAS.

Figure 2. Conceptual drawing of TDAS.

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EXPERIMENTS WITH PCBs

A selected group of PCB isomers were subjected to a series of thermal decomposition experiments using the thermal decomposition analytical system (TDAS). Specifically, experiments were conducted with 2,2',6,6' -tetrachlorobiphenyl, 2,2',5,5' -tetrachlorobiphenyl, 2,2',4,5,5' -pentachlorobiphenyl, and 2,2',4,4'5,5' -hexachlorobiphenyl.

Much of the early work was conducted with the 2,2',6,6' - tetrachlorobiphenyl, as this particular PCB isomer had previously been reported to yield significant levels of chlorinated dibenzofurans,[2] and some of our earlier work corroborated these findings.[5] The most recent work has been done with the three remaining isomers, and Table 2 shows

TABLE 2. EFFECT OF TEMPERATURE ON DECOMPOSITION

Compound	Exposure Temperature*(^{O}C)						
	550	650	675	700	725	750	775
Tetrachlorobiphenyl (2,2',5,5')	100[+]	92	74	57	21	0.14	----
Pentachlorobiphenyl (2,2',4,5,5')	100	98	80	53	9.3	0.05	0.007
Hexachlorobiphenyl (2,2',4,4',5,5')	100	100	73	26	---	----	<0.005

* - All determinations at 2 sec residence time in an environment of flowing air

+ - Values are weight % remaining after exposure

the data corresponding to their decomposition when subjected to 2.0 second exposures in air. It is observed from these data that these PCB isomers exhibit approximately the same thermal stability in air. In addition, Figure 3 shows the thermal decomposition of the 2,2',4,4',5,5' isomer along with formation profiles of some of its thermal decomposition products. In practically every case where the thermal decompositions of PCBs were studied in air, the maximum concentrations of the individual thermal decomposition occurred at the temperature corresponding to the greatest rate of thermal decomposition of the parent subtance. Also, there were many high molecular weight thermal reaction products formed during the decomposition of the PCB; however, in most cases these products were relatively low in concentration (e.g., 0.1 to 0.2 percent).

Further experiments were conducted with the 2,2',4,5,5' -pentachlorobiphenyl. Selection of this isomer was made because it is commonly found in most of the commercial PCB mixtures and is still a prevalent contaminant in the environment. Thermal de-
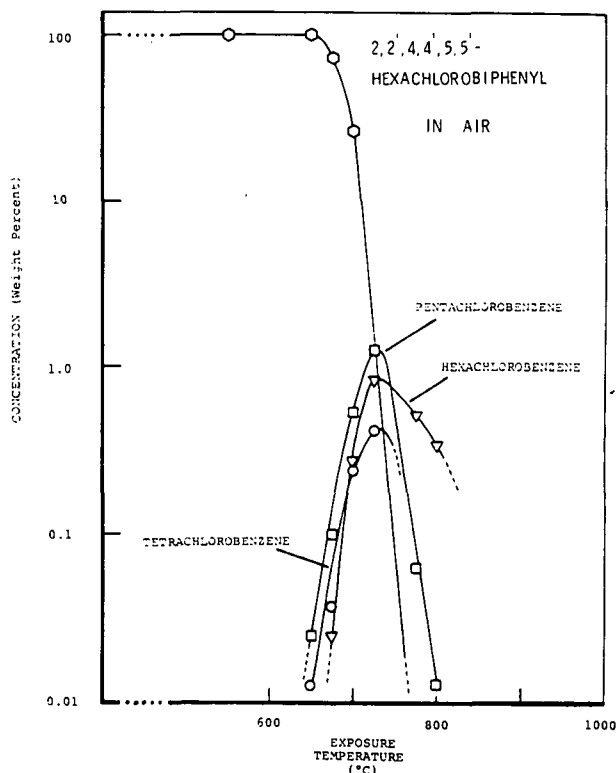

Figure 3. Decomposition of Hexachlorobiphenyl.

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composition profile experiments were conducted using a variety of gaseous atmospheres: (1) 40 percent oxygen in nitrogen; (2) compressed air, (3) 2.5 percent oxygen in nitrogen; and, (4) nitrogen. Two tests were also conducted in helium, and these are also reported as they presented some interesting results.

The data from the thermal decomposition studies with the 2,2',4,5,5' -pentachlorobiphenyl are tabulated in Table 3 and plotted in Figure 4. It is apparent from

TABLE 3. EFFECT OF ATMOSPHERE ON THERMAL DECOMPOSITION

Flowing Atmosphere	Exposure Temperature* ($^{\circ}$C)														
	550	600	650	675	700	725	750	775	800	825	850	875	900	925	950
40% Oxygen in Nitrogen	100[+]	---	85	65	27	1.1	0.05	---	---	---	---	---	---	---	---
Air ($\sim$ 21% O_2)	---	---	98	80	53	9.3	0.05	0.007	---	---	---	---	---	---	---
2.5% Oxygen in Nitrogen	---	100	97	---	91	---	83	37	12	0.40	---	---	---	---	---
Nitrogen	---	---	---	---	---	100	---	89	---	66	---	54	40	18	4.0
Helium	---	---	---	---	---	---	---	---	---	---	---	76	---	44	---

* - All determinations at 2 sec residence time (except helium which was 1.2 sec)
+ - Values are weight % remaining after exposure
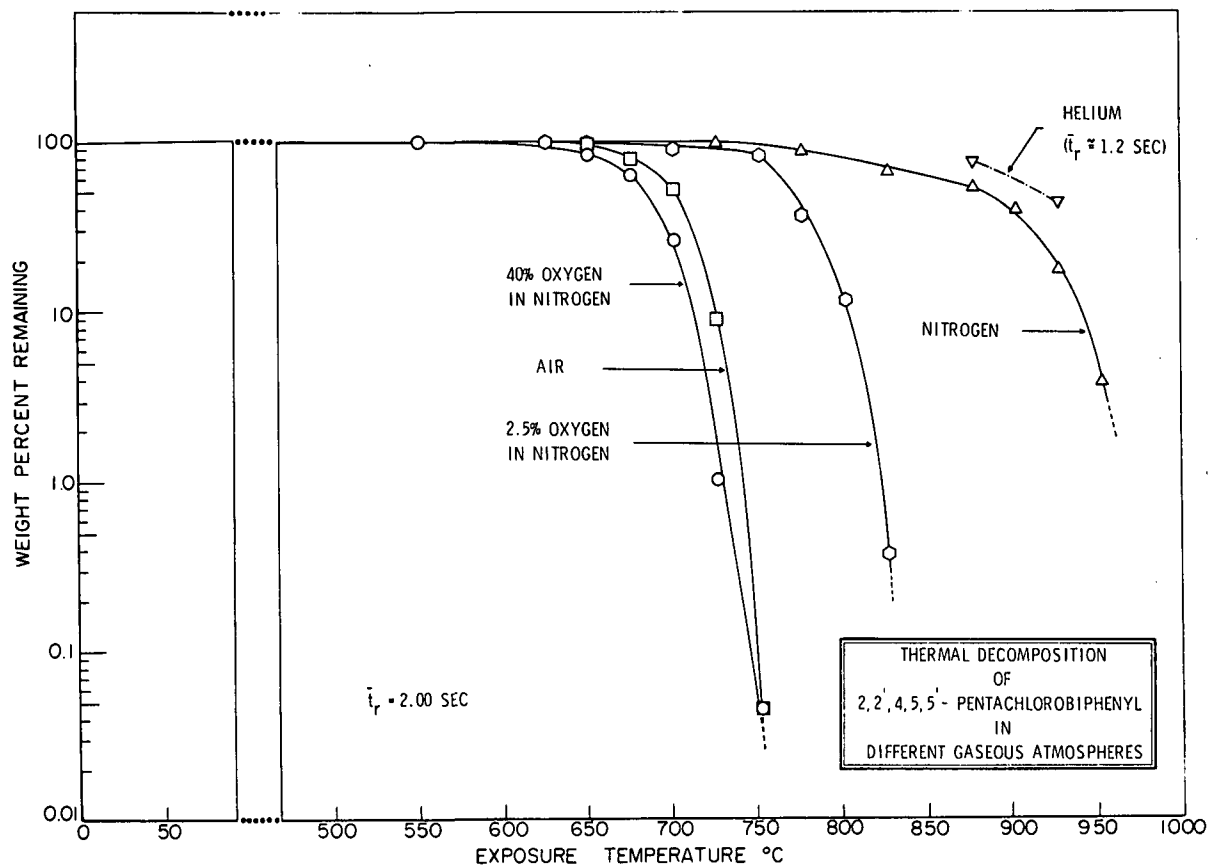
Figure 4. Effect of atmospheres.

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these data that the percent of oxygen in the reactor atmosphere has a profound effect on the thermal stability of the PCB. A comparison of the results with 40 percent oxygen and with air ($\sim$21 percent oxygen) shows only a slight effect caused by the higher oxygen level. However, the testing with 2.5 percent oxygen required temperatures nearly 100°C higher than those with air to achieve thermal decomposition. Further, when a nitrogen atmosphere was present, temperatures of well over 900°C were required for decomposition; this temperature exceeds that required in air by over 200°C.

Another way of viewing these thermal stability data is presented in Figure 5,

where exposure temperature is plotted relative to the oxygen content of the reactor atmosphere. The plotted 100 ppm oxygen value is an approximate level of trace oxygen in nitrogen gas. (This value agrees with our previous experience with bottled nitrogen carrier gases). When this 100 ppm data point is plotted along with the other oxygen concentrations, it is interesting to note the resulting linearity of the semi-log graphing, and again the effect of oxygen content. The two tests that were conducted in flowing helium are also interesting in this respect as the helium gas flowing into the TDAS is extremely oxygen-free (less than 1.0 ppm). It should be noted, however, that the tests conducted in helium had a shorter residence time, specifically the mean residence time was approximately 1.2 seconds.

2,2',4,5,5'- PENTACHLOROBIPHENYL
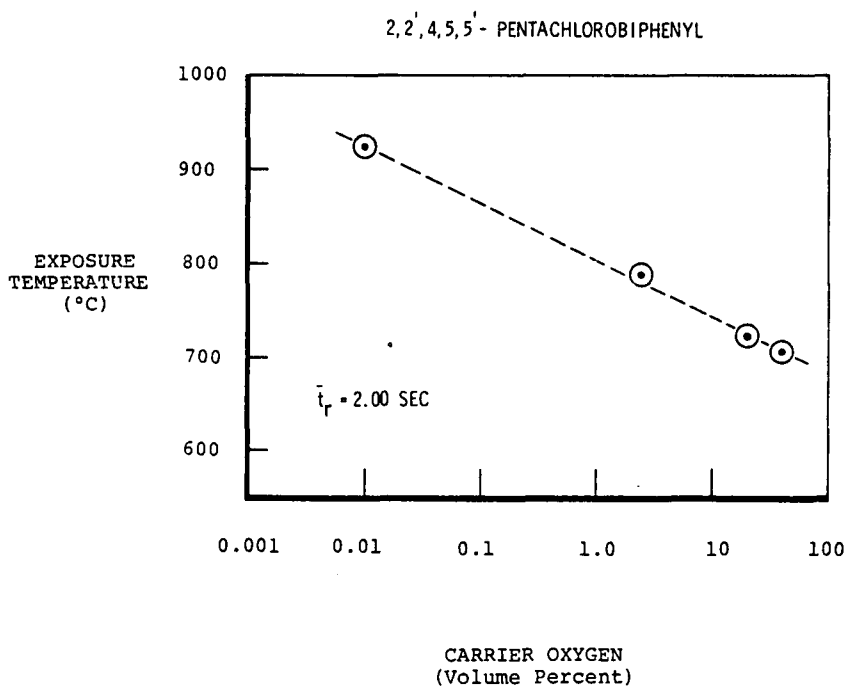
Figure 5. Effect of Oxygen content.

To sum up the thermal decomposition behavior of this particular PCB isomer, it is evident that it has immense thermal stability in oxygen deficient atmospheres. Further, oxygen content of the flowing gas seems to dictate on an orderly basis the extent of thermal decomposition at temperatures above 600°C.

Decomposition Products

The major decomposition products formed from the thermal stressing of 2,2',5,5' -tetrachlorobiphenyl, 2,2',4,5,5' -pentachlorobiphenyl, and 2,2',4,4',5,5' -hexachlorobiphenyl at 725°C in flowing air for 2 seconds residence time are itemized in Table 4. The general fragmentation

TABLE 4. COMPOUNDS FORMED FROM DECOMPOSITION OF PCB ISOMERS

Compounds*	Isomers		
	2,2',5,5'	2,2',4,5,5'	2,2',4,4',5,5'
trichlorobenzene	+	+	-
biphenyl	+	-	-
tetrachlorobenzene	+	2 isomers	+
monochlorobiphenyl	+	+	-
chlorinated compound MW204+	+	-	-
dichlorobiphenyl	+	+	-
pentachlorobenzene	-	+	+
chlorinated compound MW230+	2 isomers	-	-
trichlorobiphenyl	2 isomers	+	+
dichlorodibenzofuran	+	-	-
tetrachlorobiphenyl	2 isomers	+	-
pentachlorobiphenyl	2 isomers	+	-
trichlorodibenzofuran	+	+	-
hexachlorobenzene	-	+	+
chlorinated compound MW264+	-	3 isomers	-
tetrachlorodibenzofuran	-	2 isomers	-
hexachlorobiphenyl	-	+	+
heptachlorobiphenyl	-	-	+
pentachlorodibenzofuran	-	-	+
chlorinated compound MW288+	-	-	+

+ = tentative identification

- = not found

*Flowing air, 725°C, and residence time of 2 sec.

pattern of PCB isomers features successive expulsion of both chlorine atoms and molecules.[8] Due to the known variability of ion intensities produced with different mass spectrometers, no attempt was made to distinguish between various isomers by their primary ion mass spectra. Thus, the names used to identify the products indicate the total number of chlorine atoms present rather than their positional notation. The various PCB species were readily identified on the basis of intense molecular ions (M^+), intense $(M-70)^+$ ions, and unusually abundant doubly-charged molecular ions.

A major concern of this work was to confirm the formation of chlorinated dibenzofurans (PCDFs) from the thermal oxidation of PCBs. As is seen in Table 4 several PCDFs are generated. These include dichlorodibenzofuran and trichlorodibenzofuran from the tetra-PCB isomer, trichlorodibenzofuran and 2 isomers of the tetrachlorodibenzofuran from the penta-PCB isomer, and pentachlorodibenzofuran from

the hexa-PCB isomer. These results agree with those obtained by other workers[2,9] except in the case of the hexa-PCB isomer. Other workers have shown the formation of a tetrachlorodibenzofuran and 2 isomers of the pentachlorodibenzofuran from the hexa-PCB isomer. The chlorinated dibenzofurans were identified on the basis of calculated chlorine isotope ratios,[1] intense molecular ions (M^+), molecular ions minus the loss of the COCℓ group $(M-63)^+$, and minor characteristic fragment losses.

All of the PCB samples were directly analyzed by repetitive scanning of complete mass spectra (mass range 30-492 amu) utilizing a computer data system. After data acquisition the mass spectra (up to 800/run) were searched for PCBs, PCDFs, and other possible reaction products by examining individual mass spectra and by plotting single ion chromatograms of known fragment ions. Individual mass spectra were compared with reference library spectra if available.

Otherwise, manual interpretation of the spectra was performed.

"HEX" WASTES STUDIES

Thermal decomposition tests were conducted with the TDAS on a "Hex" waste sample supplied by the U.S. EPA. The complexity of this mixture is evidenced by the chromatogram shown in Figure 6. Specifically, the major constituents of this sample consist of hexachlorocyclopentadiene

(HCCPD), octachlorocyclopentene (OCCP), pentachlorobenzene (PCBZ), and hexachloro-benzene (HCB). The balance of this sample includes a conglomerate of unsaturated conjugated diene systems, both chlorinated and nonchlorinated, as well as chlorinated benzenoid systems, and a variety of mostly aromatic organic compounds. Aliquots of this Hex mixture were subjected to a series of thermal decomposition tests at 100°C intervals between 300°C and 1000°C, each at a residence time of 2.00 seconds in flowing
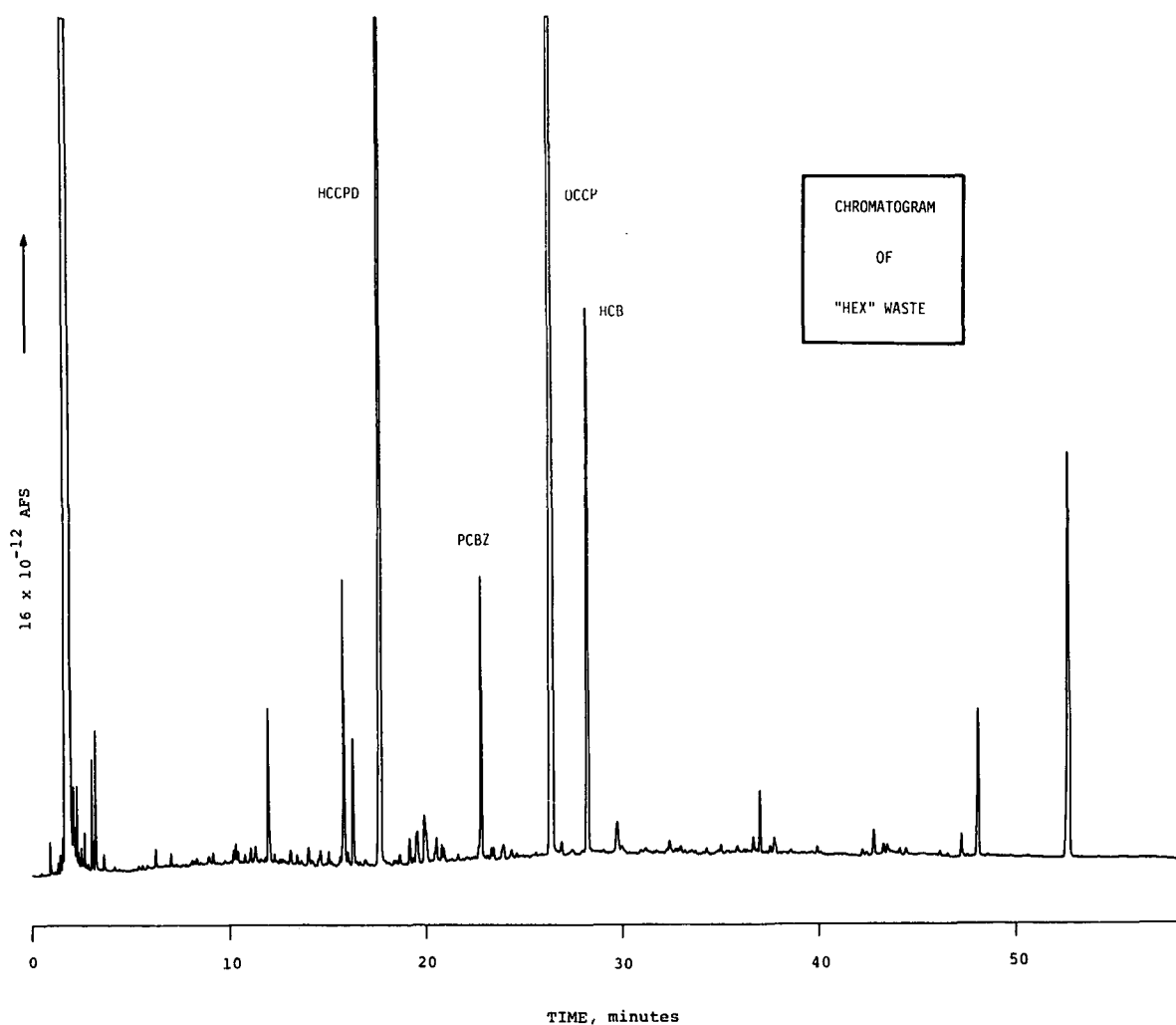
Figure 6. Chromatograph of Hex wastes.

air. The chromatographic data resulting from these thermal exposure tests are presented in the form of log-skeletal chromatograms as shown in Figure 7.

Careful examination of these chromatograms reveals several significant findings. Among these include the fact that the chlorinated conjugated diene systems (OCCP
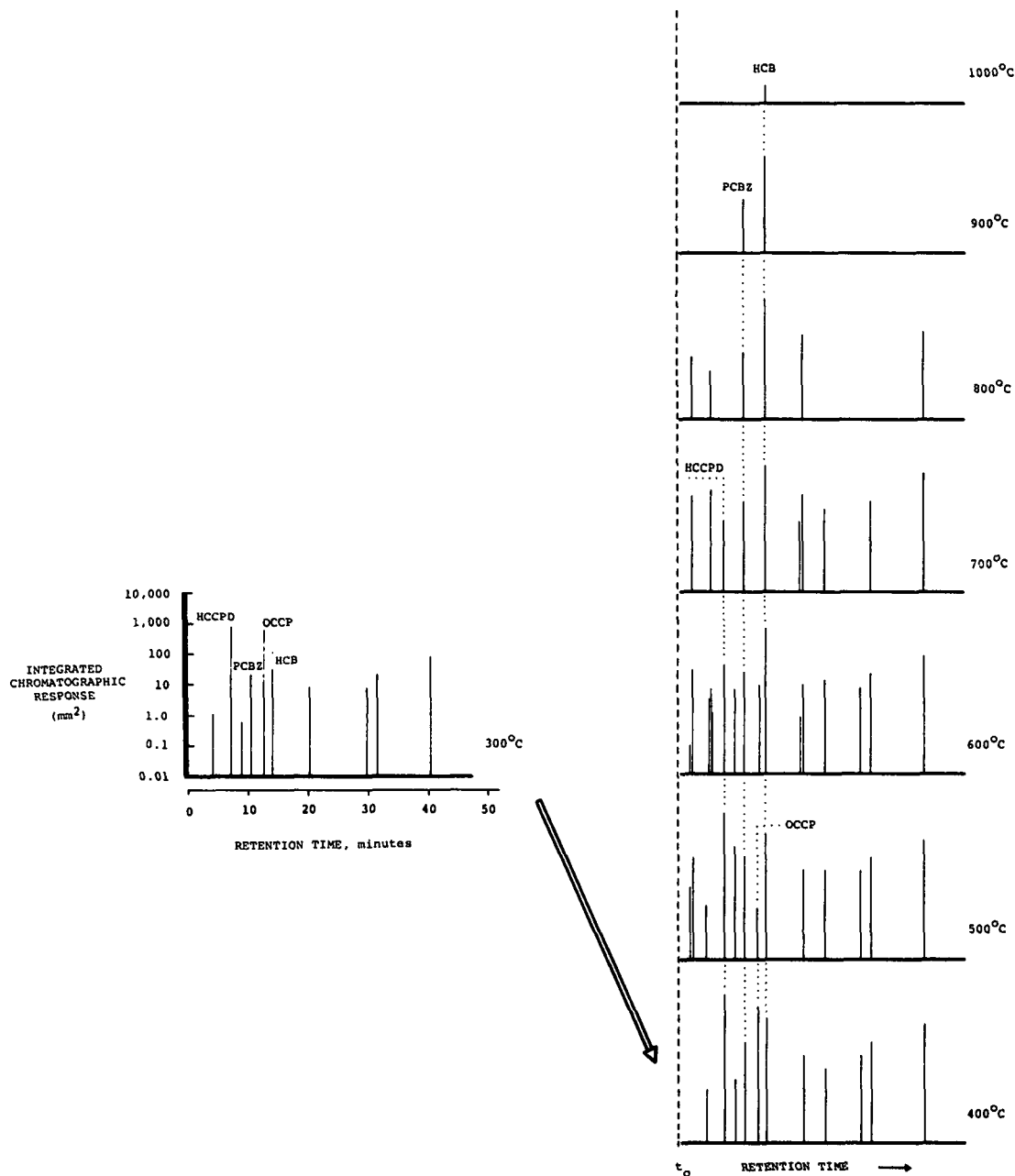
Figure 7. Decomposition profile of Hex wastes.

and HCCPD) are thermally labile in comparison to the chlorinated benzene systems (PCBZ and HCB). In addition, other compounds are formed in the decomposition process which have greater thermal stability than either OCCP or HCCPD. Mass spectral inspection of certain of these intermediate compounds discloses the incorporation of oxygen from the flowing air stream in the reactor into certain of these molecules to yield products of enhanced thermal resistance. These 'new' species are subsequently destroyed at higher thermal exposure temperatures.

Perhaps one of the more profound observations is the fact that there is a definite increase in the concentration of HCB after the first few thermal exposures as compared to its concentration in the 'non-decomposed' sample (300°C exposure). To verify this phenomenon, a plot of the relative concentrations of HCB from the various chromatograms versus exposure temperature was prepared and is presented in Figure 8.
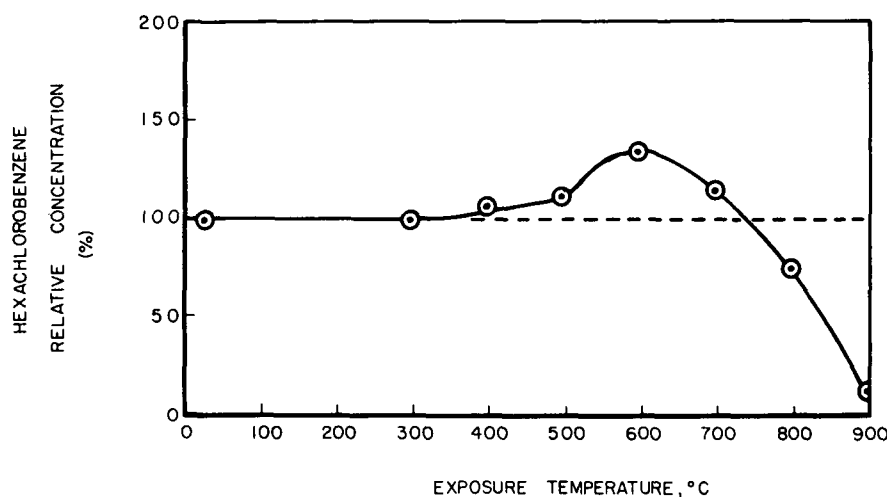
Figure 8. Concentration of HCB.

From previous work[4], it was shown that HCB is formed as a decomposition product from several different chlorinated compounds, in particular, Kepone and Mirex. In this case, a sample of HCCPD, a representative major constituent of Hex waste, was subjected to a 600°C thermal decomposition test. The result of this test showed HCB as a major product arising from the thermal decomposition of HCCPD.

The high degree of thermal stability of HCB in air has been shown in previous work[5]. The same study also pointed out the strong influence of residence time on the thermal destruction of HCB. In this current study of Hex waste it is seen that temperatures as high as 1000°C are required for the virtual destruction (99.9980 percent) of Hex waste. Even at that temperature, HCB remains at a level of approximately 20 ppm of the starting sample. It follows, then, that the possible formation of highly sta-

ble intermediates as well as highly stable initial materials be considered in specifying conditions for ultimate disposal of organic waste.

ACKNOWLEDGEMENTS

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SOCIOECONOMIC ANALYSIS OF HAZARDOUS WASTE MANAGEMENT ALTERNATIVES

Graham C. Taylor
Industrial Economics Division
University of Denver Research Institute
Denver, Colorado 80208

ABSTRACT

This paper presents a methodology for analyzing the economic and social effects of alternative approaches to hazardous waste management. The methodology recognizes the role of sociological factors in decision-making, and overcomes some of the difficulties that may be encountered if conventional economic analysis for pollution control is applied to hazardous wastes. The methodology involves the generation of a series of environmental "threat scenarios" that might arise from the use of different hazardous waste management techniques, and utilizes a simple interaction model that links policy, technological and socioeconomic aspects of waste management alternatives. A key element in the methodology is identification of "parties-at-interest" to the various waste management 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 including equity and public attitudes towards risk-taking. It is shown that while the methodology simplifies the decision-maker's task, the ultimate decision will depend on the degree of risk aversion favored, and may require subjective judgements.

Use of the methodology is illustrated by some results from a case study of hazardous waste management alternatives for Oregon.

INTRODUCTION

This paper outlines and illustrates a methodology for making hazardous waste management decisions that is based on economics, but is cognizant of sociological factors. A complete procedure for utilizing the methodology, together with extensive supporting data, will be published shortly (Taylor[9]).

It is believed that the work 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 exploit more sophisticated data when these are available. Ultimately, however, it requires a human decision-maker to choose among screened alternatives.

The methodology could be applied to the choice among alternatives for the treatment or disposal of a specific waste stream, or it could be used to help in the development of a waste management plan for a geographic area or region. Other potential applications include analysis of alternatives for the treatment or disposal of a particular category of waste at the regional or national level, and as an aid to comparing the non-technical aspects of promising new disposal techniques with existing ones. Furthermore, the methodology could be extended to assist in a wide variety of decision-making situations (not necessarily related to waste management) where costs, risks and benefits cannot readily be compared, and where sociological considerations are important.

BACKGROUND

The analysis of the special features of hazardous waste management that led to the development of the methodology has already been published (Taylor and Albrecht:[10] also see Taylor[9]) and will only be summarized here. A basic characteristic of hazardous wastes is that they pose far stronger threats to man or the environment than common wastes or pollutants. Because of the strength of these threats, 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 the latter characteristics may also be found in non-hazardous wastes, they are particularly significant to the analysis of hazardous waste management alternatives, as they make it difficult to precisely define the threats that are posed by hazardous wastes.

Because of the special characteristics of hazardous wastes, traditional approaches to the economic analysis of pollution control (e.g., see Freeman, Haveman and Kneese[3]) may not be appropriate, and comprehensive cost-benefit or risk-benefit studies may be neither feasible (due to data limitations) nor warranted for many hazardous waste problems. Instead, the author has developed 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. Since the methodology builds on a cost-benefit foundation it could also be used to supplement a cost-benefit study in order to take account of those effects that are difficult to quantify.

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 (Fisher and Peterson[2]). Instead, a central feature of the author's methodology is the use of environmental "threat scenarios." These scenarios 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," discussed below.

THE SOCIOECONOMIC INTERACTION PROCESS

Another key feature of the methodology is its explicit recognition of the role of social factors in hazardous waste management decision-making. Figure 1 illustrates a simple conceptual model that was developed to enhance our understanding of the relationships between hazardous waste management policies, what may physically happen to the wastes and the effects that this has on society. The model 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. *Policy objectives*, dealing with normative issues, are considered to be an exogenous input to the model, while *approaches* to hazardous waste management represent strategies or plans for the control of hazardous waste which are consistent with the policy objectives.

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*A technique for identifying possible threats, a bibliography of documented "incidents" (i.e., threats that have materialized) and a discussion of the valuation of environmental effects are included in Taylor.[9] Major threats associated with the various hazardous waste management techniques are listed in Taylor[9] and in Taylor and Albrecht.[10]
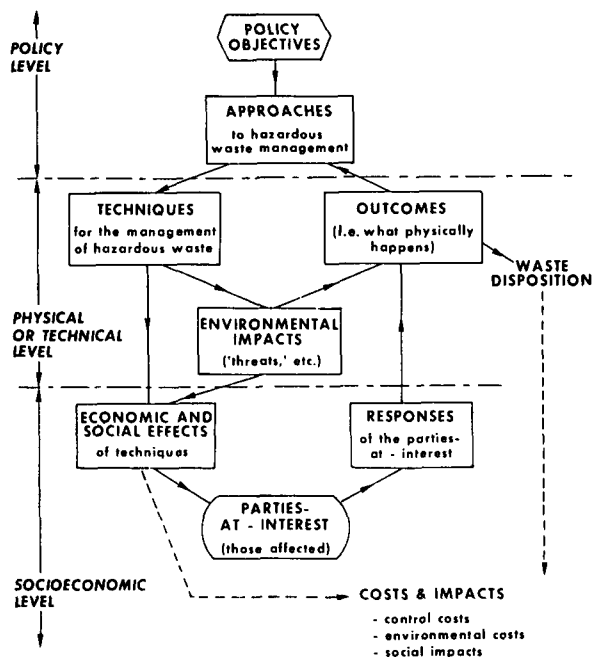
Figure 1. Interaction model for hazardous waste management.

Decisions at the policy level are largely responsible for determining what occurs at the technical level, which deals with what physically happens to the wastes and to the environment. Thus, selection of an approach will favor the use of certain techniques, i.e., the physical methods (e.g., treatment, landfilling) that may be used to manage or control hazardous wastes. The use of a given technique will cause environmental impacts. These are the physical effects, or potential effects, that could arise from the use of various hazardous waste management techniques. As noted above, they occur largely in the form of "threats."

Actions at the technical level have effects at the socioeconomic level, i.e., on society. The economic and social effects are the effects that the techniques have on man. Effects such as control costs follow directly from the use of techniques, while others arise indirectly via environmental impacts (e.g., the threat of landfill leaching, leading to groundwater contamination). 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. 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 plan or policy, moving to another location to avoid an adverse effect, etc.

There is feedback from the socioeconomic level to the technical level. Outcomes represent what physically happens in terms of hazardous waste management, allowing for the interactions and linkages that exist in practice. Thus outcomes include waste stream changes and dispositions, the responses of the parties-at-interest and the environmental impacts that occur or are threatened. Once outcomes are predicted, they can be examined for conformity with policy, and if necessary the approaches can be modified to provide results acceptable to the decision-maker.

OUTLINE OF THE METHODOLOGY

Use of the methodology involves three phases, as follows:

I. Obtain prerequisite information for analysis
II. Apply the analytical framework
III. Decision-making

The steps involved in each of these three phases are listed in Table 1, and discussed below.

Prerequisite Information for Analysis (Phase I)

Definition of the Scope of the Study (Step I.1)--

There are two aspects to the scope of the study: the geographic scope and the types of wastes to be considered. 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 cause complications.

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TABLE 1. SUMMARY OF THE 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).
9. 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.

Two aspects of *waste type* need to be considered. These are: the *source-related categories of waste*, and within these categories, the choice of a *definition of hazardous waste*. Because different categories of wastes may be amenable to different control approaches, it is often useful to distinguish between wastes from different sources; e.g., industrial process wastes, radioactive wastes, hospital wastes (pathological), chemical laboratory wastes, surplus pesticides, pesticide containers, obsolete explosives, etc. Thus, radioactive wastes are already subject to dif-

ferent regulations than chemical wastes, while regulations developed to deal with industrial process wastes might be very cumbersome if applied to small quantities of laboratory wastes, or to pesticide containers.

In many cases, definition of what makes a waste hazardous will be established by legislation or some other external dictate. In these situations, the problem may become that of predicting which wastes would test out as hazardous. In other situations, the analyst must choose a

definition of hazardous waste. This is by no means a simple matter, and reader is referred to the literature. (Criteria for determining hazard are reviewed by Taylor;[9] also see Kohan.[5])

Inventory the Existing Hazardous Waste Situation (Step I.2)--

Before detailed analysis can be commenced, it is necessary to obtain a general understanding of the existing hazardous waste situation within the study area. The information required will depend upon the objectives of the study, but for a broad planning study it would be appropriate to obtain the following data:

- Sources of wastes (SIC categories and locations)
- Types of wastes (emphasizing the hazardous components)
- Annual quantities
- Current dispositions of wastes

Many waste surveys also include estimates of future waste generation. This can be particularly important when new air and water pollution controls are expected to lead to additional wastes for disposal (e.g., scrubber and water treatment sludges), or where process technology is undergoing change.

Determination of Existing Control of Hazardous Wastes (Step I.3)--

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 necessary to determine how hazardous wastes are currently 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 should be identified. For example, regular landfills in the study area might be restricted or prohibited from accepting industrial wastes. It is therefore necessary to examine rules and regulations, licensing requirements and practices to seek out indirect ways in which hazardous wastes are controlled.

Ascertain Policy Objectives (Step I.4)--

The final prerequisite is to ascertain the policy objectives that will cover the approach to hazardous waste management 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. The goal of economic efficiency in the allocation of resources (i.e., striving towards a potential Pareto optimum) is often assumed without question (for example, see Haveman and Weisbrod;[4] Planning Branch, Treasury Board Secretariat[6]), even though it may not be realizable in practice. Other policy objectives might cover the following topics:

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

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

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

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

(v) 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 may reflect the mores of that society.

Application of the Analytical Framework (Phase II)

Application of the analytical framework involves a series of steps that largely follow the interaction model already described (Figure 1).

Development of Alternative Approaches for Hazardous Waste Management (Step II.1)--

Each *approach* represents a general philosophy or actual strategy for managing hazardous wastes that is broadly consistent

with the policy objectives. For example, one approach could be to <u>require</u> all haz- ardous wastes either to be detoxified or to be disposed of in a chemical landfill. Another example could be an incentive approach to <u>encourage</u> disposal at chemical landfills by subsidizing their operation. Different definitions of hazardous waste and what constitutes 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.

Each of the remaining steps in Phase II must be applied to every approach.

Allocation of Wastes to Techniques
  (Step II.2)--

As a preliminary action it is necessary to determine which waste management *techniques* should be considered. Techniques can be ruled out for a variety of reasons, including local infeasibility (e.g., evaporation lagooning in wet climates), technical infeasibility (e.g., biological treatment when there are no biodegradable wastes), conflict with policy (e.g., the use of ocean dumping), or excessive cost (e.g., disposal into space). However, some environmentally unacceptable techniques, such as surreptitious dumping, may occur.

The next action is to try to predict what techniques will be used to control which wastes. Each approach will have a different influence on the techniques that are used. In the absence of any specific requirements about waste disposal, firms will favor disposal or treatment techniques that minimize their costs. 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. At this stage in the evaluation process only a tentative allocation of wastes to techniques is possible, as outcomes have yet to be predicted.

Development of Threat Scenarios,
  Etc. (Step II.3)--

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, a scenario for that threat

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. For example, if it becomes apparent that the public is largely concerned with a particular threat, an appropriate threat scenario can readily be included.

In addition to threats, "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 given technique are accounted for via the control costs, these topics may also be of interest in their own right, as may land use.

Determination of Economic and
  Social Effects (Step II.4)--

The *economic and social effects* are the effects that use of the techniques have on man. These effects include costs and impacts (i.e., control costs, environmental costs and social impacts) which are an important output from Phase II of the methodology (see Step II.8).

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

Determination of the economic and social effects leads directly to identification of the *parties-at-interest*. Table 2 provides some generalizations about attitudes and behavior of the parties-at-interest, based on the author's experience and a survey of research on attitudes towards the environment (Taylor and Avitable[11]). These data can be used to predict the nature and degree of impact that a waste management technique may have on a party-at-interest.* In many situations it may be more appropriate to conduct a parties-at-interest analysis in terms of *approaches* (which could encompass more than one technique), rather than *techniques*.

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*General matrices of waste management techniques vs. impacts on parties-at-interest are presented in Taylor,[9] and Taylor and Albrecht.[10] A matrix for specific alternatives is included later in this paper.

TABLE 2. 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.

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 farther 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.

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

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 environmental 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 Outcomes (Step II.7)--

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. 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. If there were no socioeconomic interactions, simple cost minimization should determine the ways in which 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 these actions might thereby render these techniques unavailable to the waste generators, or cause them to become less attractive than others. Hence waste dispositions other than those based directly on generator's cost minimization may be chosen.

At this stage in the analysis, it is also appropriate to consider how the quantities of wastes will change in the future. It can be expected that the quantities generated will exhibit some response to price, and that increased disposal costs will encourage in-plant treatment, volume reduction and resource recovery. Known plans for new plants or expansions of existing ones can be factored in at this stage, but it should be noted 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.

Environmental threats can also be considered outcomes. Of course, only those that materialize constitute actual physical outcomes, but it seems inappropriate to segregate definite (though ill-defined) outcomes such as groundwater system modification due to deep well injection, 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 II.8)--

Once the waste dispositions are predicted, it is possible to list all the costs associated with that approach to hazardous waste management. These include generators' costs associated directly with the disposition of the wastes, and other costs of control, e.g., administrative costs, and "social costs" such as subsidies given for some forms of disposal. In addition to these costs, there may be some definite environmental costs or social impacts that can be specified, such as changes in property values or noise insult to residents along a road leading to a landfill. However, many of the environmental costs and social impacts 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. For example, transport accident statistics are widely available, whereas estimation of the probability (and consequences) of landfill liner failure would be much more difficult.

Reiteration of the Procedure (Step II.9)--

Once the above procedure (Steps II.2 through II.8) has been carried out, and the outcomes, costs and impacts associated with any approach are predicted, feedback to the policy level is possible. 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. 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 modify the levels of taxes or
subsidies to enhance effectiveness of a
situation. However, changes made at this
step are intended to be comparatively
deterministic in nature; trade-offs involv-
ing judgement are better made in Phase III
when the results of all the approaches are
compared.

Decision-Making (Phase III)

Once the application of the analytical
framework (including any suboptimization
within each approach) is reasonably com-
plete, the decision-maker can compare the
results among approaches. There are a
number of actions, detailed below, that can
simplify the decision-maker's task.

Arraying the Alternatives (Step III.1)--

Although the methodology presented
here draws strongly on the techniques of
cost-benefit and risk-benefit analysis, it
is the author's view that reducing all data
to dollar terms (which would involve using
"expected values" for risks) suppresses too
much information for environmental plan-
ning. Instead, the recommended approach
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 physi-
cal outcomes, are set out for each ap-
proach. The decision-maker is then in a
position to make his own trade-offs between
approaches.

Elimination of Subservient
  Approaches (Step III.2)--

There may be some situations in which
one approach can be unequivocably eliminat-
ed from further consideration by compari-
son with another. Consider, for example,
two projects A and B that are designed
to achieve the same objective (e.g., dis-
posal of a waste). 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, as-
suming that the only factors that enter
into the comparison of the two approaches
are the monetary control costs and the
environmental costs, approach A is sub-
servient to B and can be discarded. Analy-
sis for dominance can be a useful way of

eliminating approaches without needing to
fully evaluate some of the costs (Fisher
and Peterson[2]).

Comparison of Approaches with
  Objectives (Step III.3)--

Although the policy objectives may
have been considered during individual
approach suboptimization (Step II.9), a
more detailed scrutiny is appropriate at
this stage, when all the approaches can
be compared. It is possible that no ap-
proach will fully satisfy all the objec-
tives, and that trade-offs between objec-
tives will be necessary. Since these
trade-offs will call generally for the
exercise of some judgement, the decision-
maker should be involved.

For example, decisions about equity
are normative, as there are no established
standards of what is equitable. The
identification of the parties-at-interest
is a particularly useful tool for consider-
ing equity aspects, 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 judge the acceptability of the results.
If appropriate, he could then devise
mechanisms to render a given approach
equitable by finding ways to shift some
of the costs and impacts from one party-
at-interest to another. This process
might compromise some other objective
(e.g., administrative simplicity), calling
for a judgement on the acceptability of
the compromise.

Examination of Cost/Threat Trade-Offs,
  and Selection of an Approach
  (Steps III.4 and III.5)--

In the final analysis, the decision-
maker will usually find that he has some
comparatively well established costs, and
a series of ill-defined threats. These
costs, and threats (and any other factors,
of importance, such as resource use) will
differ from alternative to alternative.
One approach to decision-making is to make
a series of paired comparisons among the
approaches, examining the trade-offs
between changes in costs and different
environmental threats, or changed probabil-
ities that given threats will materialize.
A complicating aspect of this decision

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situation is that the 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 feel threatened (even if the threat does not materialize), then their welfare is reduced; i.e., feeling threatened is a cost. Practically everybody is risk-averse to a lesser or greater degree, and the decision-maker needs to reflect an appropriate degree of risk aversion in his choice among alternatives. There is a growing body of research (which has been reviewed by Taylor[9]) on the public acceptability of different types of risk, and this does provide some background information for such decisions. For example, a number of workers have examined how "acceptable risk" is related to perceived benefits, as a function of the nature of the risk. The results are illustrated in Figure 2, which includes Starr's[7] well-known result to that voluntary risks are

more acceptable than involuntary ones, and which also shows that controllable, familiar and known risks are more acceptable than uncontrollable, new and unknown risks. A particularly interesting (and possibly surprising) finding is that the public finds that risks with immediate conse-quences are, ceteris paribus, more acceptable than those that have delayed consequences (e.g., the dangers of aviation vs. those associated with pesticides). One effect of these preferences is to favor established technology over new technology (Fischhoff, et al.[1]).

At present, however, the research on risk evaluation does not offer specific guidance on the degree of risk aversion that should be incorporated into environmental decisions. Hence with the present state of our knowledge, selection of an appropriate degree of risk aversion remains the responsibility of the decision-maker, who must subjectively incorporate public feelings into his judgement. However, by comparing the costs of alternative approaches, he can assess the known economic penalty for the choice of one risk (or set of risks) in preference to another.

CASE STUDY

The author has demonstrated the use of the methodology by application to two widely differing situations. In one case, a decision-maker is required to choose between alternative techniques for the disposal of a single high-volume waste stream (Taylor;[9] also see Taylor and Albrecht[10]).

The second demonstration involves a case study of hazardous waste management alternatives for Oregon, and some excerpts from this study are presented here to illustrate certain aspects of the methodology's application. These excerpts do not constitute a complete demonstration of the methodology, and even the full case study (Taylor[9]) would not be sufficiently detailed or comprehensive to provide definitive planning guidance to the Oregon Department of Environmental Quality. Furthermore, it should be emphasized that some of the options considered might not be acceptable under either the Resource Conservation and Recovery Act (RCRA) or Oregon environmental laws, while the definitions used to establish whether or not a waste was hazardous do not coincide with current regulations.
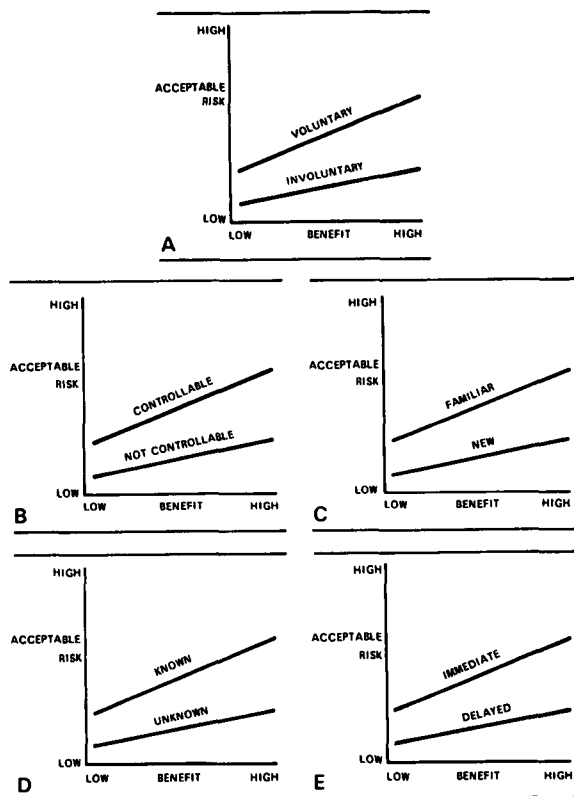
Source: Slovic and Fischhoff[8]

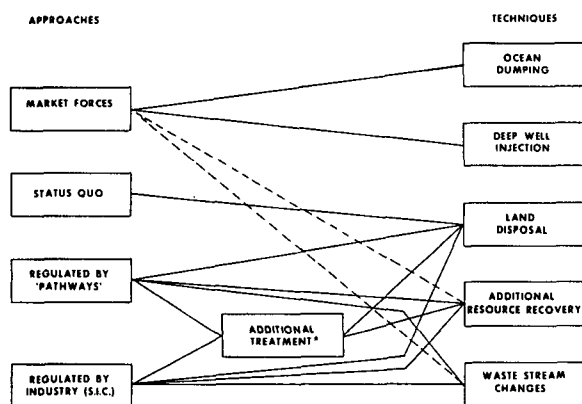Figure 2. Determinants of acceptable risks.

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Alternative Approaches for Hazardous Waste Management in Oregon

Figure 3 provides an overview of four possible approaches to hazardous waste management in Oregon, and links these approaches to the waste management techniques that may be involved. The four approaches are arranged, as one moves down Figure 3 from *Market Forces* to *Regulation by Industry (SIC)*, in increasing comprehensiveness and complexity of regulation. Depending on precisely how the approaches are specified, this could also correspond to an increasing degree of risk aversion on a decision-maker's part, or to increasing anticipated environmental quality.

The *Market Forces* approach would essentially allow waste generators to decide what they wished to do with their wastes (subject to normal legal remedies for abuses). This would open up the possibilities of ocean dumping and deep well injection, and might cause changes in waste streams and resource recovery (the latter relationships are shown dashed in Figure 3).

The *Status Quo* approach, i.e., continuation of the circa 1977 approach to hazardous waste management in Oregon, is used as a "base case." The emphasis in the *Status Quo* is on responsible land disposal.

Regulation by Pathways is intended to be similar to the approach that the Envi-

ronmental Protection Agency is adopting under RCRA. The concept is to rigorously control the "paths" that the wastes can take, but not to mandate any special forms of treatment technology, etc. The general effect of this approach would be to enhance the security of land disposal with respect to the *Status Quo*. Economic forces could tend to cause changes in waste streams and increase resource recovery.

If wastes were *Regulated by Industry (SIC)*, this could involve specifying the control or treatment technology, and/or the means of disposal for each industrial category. This approach could be arranged to give a higher or lower expected level of environmental quality than *Regulation by Pathways*, depending on the levels of treatment required and the wastes encompassed. However, this approach is extremely complex in terms of the degree of regulation required. This complexity was judged to be unjustified when measured against the achievable benefits, and consequently the approach was discarded without detailed evaluation.

Waste Disposal Under Different Approaches

Analysis showed that, even if acceptable, the techniques of ocean dumping and deep well injection were not likely to be used for economic reasons. The quantity of suitable wastes generated in Oregon is too small to make incineration a viable proposition, and it appears unlikely that any approach would cause much change in the extent to which wastes are subjected to resource recovery. (There is already a high degree of resource recovery from hazardous wastes in Oregon.) Other than for one major industry (primary aluminum production) it was not feasible to analyze in-plant waste stream changes, and hence the analysis centered on examining the costs and risks arising for the use of various alternative landfills and lagoons.

Most of Oregon's wastes arise in the Willamette Valley, a wet area of the state. Disposal possibilities considered included the use of "local" landfills (largely in the Willamette Valley) which would not provide groundwater protection, and use of the existing secure disposal site at Arlington (located in a dry part of the state, where groundwater protection is not a problem, but which is some 200-300 road kilometers from the Willamette Valley). In

*Treatment includes incineration.

Figure 3. Approaches for hazardous
waste management in Oregon.

addition, two other possibilities were considered, i.e., allowing generator's secure landfills in the drier portions of the state, and establishment of a chemical landfill in the Willamette Valley which would utilize leachate collection and treatment facilities and which would accept only solids and sludges.

Three different schemes were developed for the *Regulation by Pathways* approach. Details of these are given in Table 3, which also lists the principal threats associated with each approach. Table 4 shows an analysis of the impacts of the different approaches on the parties-at-interest, while Table 5 compares the five approaches. By making a series of comparisons, the author reduced the final choice to two approaches, the *Status Quo* and the Scheme III of *Regulation by Pathways* which utilizes the chemical landfill in the Willamette Valley in addition to the Arlington secure disposal site. Note, however, that this step called for the exercise of some judgement (assisted by the composite parties-at-interest score, shown in Table 4) since no approach could be rigorously eliminated because it was subservient to others.

Comparison of Two Approaches

Whereas the elimination of three of the approaches was reasonably straightforward and comparatively non-controversial (for the data assumed), choice between the remaining two approaches is more difficult. Table 6 presents a comparison of these approaches, using more detail than Table 5.

If it is assumed that, should threats materialize, they will do so after ten years (in which event new methods of disposal would be required), then the numerate part of the decision-maker's choice is between a present value (PV) of control costs of $2.3 million for the *Status Quo*, and $3.7 million for Scheme III of *Regulation by Pathways*, a difference of $1.4 million. This is offset by threats (of unknown probabilities) which would have PV's of $1.4 million and $0.2 million respectively on materialization. If both threats were taken as certain to materialize after ten years, the difference would be $1.2 million, suggesting that the *Status Quo* would be the preferred choice if those were the only factors involved, and the decision-maker was not risk-averse. If neither threat

TABLE 3. SUMMARY OF APPROACHES

Approach	Waste Dispositions	Principal Threats
Status Quo	Use of Arlington secure disposal site, and local landfills/lagoons	Leaching from local landfills, overflow from lagoons; leading to fish kills, etc.
Market Forces	Greater use of local landfills than under *Status Quo*	As above, but more severe
Regulation by Pathways		
Scheme I	All wastes to Arlington secure disposal site	Washout of disposal site (unlikely)
Scheme II	Wastes to Arlington, or generator's secure landfills	Washout of disposal sites
Scheme III	As Scheme II, but Willamette Valley solids and sludges sent to chemical landfill in the Valley	As above, plus Willamette Valley chemical landfill liner failure; leading to limited fish kills, etc.

TABLE 4. IMPACTS OF DIFFERENT HAZARDOUS WASTE MANAGEMENT
APPROACHES ON THE PARTIES-AT-INTEREST

Waste Management Approach

Weighting Factor	Party-at-Interest	Market Forces	Status Quo	Pathways-Scheme I (all wastes to Arlington)	Pathways-Scheme II (all wastes to dry zone disposal sites)	Pathways-Scheme III (including Willamette Valley chemical land-fill)
3	Major generators of hazardous waste	2	1	-3	-1	-1
2	Minor generators of hazardous waste	2	0	-3	-3	-1
1	Competing firms (different process)	-1	0	1	1	1
1	Waste transport sector	-1	0	2	1	1
1	Firms generating wastes deemed to be non-hazardous	1	0	2	2	2
2	Operators of sanitary landfills	2	0	-1	-1	-1
3	Residents/land owners adjacent to sanitary landfills	-2	-1	0	0	0
2	Operator(s) of chemical land-fill(s)	-3	1	3	2	2
2	Residents/land owners adjacent to Willamette Valley chemical landfill	-	-	-	-	-2
1	Resource recovery interests	-2	-1	2	1	0
2	Water supply officials	-3	-1	3	2	0
2	Anglers	-2	-1	2	2	1
2	Environmentalists	-3	-2	3	2	1
5	General public	-1	0	1	1	1
	Composite score	-22	-7	17	15	6

TABLE 5. COMPARISON OF FIVE APPROACHES

	APPROACH				
	Market Forces	Status Quo	Regulation by Pathways		
			Scheme III	Scheme II	Scheme I
CONTROL COSTS (dollars per year)					
Generators' costs*	98,200	270,200	306,400	474,400	536,500
Administrative costs	50,000	100,000	300,000	300,000	300,000
Total Control Costs	148,200	370,200	606,400	774,400	836,500
THREAT SCENARIOS (ranked by significance across approaches, 1=most significant, 5=least)					
A Transport accidents	5	4	3	2	1
B Illicit dumping	5	4	3	1	1
C Leaching from local land-fills and lagoons	1	2	NA	NA	NA
D Lagoon overflow	1	2	3	3	3
E Odor problems	1	2	3	4	4
F Arlington site washout	5	4	3	2	1
J Liner failure at Willamette Valley chemical landfill	NA	NA	1	NA	NA
OTHER EFFECTS					
Transportation distance* (thousand kilometers)	40	120	116	203	214
Parties-at-interest: composite impact score	-22	-7	6	15	17
Ranking in terms of incentive for resource recovery (1=most, 5=least)	5	4	3	2	1

NA = Not Applicable.

*Excluding materials sent for resource recovery (taken as uniform across approaches).

TABLE 6. COMPARISON OF TWO APPROACHES

	APPROACH	
	Status Quo	*Regulation by Pathways* Scheme III
CONTROL COSTS (dollars)		
Generators' Annual Costs[a]	270,200	306,400
Annual Administrative Costs	100,000	300,000
Total	370,200	606,400
PV of total control costs[a] over 10 years discounted at 10% per year	2,274,700	3,726,100
As above, over 30 years	3,489,800	5,716,500
THREAT SCENARIOS		
Major Threat Scenario	C: Leaching from local landfills and lagoons	J: Liner failure at secure landfill in Willamette Valley
At risk	Partial loss of fishing valued in total at $9.8 million/year.[b] Aesthetic damages.	Minor loss of fishing valued in total at $9.8 million/year.[b] Aesthetic damages.
Dollar estimate	10% loss of fishing ($980,000/year) from years 11 through 15. PV=$1,432,100.	Counterpumping cost of $200,000 in year 11. Fishing loss of $100,000 in years 11 through 15. PV=$223,200.
Additional risks	Contaminant concentrations might locally become high enough to render well water unsafe. If threat occurs, cost of providing alternative water supply would be involved.	
Other Threat Scenarios		
A Transport accidents	Very minor threat.	Very minor threat.
B Illicit dumping	No significant difference anticipated.	
C Leaching from land-fills, etc.	(See above)	Judged very minor threat.
D Lagoon overflow	Judged a minor threat, c.f. threat C.	Judged very minor threat.
E Odor problems	Can be controlled to be a minor threat.	Can be controlled to be a minor threat.
F Arlington site washout	Very minor threat.	Very minor threat.
OTHER EFFECTS		
Resource recovery	Little difference in incentive.[c]	
Energy use: diesel fuel consumption in trans-portation	65 cu.m.	63 cu.m.
Composite score for impact on parties-at-interest (range for 5 approaches evaluated -22 to +17)	-7	6

[a]Excluding wastes shipped for resource recovery.

[b]This is the annual value of fishing on the relevant portions of the Willamette River system.

[c]Incentive is reduced for Willamette Valley solids and sludges and increased for other wastes.

materialized, the difference in the PV's over a 30 year technological life would be $2.2 million, providing an indication of the direct cost of making the less risky choice.

In actually making the choice, there are, however, many other factors to be considered, some of which are indicated in Table 6. Also, it must be remembered that although the threats may not materialize, if they do, it is possible that they could cause greater damage, or materialize earlier, raising the PV's given above. If one examines the impacts on the parties-at-interest, it will be seen that *Regulation by Pathways* appears more desirable than the *Status Quo* (composite score 6 vs. -7). This might well be significant enough to cause a decision-maker to prefer the *Regulation by Pathways* approach, especially if he is relatively risk-averse and is concerned about the additional unquantified risks (e.g., of water supply contamination) which would be greater for the *Status Quo*.

How the decision-maker weights the many factors involved in choosing between these alternatives is (in absence of any specific agency policy guidance) up to him, although he should try to reflect public attitudes towards risk-taking in his judgement. Any decision should also be tested to see how sensitive it is to the various assumptions, particularly those like the threat scenarios that are somewhat arbitrary or based on inadequate data. However, the author hopes that by carefully arraying and examining these difficult-to-quantify and subjective aspects, the decision-maker will be helped to make good decisions.

ACKNOWLEDGEMENTS

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THE USE OF COST-BENEFIT ANALYSIS FOR HAZARDOUS WASTE MANAGEMENT

Robert C. Anderson and Roger C. Dower
Environmental Law Institute
1346 Connecticut Avenue, N.W.
Washington, D.C. 20036

ABSTRACT

Hazardous waste management poses special problems to decision makers interested in structuring an effective and efficient regulatory policy. This paper addresses the applicability of cost-benefit techniques as tools for assisting regulatory policy development for hazardous wastes. The underlying assumption is that regulatory strategies based on considerations of costs and benefits will improve resource allocation.

The paper is divided into two main sections. First, we outline the important characteristics of cost-benefit analysis and its variations. Most notably risk-benefit and cost-effectiveness analyses. We stress some obvious difficulties in applying these techniques to issues of environmental, health and safety risks; such as uncertainty over health effects and economic costs, questions of inter- and intra-generational equity and the proper value for human life. Where possible, these important issues are illustrated with examples from actual federal rulemaking processes. Undoubtedly, the same issues will arise in using cost-benefit techniques for hazardous waste management.

Second, we offer some tentative observations on current command and control approaches to hazardous waste management and the potential for improvement that could be achieved from viewing regulatory alternatives in a cost-benefit perspective. For example, a dearth of information on the location and hazard characteristics of many sites and the lack of incentives for private provision of this information may severely limit the effectiveness of the regulatory approach. Creating incentives to reveal information and to reduce the flow of hazardous wastes into the environment should improve the cost effectiveness of hazardous waste management programs.

INTRODUCTION

A major environmental problem confronting the nation over the coming decade is the proper government response to the management of hazardous wastes. It has been estimated that over 30,000 hazardous waste dump sites exist nationwide of which several hundred pose immediate health hazards, and that the costs of upgrading all sites to acceptable standards could be as high as $50 billion. The magnitude of the costs and the severity of the problems require that every effort be made to insure that resources aimed at the problem are utilized in an effective and productive manner.

EPA has structured a preliminary response to several aspects of this problem. The Agency is developing and implementing regulations under Subtitle C of the Resource Conservation and Recovery Act

(RCRA) to place technological and performance standards on all currently active hazardous waste disposal sites as well as other activities in the generation, transportation and disposal of hazardous wastes. In terms of inactive or active sites that are defined emergency situations, litigation action against current owners can be taken under Section 311 of the Clean Water Act or Section 7003 of RCRA. While no strict regulatory structure exists for coping with presently safe inactive sites, efforts to identify sites, disposed materials and disposal methods are underway.

This paper examines these regulatory problems facing EPA from a cost-benefit perspective and discusses the extent to which such methodologies can be used to aid EPA in its response to the problems of

hazardous waste management. The implicit question underlying the analysis is whether the regulatory strategies are or can be structured so that resources are allocated efficiently. Our research effort has been divided into two phases; first, a review of a number of federal regulatory decisions regarding health, safety and environmental risk within the general framework of cost-benefit analysis, and second, the application of insights gained in this review to the special problems of managing hazardous waste sites. As of this writing, the first component of the research is sufficiently complete to permit a fairly detailed discussion here. Much work remains to be done in the second component of the study, and consequently, only a few tentative hypotheses can be offered at this writing.

I. CHARACTERIZATION OF COST-BENEFIT, RISK-BENEFIT AND COST-EFFECTIVE ANALYSIS

Cost Benefit analysis is the single most important perspective for evaluating proposed public expenditures. Its cornerstone, the principle of economic efficiency, is stated clearly in the Flood Control Act of 1936. This act requires that only those projects for which the "benefits to whomsoever they accrue exceed their costs" shall be submitted for congressional action. Stated in other terms, this principle asserts that if the beneficiaries of a project had to bear the entire cost of the project, they would consider it worthwhile.

The criterion that benefits exceed costs applies to entire projects as well as their constituent parts and to small modifications thereon. Thus, one must consider both marginal costs and marginal benefits as small changes are made in a project plan and compare these incremental changes with the relevant alternatives.

In a cost-benefit analysis, all consequences are converted to a common unit of measurement, most often dollars but conceivably other measures such as lives saved or environmental quality could be used as well. When applied to the management of hazardous wastes or other environmental, health and safety risks, cost-benefit analysis runs into the delicate and controversial issue of the prices to be placed on various outcomes. For example, what price should be placed on a change of one percent in the risk of an individual

developing cancer? Or what price should be attached to the preservation of a given level of water quality in a stream?

Benefits are normally measured by the amount that beneficiaries would be willing to pay to obtain the goods and services that flow from the program. In the case of health, safety and environmental risks, the beneficiaries frequently are not identifiable individuals. Rather, the benefits typically flow to larger populations and are best expressed as a reduction in the statistical probability of incurring an adverse health effect.

Many government decision makers would reject the notion that health, safety or environmental risks should be valued at the amount individuals are willing to pay. They would prefer to use their own judgments of a program's value, giving little regard to numerical estimates of benefits at costs. A basic premise of our research effort is that actions and decisions made in this manner without consideration of benefits and costs will tend to be wasteful of resources and will lead to end results that are not as highly valued by society.

Unfortunately, a number of difficulties arise when one attempts to employ cost-benefit analysis for the management of hazardous wastes. First, rarely does scientific information permit a full determination of the health and environmental risks posed by hazardous wastes. Not only will information on the constituents of the site be incomplete, but also, in the case of abandoned sites, location and the magnitude of release of various substances to the environment may be equally uncertain. Moreover, the actual human and environmental exposure and ultimate risk may be poorly known, even when the actual releases of various substances can be monitored.

Second, even if the precise health and environmental risks were known, one would still need a means of valuing those risks. This requires in essense that one place dollar values on small changes in the probability of such adverse outcomes as cancer, heart disease and ecosystem disruption. These risks present quite a different situation from more traditional uses of cost-benefit analysis such as water resource planning. Health and

environmental risks are not traded on markets, though sometimes they may be a component of market transactions -- as when wage premiums are paid for risky employment. But unlike water, not everyone is participating in these transactions. Some individuals would not accept risky forms of employment even with wage premiums ten or twenty times as large as those which exist. Thus, inferences based upon market transactions, even where possible, may understate the value of health, safety and environmental risks to certain, perhaps large, segments of society. The alternative of directly questioning individuals about their preferences for risk encounters another difficulty. The individuals have little or no experience in acquiring and consuming the commodity, "reduction in risk to life." And how many can evaluate the significance of small changes in probabilities for the adverse outcomes? In fact, experimental evidence of human behavior indicates that individuals underrate, in an expected value sense, the losses from low probability low cost outcomes, but overrate very low probability and highly adverse outcomes. (For an interesting treatment of common biases in the interpretation of statistical information see reference 8. This specific bias is also discussed in reference 5.)

Although valuing health effects involves difficult questions of the appropriate methodology and assumptions, the underlying philosophy of cost-benefit analysis, that any group should pay for goods and services the amount that they are worth, forms a guiding principle for hazardous waste management. So, for example, if an additional unit of risk reduction, through regulation of hazardous waste sites, is valued at $10 and it costs only $8 to produce that reduction in risk, resources should be devoted to that program. To the extent that exact valuation of the risks cannot be undertaken, variants of cost-benefit analysis, discussed below, may be implemented that at least approximate the solution ideally obtained through a more rigorous framework.

Risk-benefit analysis starts from the same initial point as cost-benefit analysis in evaluating all consequences of an action. However, risk-benefit analysis stops short of a total aggregation of consequences, choosing instead to divide consequences

into two or more categories such as risks to health, safety and the environment on one hand and economic benefits on the other hand. These two categories of consequences would then compete against one another in the decision process. In general it is not necessary to place a value on the risks imposed.

Hazardous waste management decisions may be more complex than many of the familiar risk-benefit situations. For example, information must be obtained concerning the existence and magnitude of hazard posed by abandoned waste disposal sites. How much information to seek is a complex issue and is even further complicated by the fact that in some instances the acquisition of information through physical sampling may increase the risks of subsequent releases to the environment.

As noted, in risk-benefit analysis one seeks to quantify all of the consequences of a regulatory decision, trading one group of consequences off against a second (or third) group of consequences. One feature is that the final decision on how to trade risks off against benefits is not resolved explicitly. In this mode of analysis, certain alternatives can be shown to dominate others, thereby narrowing the range of decisions to be considered. However, one usually cannot eliminate alternatives by simply comparing the ratio of benefits to risks since choices based on ratios are appropriate only when projects can be extended in scale. Some of these points are illustrated in Figure 1.

Figure 1
RISK-BENEFIT TRADEOFFS
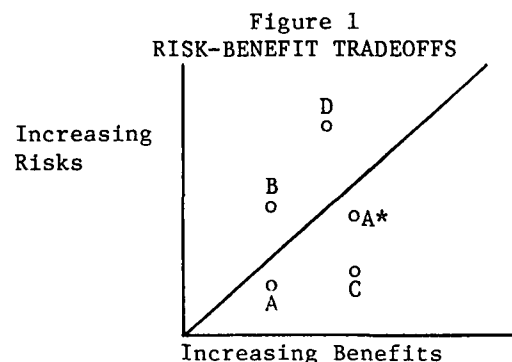
Alternative A is preferred to B because it offers less risk for the same level of benefits; likewise C is preferred to B. Alternative A is preferred to D

only if A can be extended in scale, doubling to A* where it now offers greater benefits and less risk than D. If scale expansion is not possible, one cannot choose easily between A and D.

Cost-effectiveness analysis is a generalized version of which risk-benefit analysis is the special case. Here, the consequences are aggregated into categories but there is no attempt to compare the two. Cost-effectiveness analysis sets the constraint that for a given level of control (or risk reduction) the costs of achieving that goal are minimized. Alternatively this can be expressed as maximizing the amount of control (or risk reduction) for a given level of expenditure. It is possible, therefore, that costs could exceed benefits in a cost effective solution. As in the case of risk-benefit analysis, cost-effectiveness techniques do not strictly require the valuation of risk reduction, only the measurement of the amount by which risks are reduced.

This approach can be extremely useful in choosing among alternative regulatory approaches or controls to meet a set standard for emission or some other environmental parameter. For example, when the Occupational Safety and Health Administration (OSHA) promulgated the cotton dust and coke oven emission standards, which were primarily technology based regulations, questions were raised as to whether other types of controls, such as personal protection devices, would provide the same level of risk reduction at a significantly lower cost.

Other Approaches

One criterion that provides a tempting alternative to cost-benefit approaches is "minimax" regret under which decision makers minimize the chance that the worst thing can happen. This approach provides a comfortable rationale for the decision maker who wants to protect against a major failure but is not concerned about a steady stream of small, possibly unpublicized losses as a consequence. For example, by mandating extensive testing for new drugs, an agency may protect against a very harmful drug reaching the market, but only at the expense of blocking the approval of many other beneficial new drugs if their total safety cannot be demonstrated con-

clusively. Such decisions would likely meet with opposition from a fully informed public, for if the worst outcome is highly improbable it is likely that most individuals would not seek such expensive insurance.

Another alternative to cost-benefit analysis that has recently been suggested involved soliciting public views on the value of risk reduction in general. (This concept was discussed in a presentation by Edna Loehman of the Stanford Research Institute at the American Economics Association's 1979 Annual Meeting in Atlanta.) This information, as well as other characteristics of a specific regulatory program (such as level of control, who is affected, costs, etc.) is placed within the framework of a political decision model that predicts whether the public would vote to undertake the particular program. An interesting aspect of the model is that voter response is not a function of net benefits but of the ratio of costs to benefits. While the required socio-economic survey and benefit information for this technique may be costly to obtain, it represents an intriguing alternative to the other more standard approaches.

This introductory discussion suggests that the use of cost-benefit analysis and its variants can provide improvements in the manner in which society allocates resources for the reduction of environmental, health and safety risks. For example, hazardous waste managers reviewing inactive disposal sites often face situations where there is a small probability that a serious pollution incident could result (e.g., a Love Canal) and a large probability that the wastes will remain safely contained. If waste management practices are all geared to prevent the next Love Canal, a serious misallocation of resources could result. That is, the health, safety and environmental improvement purchased by guarding against future Love Canals may provide these improvements at significantly greater cost than if resources were devoted to improvements in other areas. This point is dramatized in Table 1, which provides estimates of the cost per life saved in several environmental, health and safety programs supported, operated or mandated by the government.

The very large differences in cost per life saved indicate the great potential for using resources more effectively. Were OSHA to abandon its plans to protect so fully against occupational exposures to coke oven emissions and acrylonitrile and permit some of the money to be spent in areas where lives are saved more cheaply, hundreds of additional lives could be saved. For example, if $10 million could be diverted from the protection of coke oven workers, where the average cost per life saved is probably at least $5 million, to the elimination of railroad crossings, where the cost per life saved is more like $100,000, giving up two coke oven worker lives might save the lives of one hundred motorists.

Table 1
ESTIMATES OF COST PER LIFE SAVED

Program	Cost per Life Saved (dollars)
Medical expenditure	
Kidney transplant	72,000
Dialysis in hospital	270,000
Dialysis at home	99,000
Traffic safety	
Recommended for cost-benefit analysis by the National Safety Council	37,500
Estimate for elimination of all railroad grade crossings	100,000
Military policies	
Instructions to pilots on when to crash-land airplanes	270,000
Decision to produce a special ejector seat in a jet plane	4,500,000
Mandated by regulation	
Coke oven emissions standard, OSHA	4,500,000 to 153,000,000
Proposed lawn mower safety standards, CPSC	240,000 to 1,920,000
Proposed standard for occupational exposure to acrylonitrile, OSHA	1,963,000 to 624,976,000

Source: Reducing Risk to Life, Martin J. Bailey, American Enterprise Institute, 1979.

One of the most significant underlying reasons for these large differences in cost per life saved in Table 1 is that OSHA and other regulatory agencies typically have been given strict legislative mandates that limit the flexibility for more effective agency decision making. As a case in point, promulgation of the coke oven emission standard was directed by Section 655(b)(5) of the Occupational, Safety and Health Act (OSH Act) which states in relevant part

The Secretary...shall set the standard which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life... In addition to the attainment of the highest degree of health and safety protection for the employee, other considerations shall be the latest available scientific data in the field, (and) the feasibility of the standards.... 29 U.S.C. §655(b)(5) (1970).

It is clear that the Agency is to give greater emphasis to reducing health effects than it is to costs. Although feasibility is required, the term has been loosely defined by the courts to include technological feasibility (currently in use or "looming on the horizon") and economic costs (allowing some firms to go out of business but not to force "massive dislocation"). While there is a legal question as to whether OSHA must explicitly weight costs and benefits, current Agency interpretation dismisses this requirement. The OSH Act provides little leeway to the OSHA if a substance is known to be toxic; it must regulate up to the point of economic and technological feasibility, regardless of the relationship between costs and benefits.

A similar but distinct example involves the Food and Drug Administration's (FDA) handling of saccharin and aflatoxins under the Food, Drug and Cosmetics Act (FDCA). Both substances are known to be potential carcinogens in humans, saccharin very weak and aflatoxins relatively strong. Because the FDCA distinguishes

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between food additives such as saccharin and naturally occuring substances such as aflatoxin, placing much greater emphasis on additives, FDA is forced to regulate saccharin closely while limited action is taken against aflatoxin.

In general, legislative mandates affect the extent to which regulatory resources can be allocated. Although several recent acts have been passed or amended with language that permits or requires an Agency to compare in some fashion the costs and benefits of proposed regulations, nothing in present regulatory laws calls for an integrated strategy across agencies to produce the greatest improvement in health, safety and the environment for the resources that are used. (We note, however, that in recent sessions a number of bills have been introduced that would mandate some form of cost-benefit analysis for social regulations.)

II. DIFFICULTIES WITH THE COST-BENEFIT APPROACH

The case has been argued that a careful consideration of the costs and benefits of proposed governmental actions may lead to better decisions. It is now appropriate to reflect upon some of the difficulties with the approach, several of which have already been alluded to. In reviewing these problem areas it is important to recognize that decision mechanisms other than cost-benefit analysis are plagued with problems that are at least as serious. Therefore, the difficulties in the cost-benefit approach might best be viewed as areas where future attention should be devoted, rather than an indictment of the whole approach.

Scientific Evidence

The area that has been singled out by the EPA Science Advisory Board as most damaging to the cost-benefit mode of analysis for health, safety and environmental regulations is the paucity of hard scientific evidence on most of the substances the EPA will be regulating. The Science Advisory Board, on which sit a number of prominent environmental and resource economists, concluded recently that the poor quality of much of the scientific information on releases, exposures and ultimate human health impacts

of many environmental pollutants renders virtually useless the direct application of cost-benefit analysis for many of the regulatory decisions that EPA will be facing.

The weakness of much scientific information regarding pollution and the environment is clearly illustrated by the controversy over evidence on the carginogenic properties of saccharin. At the time of the proposed rules, a series of epidemiological and animal (rat) studies on saccharin were available to FDA. The epidemiological studies were inconclusive as to whether saccharin caused an increased risk of bladder cancer among the consuming population. The animal studies, on the other hand, showed, in general, a statistically significant increase in bladder tumors among second generation male rats. All of these studies were plagued by general methodological concerns (for example, the ability of epidemiological studies to detect low level health risks) as well as questions more applicable to specific tests (such as the purity of saccharin used.

In the face of conflicting and uncertain evidence, FDA chose to heavily rely on the results of a two-generational animal study in concluding that saccharin is carcinogenic. Even then, questions were raised as to how these results could be used to estimate the decrease in the risk of developing bladder cancer among consumers that could be attributed to the proposed regulation. Different techniques for extrapolating results from rats to humans as well as different techniques for extrapolating the high doses fed to rats to the low doses consumed by humans lead to remarkably divergent estimates of risk reduction. Although FDA finally estimated a reduction of between 0 and 4 lifetimes' risk of developing bladder cancer per 100,000 people would result from banning saccharin, this estimate of the health benefits of regulation is highly uncertain and depends crucially on several significant assumptions.

With such uncertainty surrounding the benefits from controlling a substance for which extensive testing has been done, the outlook may appear bleak for benefit estimation on substances for which little evidence is available. Such a conclusion

would cast considerable doubt on the wisdom
of pursuing a benefit analysis of future
regulatory actions. If the scientific data
base is weak, how can benefits be estimated?
In fact, there are many situations where
some benefits can be fairly accurately
measured because the scientific and engi-
neering data are reasonably good. A case
in point is the upcoming EPA regulation on
corrosive water. While the adverse health
impact of corrosive water is still open
to speculation and doubt, the damages to
municipal water supply systems are quite
well known. Cost-benefit analysis can
be used to determine the optimal treatment
of drinking water to protect supply systems
and any health benefits can simply be
viewed as an unquantified benefit. While
the actual level of corrosivity reduction
that is chosen may be somewhat less than
ideal, were all factors known and con-
sidered fully, the regulatory decision will
at a minimum be guaranteed to produce sig-
nificant net benefits to society. If
decision makers can be certain of produc-
ing positive net benefits, they can act
with much greater confidence than at
present where allegations are frequently
heard that the benefits of many of the
nation's health, safety and environmental
regulations are outweighed by the costs
of achieving compliance.

Even when the scientific data base
does not permit accurate estimation of the
human health effects from a substance being
considered for regulatory action, there
exist a number of methods, some of which
have already been mentioned in reference
to saccharin, for making informed guesses
as to effects. One of the more appealing
is the use of subjective probability
assessments provided by experts on the
issue. (A recent example of this type
of analysis is found in reference 9.)
In such a procedure, the several steps from
release and exposure to ultimate health
effects are carefully described. A panel
of experts is convened to evaluate the
parameters for each step. The resulting
range of opinion can be used both as
a measure of the central tendency of
expert opinion and as an index of the
dispersion of uncertainty inherent in
that body of opinion.

When scientific data is better, a
number of other approaches may be used.
Where data permit it, a popular approach

for assessing the possible long run
human health effects from exposure to a
suspect substance is to use multiple
regression analysis, expressing possible
adverse health effects as the dependent
variable and exposures to suspect sub-
stances as the independent variables.
(See references 2 and 6.) In such an
assessment, it is critical to control for
other variables that may also affect
health -- such as income, occupation, age
and smoking, eating and drinking habits
of the population. Most criticisms of
the epidemiological approach, especially
from the scientific community, center
around the inadequacy of these control
variables and the failure to specify the
models according to well-formulated
scientific hypotheses. While these
criticisms are certainly valid and point
out the limitations of epidemiological
studies in general, there remains the
fact that epidemiological approaches can
provide useful if imprecise information
on the linkages between past exposures
and current health effects.

A related approach termed an epi-
sodic study can be used to measure short-
run health impacts from current exposures
to a substance. In episodic studies
multiple regression analysis may again be
used to explain hospital admissions, for
example, with data on current or recent
population exposures to various air
pollutants. Such approaches reveal little
or nothing about long run impacts, but
they do reveal a wealth of information
on short-run morbidity impacts. These
latter impacts may be just as interesting
to the regulatory agencies as are chronic
morbidity and mortality.

Yet another possible means of expres-
sing environmental risks is termed the
fault tree. This approach has been widely
used to assess the probability of cata-
strophic events involving safety -- as for
example the safety of nuclear reactors. (10)
In a fault tree assessment, all known path-
ways to an ultimate catastrophy are
delineated and probabilities are attached
at each separate division in the path.
The probability of adverse outcomes is
obtained by summing the probabilities of
successfully following any of the separate
paths to disaster. The main criticism
of this approach is not so much that the
probability of the events described is

accurate, but that unknown pathways exist and may always exist for new technologies. Thus, in the case of hazardous waste management, one may be able to define probabilities of leakages to the environment for all known pathways, but just as one confidently places a very low probability on an adverse outcome a human operator error or some other event occurs that casts doubt upon the validity of the analysis.

Just as significant uncertainty may be associated with benefit estimates, the costs associated with a particular regulatory program may also be difficult to quantify accurately. During the rule-making process for the OSHA coke oven emissions standard, several groups provided cost estimates for the regulations. These estimates, arrayed in Table 2, reflect the wide variation in the assumptions made concerning: a) how the regulations are to be interpreted; b) the length of time before 100% compliance is achieved; c) and the cost elements that should be included in the analysis. Perhaps more importantly, though, is the difficulty of predicting the actual costs that will be incurred by an industry given shifts in the utilization of resources and technologies within a firm that occur after the regulation is in place. For example, during the course of the rulemaking process on OSHA's vinyl chloride standard, industry claimed that the regulation would impose huge costs on the industry. In fact, though, actual costs have been significantly lower due to production and technology shifts in the industry. (See reference 4.)

Cost measurement difficulties are compounded by the expense of acquiring information on firms in the industry. For all but the smallest industries, it is not possible to estimate costs for each firm. Rather, agencies must rely on model plant data which is extrapolated to the industry as a whole. If the model plant is descriptive of much of the industry, such analysis may provide a realistic picture of the costs imposed by a regulation, but if the industry is particularly heterogeneous, this approach may reveal little about plant closings, unemployment and the like. Furthermore, in estimating these costs, Agencies must rely primarily on industry provided data. If an industry

feels that the regulation will cause significant financial harm, it may have an incentive to bias upwards the cost estimates it gives to the Agency.

Finally, it is noteworthy that the usual engineering-type cost-estimates generated during the course of a rule-making process are not, in the form normally reported, appropriate for use in a cost-benefit analysis. In a strict sense, the costs of a regulatory program are measured by the change in consumer and producer surplus that result from price changes. Calculation of surplus losses or gains requires a knowledge of the market demand and supply conditions for the affected commodity and the shift in the supply of the commodity due to increased regulatory costs. Rarely are these parameters developed. If they were, the social or welfare cost of a regulation would generally appear lower than the simple capital and operating and maintenance costs usually provided.

This point is illustrated by the cost estimates provided by FDA during promulgation of the proposed saccharin ban. These costs were estimated to range from $715-$2079.6 million and included lost sales to diet food and beverage industries, lost sales to the sole domestic producer of saccharin and the costs of reformulating products with alternative sweeteners. (These estimates do not include the costs of banning the use of saccharin in drug products. These were treated separately by the FDA.) These costs are misleading in two respects. First, the value of lost sales is not a true cost since resources previously used in the production of products containing saccharin are transferred to other productive services which generate other sales. There is a short-run cost involved in the loss of the production capacity. In the long-run, though, resources will be employed in other uses. If the value of lost sales is subtracted from the cost estimates, the potential cost of the regulation in terms of increased production costs is in the range of $10⁷.ᵻ-$110.3 million.

Second, if these costs were passed on to consumers through price increases and then translated into consumer surplus losses, they would, most probably, be

Table 2
COST OF COMPLIANCE ESTIMATES FOR
PROPOSED OSHA COKE OVEN EMISSION STANDARD
(in millions of dollars)

Source of Estimate	Total Capital Costs	Annual Capital Costs	Other Annual Costs	Total Annual Costs
D.B. Associates-1*	451	68	173	241
D.B. Associates-2	451	45	173	218
D.B. Associates II	860	130	1,150	1,280
Council on Wage and Price Stability (CWPS)-1	410	62	98	160
CWPS-2	410	41	98	139
Steel Workers**	200	30	173	203

*Contractors for the Food and Drug Administration
**United Steelworkers of America

significantly less. This is due to the fact that the proposed ban does not restrict all uses for saccharin and the demand for saccharin products may be quite elastic, considering the number of alternatives to presweetened saccharin-containing products. The Council on Wage and Price Stability estimated the lost consumer surplus at $144-$182 million, but only by assuming an inelastic demand and a total ban on saccharin consumption.

Perhaps less troublesome than the inadequacy of scientific information to support many benefits assessments and the difficulty in accurately calculating costs are the methodological concerns economists have with the cost-benefit approach itself. These latter issues revolve around the proper treatment of uncertainty, the distribution of costs both intertemporally and among members of society today, and the values to attach to certain benefits, particularly human lives saved. Useful techniques have been identified that help one to cope with uncertainty in program evaluation. One can compute the expected value of benefits and costs by identifying the benefits and costs associated with each possible outcome and aggregating

these values using as weights the probability of each outcome.

With respect to distributional considerations, economics has little normative advice to offer. While our sensibilities may be offended by regressive programs that produce positive net benefits, economists are quick to point out that income transfers can always be arranged to compensate for adverse distributional considerations. Even when intergenerational equity is involved, it is often possible, at least in theory, for the beneficiaries in one generation to set aside a portion of the benefits to serve as compensation to the victims in some future generation. Only when the potential adverse outcomes in the future are large, as may be the case for ozone depletion by chlorofluorocarbons, may it be impossible for current beneficiaries to compensate future losers.

A recent study be economists at Resources for the Future and the Universities of Wyoming and New Mexico is one of the first careful attempts by economists to determine the intergenerational distribution consequence of cost-benefit analyses. (See reference 1.) Their

study addresses the effect of alternative ethical assumptions on the solutions obtained through a balancing of costs and benefits. Treatment of inter- and intragenerational issues enters through the discount rate and is dependent on the implied valuation of the ethical foundations. An in depth description of the study's assumptions and results are not warranted here, it is sufficient to note that the appropriateness of any regulatory scheme depends on whether the policy objective, for example, is to maximize the well-being of the worst off member of that society (whether society is defined in terms of current or future generations) or to benefit all (the standard economic criteria). This work represents a preliminary but extremely important step in understanding the distributional and ethical consequences of undertaking cost-benefit analyses.

Another controversial issue in cost-benefit evaluations is the appropriate value that should be assigned to human lives saved. While this thorny issue is skirted in cost-effectiveness and risk-benefit analysis, cost-benefit analysis must directly confront the problem of valuing morbidity and mortality effects in dollar terms. Information on these values can be obtained through a variety of avenues, such as the present value of future earnings, the wage premiums earned in risky occupations, or expenditures on life and medical insurance. Martin Bailey in <u>Reducing Risks to Life</u> describes these and other approaches in considerable detail and after thorough consideration of the valuation issue recommends that a range of about $250,000 to $450,000 be used as the value of a life for purposes of program evaluation. This valuation is independent of other factors that one may want to consider -- such as the average age and health of the population at risk -- and consequently may not be taken as the final word.

Applications to Hazardous Waste Management

The preceding discussion has attempted a balanced view of cost-benefit analysis, and associated techniques. On one hand, it has been argued that the use of these techniques can lead to social welfare gains as society's resources are more efficiently allocated. At the same time, an effort has been made to portray

accurately the difficulties encountered in applying these tools and in interpreting their results. This final section offers some tentative observations on the incorporation of cost-benefit concepts in hazardous waste management. As has been alluded to earlier, hazardous wastes pose special problems that may constrain, at least at the present time, the applicability of rigorous cost-benefit analyses.

Perhaps the most severe barrier to the application of cost-benefit approaches to hazardous waste management is the paucity of information concerning the nature of the hazards. This is particularly acute in regards to the management of inactive or abandoned disposal sites. Although there have been recent attempts to identify the location of disposal sites, many more are still undiscovered. (See reference .) The cost to the government of locating abandoned hazardous waste disposal sites is huge and the entire process will become progressively more difficult as the easily identifiable areas are found. Even if all the sites can be identified, the wastes contained in the sites (their chemical composition, etc.) are only imperfectly known. Extensive testing of the site must be undertaken to determine what hazards are posed by the wastes. Furthermore, safe inactive sites have to be distinguished from those sites that have the potential to become health hazards.

The current regulatory approach to the problems briefly discussed above has the federal and state governments taking the lead for locating, identifying and characterizing waste disposal sites. Cleanup costs and penalties are being recovered from the current owners or otherwise responsible parties through civil proceedings. Unfortunately in such a process, there exist perverse incentives for the disposing party to conceal valuable information from the government and perhaps contribute to further social harm. The total cost of acquiring the necessary information could be lessened if the entities that can generate the information most cheaply, private firms for example, had incentives to volunteer whatever site and waste characteristics they can.

Private firms in making a decision as

to whether to reveal past dumping activities that may represent a health or environmental hazard, weigh the expected private costs and benefits from providing the information. In the face of potential civil or criminal proceedings if they are found culpable, it may be in their best interest to reveal as little as possible. In structuring a cost-effective regulatory policy the government must take these private calculations into account. For example, the government may want to consider exempting firms from legal proceedings if the firms make available their knowledge on the existence and characteristics of disposal sites. Coupling such a policy with harsher sanctions (against recalcitrant firms) could provide an effective mechanism for obtaining necessary information.

Serious distributional questions arise in considering any options for cleaning up hazardous waste disposal sites. A significant portion of these questions concerns who should pay the cleanup costs. Generally accepted notions of equity would suggest that those who benefited from the disposal operation (i.e., the firm that experienced lower disposal costs and therefore the consumers of the product produced by the firm or in the case of a municipal site, local taxpayers) should pay the costs associated with the activity. Unfortunately, this position is weakened by the long periods between the disposal time and the point of regulatory action, making it difficult to identify the actual beneficiaries of the waste-generating activity. In addition, even if the responsible firm or disposal entity can be identified, they may be out of business or unable to meet the cleanup costs. If the firm is able to pay the cleanup costs and pass through these costs to consumers in the form of higher prices, the ultimate incidence of the costs will likely bear little relation to the earlier distribution of benefits from improper disposal. In situations such as these where it is impractical or impossible to identify the beneficiaries of the unsafe disposal practices or where the responsible parties are not able to pay the bill, the regulating agency must decide how the cleanup efforts will be financed.

Most of the proposals, thus far, that address the problem of financing cleanup efforts make no attempt to cope with the distributional questions raised here. Litigation efforts directed at demonstrating liability are only focused on current owners of land if a site is found. As is sometimes the case, the present owner may have purchased the land with no knowledge of disposal site's existence. Although the current owner may be able to institute similar litigation against the individual from whom he purchased the property, it must be demonstrated that the seller misrepresented the property to the buyer. This may be difficult to prove unless the issue of the disposal site was made explicit at the time of sale.

The "superfund" now under consideration by Congress represents an attempt to deal with cleanup costs for hazardous wastes (as well as petroleum spills in some versions of the legislation). Initial funding of the superfund would be achieved by taxing current production of materials that produce hazardous wastes as residues. (At least one bill also has the federal government supplementing the tax revenues.) Generally, the superfund would be used in situations where liability cannot be assigned or in instances where the nature of the hazard is so great that cleanup efforts cannot wait for the completion of possibly extended litigation. In the latter case, the fund would be replenished after liability had been assigned through the courts.

The idea of a "superfund" also raises questions of whether current consumers should pay for past mistakes for which they may not have benefited and whether industries, which are now safely disposing of their wastes, should have to pay for less clean or environmentally sound industries.

Thus far our discussion has focused on hazardous waste management in terms of proper management of disposal sites. A broader perspective would include consideration of other management actions that regulators may take to reduce the flow of hazardous wastes either at the point of generation or disposal. Current regulatory efforts indirectly have this effect by raising the costs of transporting and disposing wastes, thus providing an incentive to reduce the quantity of

waste which requires handling. A greater emphasis on direct economic incentive-type regulatory programs aimed at hazardous waste generation or disposal may be, in the long run, a more cost-effective program. For example, such concepts as a product change on hazardous waste generating activities, marketable disposal permits and a tax credit for recycling hazardous wastes should all be considered and evaluated as possible control mechanisms. The EPA has had considerable experience with such programs as they regard solid wastes and should be in a good position to investigate their applicability for hazardous waste management.

It would be useful to briefly discuss one last issue, namely the importance of distinguishing between different levels of hazardous waste health risks in setting regulatory policy. Our previous discussion on cost-benefit analysis suggests that more stringent (and therefore more costly standards) should be set on the more hazardous wastes and less stringent standards for those wastes that pose smaller health risks. If one set of standards is imposed on all types of health risks a serious misallocation of resources will result with some risks being overregulated, in the sense that dollars spent elsewhere would provide greater reduction in health risks, and, perhaps, some hazardous waste risks not being regulated strictly enough.

The porposed regulations under Subtitle C of RCRA do not allow for any such ranking of hazardous waste health risks or alternative regulatory strategies by health risk class. While we admit that the required scientific and medical information for establishing such classes may not yet be available, research efforts directed toward the goal of generating that information might prove of significant value.

Conclusions

The preceding discussion is not intended as a definitive treatment of the special regulatory problems of hazardous waste management. Rather, it is an attempt to offer some preliminary thoughts on what cost-benefit methodologies suggest for improving the overall management of hazardous wastes. The lack of information on hazardous dump sites and distributional and ethical questions of alternative

regulatory schemes are suggested as two prominent features of the problem that will limit the extent to which standard cost-benefit analyses can be implemented. Other considerations, such as the difficulty in estimating accurate cost figures in the face of uncertainty over types of hazards contained in a site and how to assess the health risks of potential hazards and then balance them against actual costs, are equally important. In later research, further consideration will be given to these and other related problems in hazardous waste management.

In light of the review of cost-benefit type techniques provided earlier, these concerns should not be taken as forming a solid barrier to economic approaches to hazardous waste decision making. Cost-benefit variants, such as cost-effectiveness analysis, should prove to be a highly useful tool in assuring that resources invested in regulatory management are efficiently and effectively utilized.

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ECONOMIC COMPARATIVE COST ANALYSIS OF

HAZARDOUS WASTE TREATMENT AND DISPOSAL

Warren G. Hansen
SCS Engineers
Redmond, Washington

Howard L. Rishel
SCS Engineers
Long Beach, California

INTRODUCTION

There is currently much interest in hazardous waste treatment and disposal technologies. Of particular interest are the costs and effectiveness of these technologies in mitigating surface and ground water contamination. Legislative actions under the Resource Conservation and Recovery Act (RCRA: PL 94-580) emphasize this growing national interest in the proper management of hazardous waste. Recently proposed rules (1) would require hazardous waste managers to observe strict design and operation standards and to consider treatment, neutralization or reuse as alternatives to direct disposal by landfill or incineration.

Also under potential regulation are priority pollutants contained in aqueous discharges from industry and municipal treatment plants. Although still under development, these regulations will address 1) best available technology effluent limitations and guidelines, 2) new source performance standards, and 3) pretreatment standards for 21 specified industrial categories. It is expected that all limitations and standards will be defined in terms of specific toxic pollutants (elements, compounds, or families of compounds) (3).

To minimize the costs of complying with these regulations, it is necessary to determine both the costs and appropriateness of applying various treatment and disposal options under specific applications. Major factors to consider under such an evaluation include the characteristics of raw waste inputs, the performance or effectiveness of unit processes, and the associated capital and operation/maintenance (O&M) costs. Moreover, this information must be agrigated over all component modules of a technological alternative and evaluated at various levels in the scale of operation before meaningful comparisons between treatment/disposal options can be made. For these reasons, the most appropriate approach is by computer-assisted cost/performance modeling.

Project Background

Previous computer-assisted systems for assessing waste treatment options have provided useful guidance. The system developed under this project is an outgrowth of one developed for evaluating waste treatment technologies in the fruits and vegetable industry (4). In that system, treatment alternatives were configured to achieve prescribed levels of abatement. The associated costs for capital and annual O&M were developed for each component "module" of the configured technological alternatives; and, in most cases, the most important input variables were production, flow, BOD, total suspended solids, season length, and length of the processing day. The cost estimations involved materials estimates for conceptual designs and the application of unit cost estimates (e.g. cost per cubic yard of concrete). Unit costs were estimated at different scales so that economies of scale could be observed for the technological alternatives.

A similar cost model (5) was developed for the Environmental Protection Agency

(EPA) in 1973. That system used a compu-
ter to estimate equipment costs at the
module level for such items as centrifugal
pumps, heat exchangers, and tray towers.
The estimation process simulated a con-
tractor's design and costing process by
estimating vendor-supplied costs (including
total purchased and installed costs).

More recently, a system called CAPDET
(Computer-Assisted Procedures for the
Design and Evaluation of Wastewater Treat-
ment Systems) was developed for the EPA to
provide computer-designed specifications
and cost estimate for wastewater treat-
ment plants. Like the previous systems,
CAPDET uses a bottom-up approach in which
the results for component modules are com-
bined to form technology alternatives.

Project Objectives

The COSTEC (Computer Oriented System
for Technology Engineering Costing) system
described in this paper is a logical out-
growth of these prior computer-based
systems and is intended to address the new
requirements and problems of hazardous
waste management. The system is designed
to meet 3 project objectives:

● To provide concise cost information
  on current and emerging hazardous
  waste management technologies

● To provide cost and performance
  estimates for specific technologies
  at different levels of control and
  scales of operation

● To allow comparison of available
  treatment and disposal options
  according to their cost effective-
  ness in providing environmental
  protection.

Cost System Overview

COSTEC uses a bottom-up approach in
which technological alternatives for the
treatment or disposal of hazardous wastes
are each segmented into their constituent
modules (unit processes). Thirty-five
such modules were defined by preliminary
designs so as to more readily assess com-
ponent costs and module performance.
Installed capital and O&M costs were then
defined for each module (or module compo-
nents) as a function of the scale of
operation.

In developing a cost estimate for a
certain technology, the costs for each com-
ponent are estimated for that module's
scale of operation. The accumulated capital
and O&M costs for all modules in the tech-
nology are then summed over each module's
expected lifespan to develop simple average
and life-cycle average costs.

Development of Unit Cost Data

Because technology cost estimates
ultimately depend on unit cost functions
developed for each component or each
module, particular care was taken to insure
that these unit costs functions are ap-
propriate over their relevant range of
operation. In order to avoid any regional
or temporal distortions of the cost in-
formation, all estimates were defined in
terms of mid-1978 for a site near Chicago.

Sources for unit construction costs
were "Means Engineering Cost Data-1978" (6),
various material and labor cost indices,
and costs associated with the general
literature. Cost information for specialty
hardware was obtained directly from manu-
facturers.

Costs for each component were often
obtained for up to five scales of operation,
and, where economies of scale were suspect-
ed, a curvefit methodology was employed to
more accurately estimate the appropriate
cost functions. This curve fit methodology
tested a series of candidate functional
forms to determine the best fit for a com-
ponent's cost data points. Each candidate
form was a special case of the general form:

$$COST = (A + B \times Units^D)^{1/C},$$

where all costs are in mid-1978, near
Chicago terms and where natural logarithms
for "cost" and "units" can also be used.
In all cases the selected functional form
explained at least 90% of all data variation
(i.e., the bivariate coefficient of determ-
ination, R^2, was greater than 0.9) and
could be asserted with at least 95% con-
fidence level).

As shown in Tables 1 and 2, the
resulting component cost functions were
entered into computerized capital and O&M
cost files so as to expedite the estimation
of alternative technology costs.

TABLE 1.
EXAMPLE OF ENTRIES IN THE CAPITAL

COST FILE

	CODE	A	B	C	D	DESCRIPTION	UNITS
103	WDDK		.54	1.0	1.0	REDWOOD WOOD DECKING	BDFT
104	HNDRL		15.36	1.0	1.0	1-½″ ALUMINUM HANDRAIL	LF
105	SONO		225	1.0	1.0	12″ RND SONOTUBECIP ANCHRBLTS	CY
106	KILN	135939	5616.8	1.4	1.0	ROTARY KILN INCINERATOR	LBS/HR
107	HEART	15312	35.525	1.5	1.0	MULTIPLE HEARTH INCINER	LBS/HR
108	CONDE	5.0469E09	5.0398E08	2.5	1.0	CONDENSOR	GPM
109	REBO1	2923281	21091	1.5	1.0	REBOILER	SF
110	EXCHA	1863624	13446	1.5	1.0	HEATEXCHANGER	SF
111	OILWA	50035	384.36	1.5	1.0	OIL WATER SEPARATOR PIT	LBS
112	VAPOR		3500.	1.0	1.0	CHLORINATOR	EA

TABLE 2.
EXAMPLE OF ENTRIES IN THE O&M COST FILE

O & M UNIT COST			FILE NAME:	OMMCF	
	CODE	A	B	C	D	DESCRIPTION
1	WATER	0	3.43	1.0	1.0	CHICAGO WATER RATE
2	COAL	0	126.45	1.0	1.0	ANTHRACITE COAL
3	SAND	0	388.42	1.0	1.0	SILICA SAND
4	POWER	0	.035	1.0	1.0	CHICAGO ELECTRICAL RATE
5	OPER1	0	7.77	1.0	1.0	OPERATOR LEVEL 1
6	OPER2	0	9.19	1.0	1.0	OPERATOR LEVEL 2
7	LABOR	0	6.76	1.0	1.0	LABORER
8	MECH1	0	9.40	1.0	1.0	MAINTENANCE MECHANIC 1
9	MECH2	0	11.20	1.0	1.0	MAINTENANCE MECHANIC 2
10	ELEC1	0	9.99	1.0	1.0	ELECTRICIAN 1
11	ELEC2	0	11.75	1.0	1.0	ELECTRICIAN 2
12	HELPR	0	7.70	1.0	1.0	MAINTENANCE HELPER
13	SUPER	0	12.94	1.0	1.0	MAINTENANCE SUPERVISOR

Cost System Operation

All elements of the COSTEC system structure are shown in Figure 1. The system user supplies information to the executive or "master" program which coordinates all other system elements. During typical use the process operates as follows:

The user selects the modules within the technology to be assessed and identifies their configuration along with any off-line modules, such as storage buildings. The executive program searches the selected module elements and returns to the user with a list of global parameters (ambient temperature, annual evaporation, etc.) and module-specific parameters (retention time, gas vs. oil fired, etc.) which the user must define. Then the user inputs a description of the waste stream, and the executive inputs this information to the first module. Costs are calculated and the waste stream attributes are modified according to performance equations within each module. The executive directs the accumulation of cost information and passes information on revised waste characteristics to successive modules as specified by the user's configuration. Summary information is then processed and output after all modules have been accessed.

Among the advantages to this approach are its flexability in response to user-specific configuration, parameters, and waste characteristics and the relative base with which unit cost functions for each module component can be updated or modified.
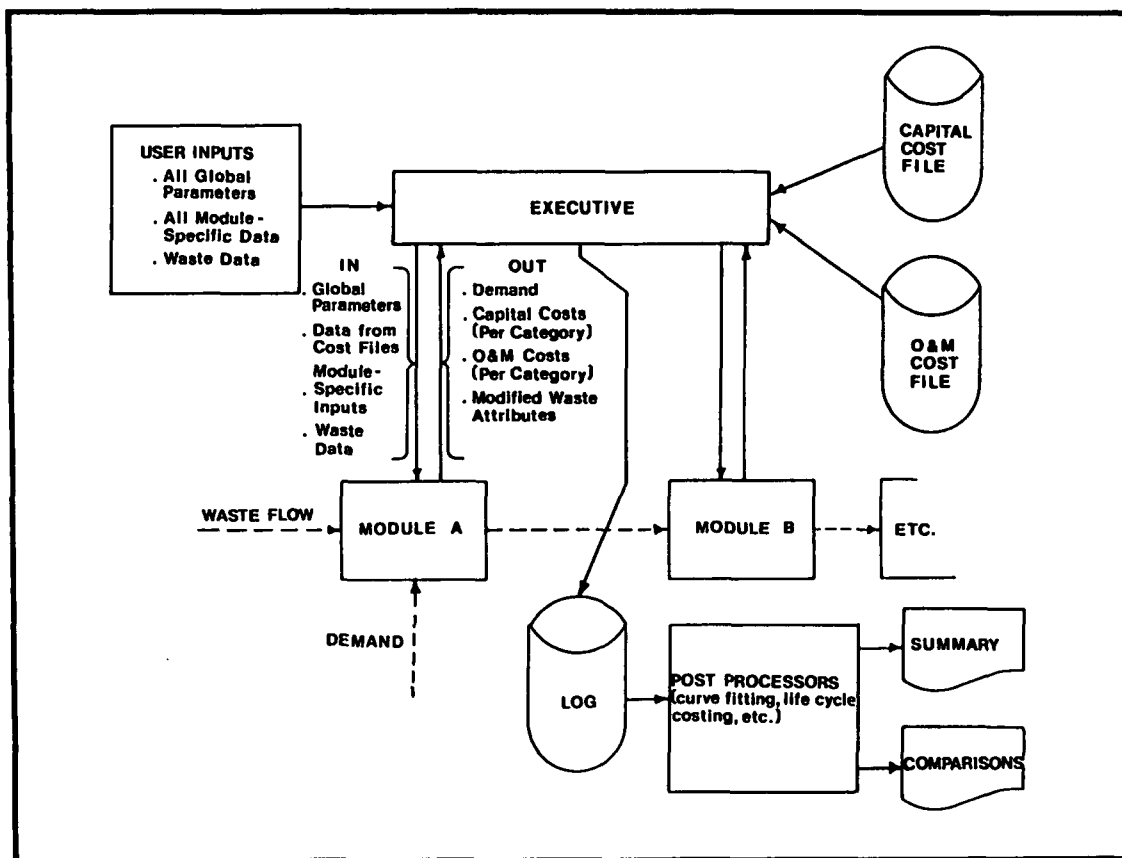

Figure 1. COSTEC System Structure.

An Example Analysis: Evaporation Module

The use of evaporator installations for concentrating organic or inorganic waste constituents is one of the 35 modules analyzed. Preliminary design, schematic diagrams (Figure 2), and engineering descriptions were used to identify components and to derive a set of equations relating component quantities to scaling factors. These equations in Table 3 are used to

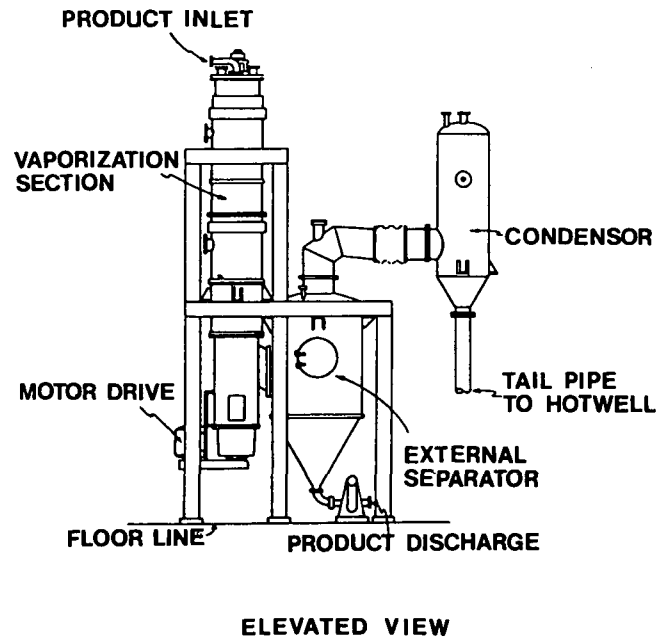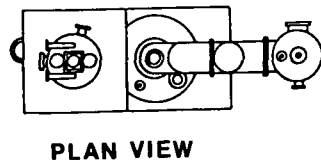**PLAN VIEW**

ELEVATED VIEW

Figure 2. Detail of single evaporator showing associated equipment included in the evaporator module.

TABLE 3. EXAMPLE CAPITAL COST EQUATIONS FOR EVAPORATOR

PROGRAM LEGEND

Program	Variable Name	Description
SYSTEM VARIABLES		
LANDAM = 0.46×QINF	QINF	Influent Flow Rate (GPM)
LANDAR = 4.0×LANDAM	VEXC	Volume of Excavation (CY)
SURFAR = LANDAR/1.91		
VEXC = 0.15×SURFAR	VCON	Volume of Concrete (CY)
VCON = 0.17×SURFAR		
SQSUF = SQRT(SURFAR)	WSTR	Weight of Support Steel (lbs)
WSTR = 35.×SURFAR+11.5×SQSUF+34.2		
WLAPL = 24.4×SURFAR+203×SQSUF+600.	WLAPL	Weight of Ladders and Platforms (lbs)
KWH = 802.88×QINF	KWH	Kilowatts/hour
HRSYR = HRS×DAYS	HRS	Hours of Operation/Day
QANF = QINF	DAYS	Days of Operation/Year
	SEPVAP	Percent of Total Discharge Flow (GPM) represented by the condensate (expressed as a percent)
CLR = CLR1×LANDAR		
GRA = GRADE×LANDAM		
EXC = EXCV1×VEXC	QSTM	Steam Demand (lbs/hr)
SITE PREP = CLR+GRA+EXC		
SLAB = SLAB2×VCON	SLUDG	Sludge (concentrate) Wasting Rate (GPM
STR = STRST×WSTR		
STRUCTURES = SLAB+STR	LANDAM	Land Area Occupied by Module (ft^2)
EVA = EVAP×QANF×1000		
CONDO = CONDEN×QANF	LANDAR	LANDAM + Buffer Area (ft^2)
STR = STRST×WLAPL		
MECH EQUIP = EVA+CONDE+STR	SURFAR	Surface Area (cross sectional) (ft^2)
ELECT EQUIP = 0.05×MECH EQUIP	CLR1	
LANDC = LAND×LANDAR	GRADE	
LAND COST = LANDC	EXCV 1	
	SLAB 2	
	STRST	COSTS FROM UNIT COST FILES
	EVAP	
	CONDEN	
	STRST	
	LAND	

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determine how much or what size of each component is required. This quantity information is then combined with the aforementioned unit cost functions to estimate capital and O&M costs for each component in the module. This information is summarized in Table 4 for installed and delivered capital costs and in Table 5 for first year operating costs.

TABLE 4. EVAPORATOR: SUMMARY OF CAPITAL COSTS

CAPITAL COST CATEGORY MODULE	COSTS (MID-1978 DOLLARS)					QUANTITIES	
	SITE PREPARATION $	STRUCTURES $	MECHANICAL EQUIPMENT $	ELECTRICAL EQUIPMENT $	LAND $	LAND (ft²)	OTHER gpm Demand lbs/hr
Evaporator	410	31,100	216,250	10,813	1,370	1,840	
Steam Generator	38	1,865	148,500		353	475	40,000
Waste Pump			2,950				
Sludge Pump			798				
Yard Piping	225		1,130				
TOTAL	673	32,965	369,628	10,813	1,723	2,315	40,000

SUPPLEMENTAL CAPITAL COSTS		
DESCRIPTION		COSTS
building		$ 97,324
	TOTAL	$ 97,324

SUBTOTAL CAPITAL COSTS	$ 513,126
WORKING CAPITAL (at one month of direct operating costs)	$ 63,615
AFDC (allowance for funds during construction at 5% of capital costs)	$ 25,656
TOTAL CAPITAL COSTS	$ 602,397

Scale: 1,000 GPM

TABLE 5. EVAPORATOR: SUMMARY OF FIRST YEAR OPERATING COSTS

O&M COST CATEGORY MODULE	COSTS (MID-1978 DOLLARS)						QUANTITIES	
	TYPE 1 OPER 1 ($7.77/hr)	LABOR TYPE 2 OPER 2 ($9.19/hr)	TYPE 3 LABORER ($6.76/hr)	ENERGY$ ELECTR. .035 KWH	MAINT. COSTS $	CHEM. COSTS $	KWHs/yr	Natl. Gas ft³/yr
Evaporator	17,703	10,476	20,513		1,125			
Steam Generator	1,179	209	15,586	319,000	1,807	372,000		44,120
Waste Pump				1,730			49,429	
Sludge Pump				173			4,943	
Yard Piping			103		6			
TOTAL	18,882	10,685	36,202	320,903	2,938	372,000	54,372	44,120

SUPPLEMENTAL O&M COSTS		
DESCRIPTION		COSTS
maintenance		$ 1,770
	TOTAL	$ 1,770

SUBTOTAL DIRECT O&M COSTS	$ 763,380
ADMINISTRATIVE OVERHEAD (at 20% of direct operating costs)	$ 152,676
DEBT SERVICE AND AMORTIZATION (at 10% interest over years)	$ 158,911
REAL ESTATE TAXES AND INSURANCE (at 2% of total capital)	$ 12,048
TOTAL FIRST YEAR OPERATING COSTS	$1,087,015

Scale: 1,000 GPM

Additional components (pumps, piping, etc.) have been added to facilitate connection of this module to others in the technology under investigation. Table 4 also includes allowances for working capital and for funds during construction; as well as the functionally-derived estimates of direct operating costs. Table 5 includes administrative overhead, debt service, real estate taxes and insurance. These indirect O&M cost components do not include an allowance for income taxes and their actual method of estimation can be changed to suit the requirements of the user.

The project report expands on this detailed cost analysis at one scale of operation by providing capital and O&M component curves over a range of operating scales. Holding other factors constant, module component requirements are depicted, as in Figures 3 and 4, as functions of such scaling factors as flow or waste loading rate. In this way the user can estimate component requirements, and hence module costs, at any scale in its potential range of operation. In addition to allowing the user to select his/her own scale of opera-
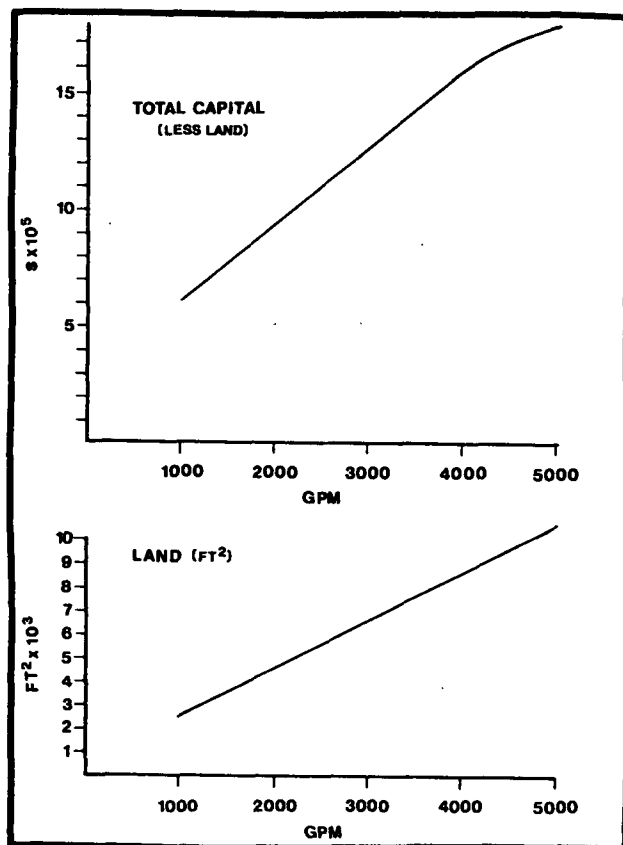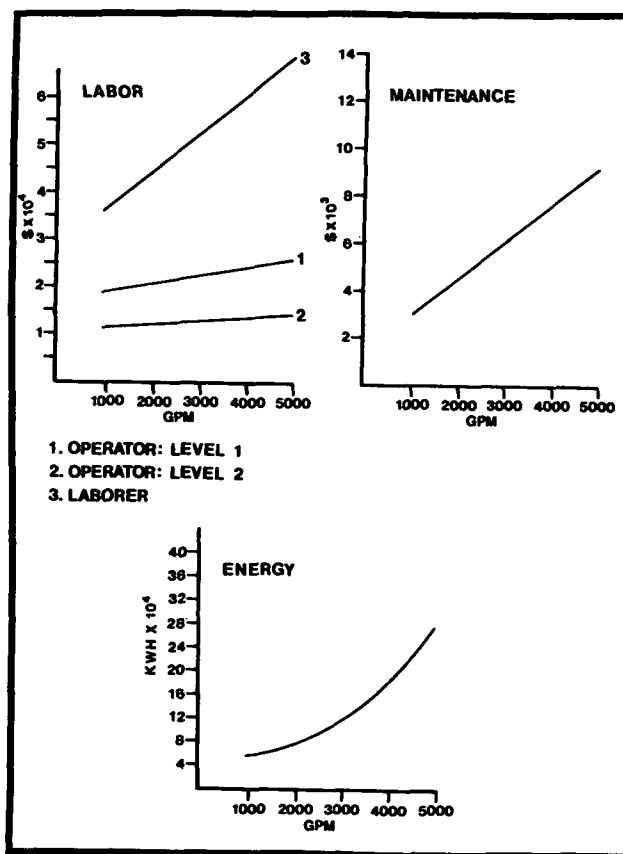

Figure 4. Evaporator: Changes in O&M requirements with scale.

tion, the depiction of such components as land or electricity in terms of units rather than dollars allows the user to apply unit costs most appropriate for local operating conditions.

As a final step in this example, the COSTEC system computes the simple average and life-cycle average costs of operating the evaporation module. As Table 6 shows, direct and indirect operating costs are calculated for each year of the module's lifespan and are summed in terms of current operating and present value operating costs. Standard interest, inflation, and discount rates are applied, but, as before, the user is encouraged to apply his/her own values for these factors.

Results

Table 7 depicts the examined technologies and their component modules. Each technology was configured with comparable input and performance requirements and all pumps and piping for connecting modules was included. The resulting simple average and life-cycle average costs were summed for

Figure 3. Evaporator: Changes in Total Capital Costs with Scale.

TABLE 6.
COMPUTATION OF LIFE CYCLE AVERAGE
COST FOR IMPLEMENTING
EVAPORATOR
(LIFETIME - 5 YEARS)

	Direct Operating Costs*	Indirect Operating Costs†	Sum Operating Costs	Present Value Annualized Costs#	Annual Quantity of Throughput (x 1,000 Gal.)**
YEAR 1‡	$ 763,380	$323,635	$1,087,015	$1,087,015	124,800
YEAR 2	839,718	338,902	1,178,620	1,071,473	124,800
YEAR 3	923,690	355,697	1,279,387	1,057,344	124,800
YEAR 4	1,016,059	374,171	1,390,229	1,044,500	124,800
YEAR 5	1,117,665	394,492	1,512,156	1,032,823	124,800
TOTALS			6,447,407	5,293,155	624,000

Simple Average (Per 1,000 Gal.)	$10.33	
Simple Average (Per Cubic Meter)	$ 2.73	
Life Cycle Average (Per 1,000 Gal.)		$8.48
Life Cycle Average (Per Cubic Meter)		$2.24

* Assumes 10% annual inflation.

† Inflation increases the administrative overhead only.

\# Assumes a 10% interest/discount rate to the beginning of the first year of operation.

** 1,000 GPM x 60 min x 8 hrs/day x 260 days/yr.

‡ First year costs in mid-1978 dollars - for Chicago example.

TABLE 7. UNIT PROCESS MODULES COMPRISING THE
HAZARDOUS WASTE TREATMENT AND DISPOSAL TECHNOLOGIES

TECHNOLOGIES \ MODULES	Flocculator	Flash Mixer	Jacketed Flash Mixer	Aerated Lagoon	Aerated Basin	Sludge Digestor	Trickling Filter	Waste Stab. Pond	Chemical Fixation	Incinerator	Sedimentation Basin	Clarifier	Rotary Drum Vacuum Filter	Air Flotation	Oil/Water Separator	Multi-media Filter	Distillation	Evaporator	Reverse Osmosis	Ultrafiltration	Carbon Adsorption	Decanter	Chemical Storage: Gas	Chemical Storage: Liquid	Chemical Storage: Solid	Sludge Equalization	Haz. Waste Land Disposal Site	Encapsulation	Deaerator	Evaporation Pond	Steam Generator	Sludge Digestor
Coagulation/Flocculation/Sedimentation	X	X									X	X												X	X							
Filtration											X		X											X								
Evaporator																		X												X		
Distillation															X									X						X		
Flotation		X									X	X												X								
Oil/Water Separator													X											X								
Reverse Osmosis																			X					X								
Ultrafiltration																				X				X								
Chemical Oxidation/Reduction	X																					X	X	X								
Hydrolysis	X																				X		X				X					
Aerated Lagoon		X									X	X	X											X								
Trickling Filter			X								X	X	X											X								
Waste Stab. Pond				X							X													X								
Anaerobic Digestion												X												X	X						X	
Carbon Adsorption																					X			X				X				
Activated Sludge		X									X	X	X											X								
Evaporation Pond																														X		
Incineration										X														X								
Land Disposal																											X					
Chemical Fixation								X																								
Encapsulation																											X					

all modules within each technology. Tables 8 and 9 present these results in metric and standard units. The scale of incineration, land disposal, chemical

TABLE 9.

COST COMPARISONS AMONG TREATMENT AND DISPOSAL
TECHNOLOGIES: STANDARD UNITS

Technology	Life	Simple Average Cost ($ per 1,000 gal.) at GPM					Life Cycle Average Cost ($ per 1,000 gal.) at GPM				
		1,000	2,000	3,000	4,000	5,000	1,000	2,000	3,000	4,000	5,000
Precipitation/Floc-culation/Sedimentation	10	2.65	2.16	1.94	1.85	1.79	1.72	1.40	1.26	1.20	1.16
Filtration	10	3.66	3.12	2.75	2.54	2.43	2.31	1.97	1.74	1.61	1.54
Evaporation	5	10.33	9.43	9.12	8.98	8.89	8.48	7.74	7.49	7.37	7.30
Distillation	5	15.86	16.36	16.37	16.36	16.40	13.02	13.39	13.41	13.40	13.43
Flotation	10	1.98	1.62	1.43	1.33	1.27	1.26	1.04	0.92	0.85	0.81
Oil/Water Separator	10	0.76	0.51	0.44	0.44	0.48	0.48	0.32	0.28	0.28	0.30
Reverse Osmosis	7	9.05	9.40	9.61	9.62	9.79	6.71	6.97	7.12	7.13	7.25
Ultrafiltration	7	4.04	3.36	3.61	3.61	3.76	3.02	2.51	2.70	2.70	2.81
Chemical Oxidation/Re-duction	5	5.31	4.56	4.52	5.23	6.22	4.36	3.74	3.71	4.29	5.10
Hydrolysis	5	0.99	0.83	0.75	0.74	0.76	0.82	0.69	0.62	0.62	0.63
Aerated Lagoon	15	5.30	3.81	3.31	3.89	4.35	2.62	1.89	1.64	1.93	2.15
Trickling Filter	15	4.70	3.82	3.63	3.30	3.19	2.37	1.93	1.84	1.68	1.63
Waste Stab. Pond	5	4.45	3.94	3.71	3.63	3.54	3.70	3.28	3.09	3.02	2.95
Anaerobic Digestion	10	7.88	6.91	6.53	6.41	6.28	5.14	4.53	4.29	4.21	4.13
Carbon Adsorption	7	27.43	16.43	12.69	10.96	9.89	20.26	12.14	9.38	8.10	7.31
Activated Sludge	10	4.84	3.54	3.11	4.02	4.84	3.08	2.28	2.00	2.57	3.10
Evaporation Pond	20	8.99	8.20	7.90	7.75	7.75	4.01	3.71	3.60	3.54	3.54

		Simple Average Cost ($ per 1,000 lbs.) at lbs/hr					Life Cycle Average Cost ($ per 1,000 lbs.) at lbs/hr				
		1,000	2,000	3,000	4,000	5,000	1,000	2,000	3,000	4,000	5,000
Incineration	5	309.90	298.23	295.10	293.34	293.64	256.55	246.91	244.34	242.88	243.15
Land Disposal	20	389.94	235.14	178.08	149.40	132.36	154.34	91.26	68.37	56.86	50.01
Chemical Fixation	7	740.84	740.85	740.84	740.84	740.85	546.85	546.85	546.85	546.85	546.85
Encapsulation	7	61.99	56.90				46.62	42.87			

fixation, and encapsulation is expressed in terms of kilograms per hour (pounds per hour). Costs for all other technologies are expressed in terms of liters per second (gallons per minute).

Discussion

The cost estimates favor coagulation/flocculation/sedimentation if discharge criteria can be met, but it may be necessary to use additional or alternative treatment processes (such as evaporators, ultrafiltration, or reverse osmosis) to insure adequate abatement. Distillation, as a treatment process, has limited application and is more expensive than evaporation. The relatively high average costs for carbon adsorption are primarily due to high capital and O&M costs for the carbon regeneration stage, but additional research could make carbon regeneration cheaper and carbon adsorption more cost-competitive and should be considered for application where sufficient land is available at reasonable cost.

The chemical fixation process was modeled after the Chemfix service (8) and should be considered for surface land disposal of liquid hazardous wastes where leaching can be a problem. The process offers the additional benefit of converting liquid wastes into a more manageable solid matrix. An alternative solidification process known as encapsulation (9) has relatively higher average life-cycle costs and should only be considered for applications where leachates would be extremely detremental (such as for disposal of PCB's or radioactive wastes).

From the results presented in Table 8 and 9, the most cost competitive disposal processes appear to be land disposal for solids, evaporation ponds for most liquid wastes and incineration for waste streams with sufficient heat value. (The incinerator defined for this analysis was a rotary kiln equipped with a secondary burner and scrubber for removal of toxic combustion products.)

Conclusions

A computer-assisted system for estimating costs of hazardous waste treatment and disposal was developed and demonstrated for 21 alternative technologies. In addition to allowing variations in scale factors

such as input flow rate and solids loading rate, the system allows user-supplied information to define technology configurations, external operating parameters, unit cost functions, and accounting methods. This flexibility and its application to hazardous waste management distinguishes the COSTEC process from earlier computer-assisted systems. Moreover, the detailed cost information presented for each module of each technology provides the user a detailed description of all cost estimates and a clearer understanding of cost effectiveness through simple average and life-cycle average cost comparisons.

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16. ABSTRACT

The sixth annual SHWRD research symposium on management of hazardous waste was held at the Conrad Hilton Hotel in Chicago, Illinois, on March 17-20, 1980. The purpose of the symposium was two-fold: (1) to provide a forum for a state-of-the-art review and discussion of ongoing and recently completed projects dealing with the management of hazardous wastes and (2) to bring together people concerned with hazardous waste management who can benefit from an exchange of ideas and information. These proceedings are a compilation of the papers presented by symposium speakers. They are divided into two volumes representing the technologies of Treatment and Disposal. The primary technical areas covered are:

(1) Waste Sampling and Characteristics
(2) Transport and Fate of Pollutants
(3) Pollutant Control
(4) Waste Treatment and Control
(5) Pesticide Treatment and Control
(6) Co-Disposal
(7) Landfill Alternatives
(8) Remedial Actions
(9) Thermal Destruction Techniques
(10) Economics

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