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Hazardous Waste Engineering
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Project Summary

Land Disposal, Remedial Action, Incineration and Treatment of Hazardous Waste: Proceedings of the Twelfth Annual Research Symposium

Harry M. Freeman and Naomi P. Barkley

Proceedings are summarized for Sessions A, B, and C of the U.S. Environmental Protection Agency's (EPA) Twelfth Annual Research Symposium on Land Disposal, Remedial Action, Incineration and Treatment of Hazardous Waste. The Symposium was held in Cincinnati, Ohio, April 21 through 23, 1986. Session A, Hazardous Waste Land Disposal, included 25 papers; Session B, Hazardous Waste Incineration and Treatment, included 25 papers; and Session C, combined HWERL posters, included 26 poster presentations. Research projects on which these papers and posters are based are sponsored by EPA's Land Pollution Control Division (LPCD), Cincinnati and Edison, New Jersey, and Alternative Technology Division (ATD), Cincinnati, of the Hazardous Waste Engineering Research Laboratory (HWERL). Land disposal subjects discussed include landfill design and operation, waste leaching and analyses, pollution migration and control, waste modification, surface impoundments, flexible membrane liners, remedial action techniques, and underground mine disposal. Incineration and treatment subjects include combustion of hazardous wastes in incinerators, boilers, and industrial processes; field evaluations, treatment options, and innovative processes for hazardous waste destruction.

This Project Summary was developed by EPA's Hazardous Waste Engineering Research Laboratory, Cincinnati, OH, to announce key findings of the research projects that are fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Fifty papers and 26 posters outlining state-of-the-art findings from research funded by HWERL were presented at EPA's Twelfth Annual Research Symposium on Land Disposal, Remedial Action, Incineration and Treatment of Hazardous Waste. Papers are abstracted and posters are listed in this Project Summary. The Symposium was conducted in three concurrent sessions—one for Hazardous Waste Land Disposal (Session A), one for Hazardous Waste Incineration and Treatment (Session B), and one for combined HWERL poster presentations (Session C). Attendees were free to alternate sessions. The Symposium provided an effective means for presenting the latest significant research results of the LPCD's and ATD's research program to industry, State and Federal agencies, universities, environmental groups, and consultants. This year's Symposium was expanded to include projects of the Releases Control Branch, Edison, New Jersey.

Session A papers were grouped into eight sessions by these topics: landfill

liners, both soils and synthetic membranes; cover systems for landfills; waste/leachate management and treatment; spills treatment; contaminated soil treatment; and control technology for Superfund sites.

Session B papers were grouped into eight sessions by these topics: treatment options for nonhalogenated and halogenated organic hazardous waste; treatment options for dioxin bearing wastes; engineering options for metals and corrosives; engineering analyses of hazardous waste incinerator performance; innovative and alternative hazardous waste technology and processes; thermal destruction research.

Session C posters were presented on selected ongoing research topics.

Papers are abstracted here. The authors listed were the speakers and/or principal investigator for the project.

Session A
Land Disposal Research Papers

Overviews

Technical Resource Documents and Technical Handbooks for Hazardous Wastes Management

Norbert B. Schomaker
U.S. Environmental Protection Agency

The U.S. EPA's Office of Research and Development (ORD) is preparing a series of Technical Resource Documents (TRDs) and Technical Handbooks to provide best engineering control technology to meet the needs of the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) respectively. These documents and handbooks are basically compilations of research efforts of ORD's Land Pollution Control Division (LPCD) to date. The specific areas of research being conducted under the RCRA land disposal program relate to laboratory, pilot and field validation studies in cover systems, waste leaching and solidification, liner systems and disposal facility evaluation. The specific areas of research being conducted under the CERCLA uncontrolled waste sites (Superfund) program relate to pilot and field validation studies in barriers, waste storage, waste treatment, modeling and post-closure evaluation. The Technical Resource Documents are intended to assist both the regulated community and the permitting authorities for development of new hazardous waste disposal facilities. The Technical Handbooks provide the EPA Program Offices and Regions, as well as the States and other interested parties, with the latest information relevant to remedial actions.

Leaking Underground Storage Tank Research Program

Richard Field and
Anthony Tafuri
U.S. Environmental Protection Agency

EPA's Office of Research and Development is undertaking research to control leaks from underground storage tanks (UST) containing petroleum products and hazardous substances regulated under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). The principal purpose of this effort is to protect the Nation's groundwater supplies from UST leak contamination as mandated by the Resource, Conservation, and Recovery Act (RCRA) reauthorization of 1984. The EPA Office of Underground Storage Tanks is responsible for the promulgation of rulemaking for UST leak control and the Hazardous Waste Engineering Research Laboratory (HWERL) together with the Environmental Monitoring and Support Laboratory-Las Vegas is responsible for the development of technical background information for the mandated rulemaking. The HWERL research program covers the areas of UST leak prevention, detection, and corrective action.

Hazardous Materials Releases Research Program

Anthony N. Tafuri
U.S. Environmental Protection Agency

An mandated by the Clean Water Act and CERCLA, EPA's Office of Research and Development is undertaking research to prevent, control and eliminate pollution caused by the releases of hazardous materials into the environment. Such releases can result from transportation accidents, in-plant discharges where the hazardous material leaves the boundary of the plant, and uncontrolled hazardous waste disposal sites. These releases pose a problem of national significance; of greatest concern is the irreversible contamination of the Nation's drinking water aquifers. What is needed, and what is being pursued under HWERL's research program, is a systematic and thorough examination/documentation of cost-effective technologies that can be applied as countermeasure operations to mitigate risk to public health and to the environment caused by these release situations.

Session A-1
Soils as Landfill Liners

Effective Porosity of Geologic Materials

Gary R. Peyton
Illinois State Water Survey

Estimation of travel times for pollu tant solutes through fine-grained, satu rated porous media is of interest in a number of areas. In all cases, such esti mation requires a knowledge of th porosity of the material. Evidence fron the chromatographic literature sug gests that the "effective porosity" of porous medium may not necessarily b the same for all solutes and/or cond tions. The object of this work was to de fine, understand and measure effectiv porosity. Diffusion is seen to play major role in determining breakthroug times in clayey materials. Approxima breakthrough times may be simply ca culated using chromatographic da analysis techniques. Differences in e fective porosity of a medium for diffe ent solutes may be very importa under the conditions of facilitated s lute transport.

Hydraulic Conductivity of Compacted Clay Soils

Andrew S. Rogowski
USDA-ARS, Northeast Watershed Research Center

To measure hydraulic conductivit field-scale research facility was c structed, consisting of a 30 × 75 f (9.1 × 22.9 m) area of clay soil co pacted in three lifts to specifications a with equipment used in construct clay liners. Analysis of bulk density, filtration and leachate data showed t zones where infiltration and leach percolation were high were also zones that were not fully saturated. analysis implied that flow may be tak place through preferential pathway areas of lower compaction density. flow rates were proportional to the

draulic gradient, in part verifying the assumption that Darcy's Law was valid. Changes in density following ponding were expressed as volume of water needed to saturate the liner. Measured swelling of the liner was very slight while overall average density increased. Infiltration and outflow rates which have increased consistently following ponding have lately begun to decline.

Geotechnical Analysis for Review of Dike Stability

Mark S. Meyers
University of Cincinnati

The structure and capabilities of a user-friendly, interactive computer program developed for the stability analysis of dikes (GARDS) are described. The GARDS program is designed to guide a geotechnical nonspecialist (EPA regulatory personnel) through the customary steps of earth dike analysis considering slope stability, settlement, liquefaction, hydraulic flow and pressure conditions, and piping. The program was developed under the sponsorship of the U.S. Environmental Protection Agency and therefore emphasizes hazardous waste applications, although it is suitable for general use. The GARDS package is designed for use on the IBM-PC/XT microcomputer.

Session A-2
Cover Systems for Landfills

The Role of Water Balance in the Long-Term Stability of Hazardous Waste Site Cover Treatments

Fairley J. Barnes
Los Alamos National Laboratory

After the 30-year postclosure maintenance period at hazardous waste landfills, long-term stability must be assured without continued intervention. Understanding water balance in the established vegetative cover system is central to predicting such stability. As part of an EPA-funded research project a series of experimental cover treatment plots were established on a closed waste disposal site. We are determining the effects of such critical parameters as soil cover design, leaf area index, and rooting characteristics on water balance under varied conditions. The results show consistent differences in soil moisture storage between soil profiles and between vegetation cover treatments. Data from these experiments are being used to examine the utility of water balance models (such as CREAMS and HELP) for predicting soil moisture storage in landfill covers.

Factors Influencing Differential Settlement and the Effects on Cover Systems

Paul A. Gilbert
USAE Waterways Experiment Station

Differential settlement can cause cracking in the cover layer of a hazardous waste landfill. If such cracking occurs, there is significant danger that the cover will be breached, releasing toxic material into the environment. Thus, there is a need for a reliable method to identify conditions which will result in excessive differential settlement, cover system cracking, and the ensuing threat to the environment.

The present work will utilize beam theory to identify material and geometric parameters which significantly influence differential settlement. It will be shown how the identified parameters may be used to control and minimize the effect of differential settlement.

An analytical procedure will be presented which allows estimation of tensile strain developed during differential settlement. Additionally, a design procedure based on this estimated tensile will be presented.

Applicability of the HELP Model in Multilayer Cover Design: A Field Verification and Modeling Assessment

Nathaniel Peters II
University of Kentucky

Data obtained from two field-scale experimental landfill covers are used to verify the ability of the Hydrologic Evaluation of Landfill Performance (HELP) model to predict the performance of a multilayer soil cover system. The data used for HELP model testing were obtained from experimental covers. The covers, which were 90 ft × 20 ft with a 3% slope in the longitudinal direction, were large enough to require field-scale compaction equipment. Extensive density and moisture testing was conducted during construction of the soil barrier layers.

A thorough description of the procedure used for estimating soil parameters is given. These initial parameters were employed in the HELP model to predict values of runoff, drainage, and percolation volumes for the covers, which are compared with actual field data. The input parameters were then optimized within each parameter's expected range, and those calibrated values were utilized to predict subsequent flows. The HELP model is shown to be capable of estimating drainage from and percolation through a multilayer soil cover for the specific geometric conditions of this site. Optimized parameters give an even better match between predicted and observed results.

Session A-3
Waste/Leachate Management

Remediation of an Industrial Dump Site—A Case History

Robert C. Ahlert
Rutgers, The State University of New Jersey

A number of industrial wastewater sludges had been accumulated in an unlined impoundment over several decades. Infiltrating rainfall produced leachate with elevated total organic carbon (TOC) and created a source of slowly diffusing groundwater contamination. Containment and treatment of leachate were straightforward means of groundwater protection. The mass of organic matter present in the lagoon translated into a prolonged period of leachate production and management. Long-term treatment and monitoring costs were considered excessive, while changes in local geohydrology might necessitate additional capital investment.

A laboratory program was carried out. An aqueous extraction scheme was developed; an optimum alkaline extraction solution was found to accelerate TOC removal by ten to fifty-fold. A parallel investigation of microbial acclimation and degradation demonstrated that traditional aerobic treatment of low-strength and high-strength leachates was about 50% effective. A bench-scale study with packed-bed bioreactors, utilizing aerobic and anaerobic microbial communities in series, exhibited greater than 95% TOC removal.

A pilot plant was designed, built and operated on-site. The pilot plant includes caustic solution preparation and application, extraction of sludge de-

posits in place, forced extract neutralization and flocculation, nutrient addition, sequential microbial treatment and effluent recycle or discharge. Typical data are presented. Pilot-scale operations have demonstrated forced leaching and complete sludge carbon destruction at high rates. It is estimated that site renovation can be accomplished in a period of 2 to 4 years, with an effluent suitable for discharge.

Reportable Quantities Guidelines for CERCLA-Designated Chemicals

Steven Gibson
Environmental Monitoring and Services, Inc.

This paper provides the technical methodology EPA has used to adjust reportable quantities (RQs) of hazardous substances which, when released, must be reported to the National Response Center. In accordance with CERCLA Section 102, the EPA Administrator must promulgate regulations to establish the level of release which triggers a response. The methodology consists of evaluating the intrinsic physical, chemical and toxicological properties of the hazardous substance. For each property a ranking scale was established from which an RQ could be derived. The final RQ for each substance is then considered for adjustment based on the substance's degradation properties (biochemical degradation, hydrolysis, photolysis). The Administrator issued the Final Rule on April 4, 1985 as 40 CFR Part 302.

Predicting Hazardous Waste Leachate Composition

Danny R. Jackson
Battelle Columbus Division

Information on the leachability and composition of leachate from wastes is needed in the design of disposal facilities and in the review of permit applications. This project is studying the use of laboratory batch extraction procedures for predicting the composition of aqueous leachate from wastes in the field. Water was passed through large diameter columns filled with solid wastes to simulate waste leaching under field conditions. The ability of selected laboratory batch procedures to predict total amounts of leachable material and maximum analyte concentrations in leachates from the large columns was investigated. This presentation describes the wastes and test conditions and compares the maximum analyte concentrations found in the column leachates and batch extracts.

Session A-4
Synthetic Membranes as Landfill Liners

Chemical Resistance of Synthetic Liner/Hazardous Waste Combinations

Gordon Bellen
National Sanitation Foundation

Laboratory testing was conducted under the sponsorship of the EPA to study the chemical resistance of flexible membrane liner materials (FMLs). Immersion tests were performed with six FMLs and 20 chemical solutions to develop liner selection guidance for FML users. The effect of time, temperature, and chemical concentration were studied. The length of immersion time ranged from one day to two years. To evaluate the effect of these challenges on the FMLs, weight, dimension, tensile properties, and tear resistance were measured. The results of the study were used to develop general principles for interpreting FML chemical immersion tests. This paper presents results and discusses interpretation principles for one FML material, a plasticized thermoplastic.

Verification of the Hydrologic Evaluation of Landfill Performance (HELP) Model Using Field Data

Lee Peyton
University of Missouri—Columbia

Simulations of 20 landfill cells from seven sites were performed using the HELP model. The results of the simulations were compared with the field data obtained from the cells to verify the HELP model and to identify inaccuracies and shortcomings of the model. Measured components of the water balance ranged from just leachate collection to percolation, lateral drainage and runoff. The descriptions and soil properties of the sites were loosely defined, requiring much judgment in the selection of HELP model input specifications and allowing significant variance in the simulation results.

Using best judgment prior to calibration, runoff was overpredicted for five cells by an average of 30% and underpredicted for six cells by an average of 20%. Evapotranspiration appeared to be underpredicted by an average of 8%, but low values of evaporative depth were used in the simulations which may account for this. Lateral drainage was overpredicted by 11% in two cells where very high leachate collection rates were observed. In three cells where very small quantities of leachate were collected, lateral drainage was underestimated by 97%, although this difference only amounted to 1.4 inches per year. Of the remaining nine cells, lateral drainage was overpredicted by an average of 7% in covered cells and overpredicted by an average of 52% in permanently uncovered cells with a weathered waste surface that supported dense vegetation.

Interfacial Stability of Soil Covers on Lined Surface Impoundments

D.H. Mitchell
Pacific Northwest Laboratory

The factors affecting the interfacial stability of soil covers on geomembranes were examined to determine the maximum stable slopes for soil cover/geomembrane systems. Several instances of instability of soil covers or geomembranes have occurred at tailings ponds, leaving exposed geomembranes with the potential for physica damage and possibly chemical and ul traviolet degradation. From an opera tor's viewpoint, it is desirable to maxi mize the slope of lined facilities in orde to maximize the volume-to-area ratio however, the likelihood for instabilit also increases with increasing slope.

Frictional data obtained from direc shear tests are compared with stabilit data obtained using a nine-square meter (m^2) engineering-scale test stan to verify that direct shear test data ai valid in slope design calculations. Inte facial frictional data from direct she tests using high-density polyethyler and a poorly graded sand cover agr within several degrees with th engineering-scale tests.

Determination of the Solubilit Parameters of FMLs for Use in Assessing Resistance to Organics

Henry E. Haxo, Jr.
Matrecon, Inc.

Results are presented of equilibri

volume swelling of 22 different polymeric FMLs and six simple polymeric compounds of known composition on immersion in water and in 23 organics ranging widely in dispersive, polarity, and hydrogen-bonding solubility parameters. Preliminary determinations of these three component solubility parameters of FMLs based on their equilibrium swelling characteristics in test liquids of various known solubility parameters are made by two graphical methods. The three solubility parameters of FMLs are being generated to use in developing a predictive model for assessing FML-waste liquid compatibility. Results indicate the potential importance of the solubility parameters of the FMLs with respect to predicting the absorption of specific organic constituents from waste liquids.

Session A-5
Leachate Treatment

Field Demonstration of In Situ Biological Treatment of Contaminated Groundwater and Soils

Roger S. Wetzel
Science Applications International Corporation

In situ biological degradation of organic contaminants was demonstrated at a waste disposal site at Kelly Air Force Base (AFB), Texas. A small-scale soil and groundwater treatment system was used to circulate groundwater by pumping and gravity injection. Oxygen, in the form of stabilized hydrogen peroxide, and specially formulated nutrients were introduced to the subsurface in order to stimulate microbial degradation of the organic contaminants. Extensive background studies were performed to characterize the site geology and hydrology, determine the contaminant profile, and demonstrate treatability in the laboratory. This project was the first field application of in situ biological treatment at a site contaminated with a complex mixture of both organic and inorganic wastes.

Problems associated with operation of an in situ biological treatment system and useful monitoring parameters are discussed. The demonstration project at Kelly AFB has provided a better understanding of the capabilities and limitations of the technology for treatment of organic contaminants in soils and groundwater.

Stringfellow Leachate Treatment with RBC

E.J. Opatken
U.S. Environmental Protection Agency

A study is underway to determine if a rotating biological contactor (RBC) can be effectively employed to treat leachate from a hazardous waste site. In this case a pilot sized RBC was installed at the U.S. EPA's Testing and Evaluation (T&E) facility in Cincinnati. The RBC was scaled down from full size to 1/10 of standard.

Prior to the leachate studies a series of kinetic runs will be made on primary effluent from the Cincinnati Mill Creek Sewage Treatment Plant to establish the capability of the RBC to convert soluble organic compounds into innocuous products. This paper reports on the results from these experiments and the effectiveness of an RBC to adequately treat leachate from a hazardous waste site.

Nondestructive Testing (NDT) Location of Containers Buried in Soil

Arthur E. Lord, Jr.
Drexel University

This paper describes work involving the detection and delineation of buried steel and plastic containers using a wide variety of NDT (remote-sensing) techniques. Seventeen techniques were considered and evaluated, and the four most promising were used in the work to be described herein. These four are electromagnetic induction, metal detection, magnetometer, and ground penetrating radar. The containers, varying in size from 5-gal to 55-gal, were buried in known distributions in a wide variety of soils, and some were also submerged in water.

As a result of the work at the five sites, a relatively complete picture has emerged concerning the strengths and weaknesses of the four major NDT subsurface container location techniques. This paper will describe the individual NDT techniques, the experimental work involved and will give a summary of the findings.

Session A-6
Spills Treatment

A Selection Guide for Mobile/Portable Treatment Technologies for the Removal of Volatile Organics from Water

Jeffrey L. Fleming
IT Corporation

This paper describes the salient features of a Guide for evaluating the applicability to hazardous substance cleanup operations of volatilization technologies such as surface sprayers, surface aerators, bubble columns, cooling towers, and steam strippers. Unaided evaporation from a pond is also addressed. The Guide enables the user to assess performance and cost under a variety of operating conditions (e.g., temperature, influent concentration, allowable liquid and gas effluent concentration, and flow rates) for "representative" equipment designs that could be transported on a trailer 8 feet wide, 45 feet long, and with a maximum height of 13.5 feet. The designs are used as a basis to calculate representative contaminant removal efficiency, treatment rates, air emissions, and treatment costs of each technology. A key parameter used in assessing these technologies is the Henry's Law Constant (H_c). A tabulation of available values of H_c is provided for CERCLA-designated volatile hazardous substances, and methods for estimating H_c are also described. Qualitative guidance is provided on other factors that should be considered during site-specific assessments of the technical and economic feasibility of volatilization technologies.

A Guidance Manual for the Selection and Use of Sorbents for Liquid Hazardous Substance Releases

Steven Gibson
Combustion Engineering, Inc.

Combined experimental and literature data were used to prepare *A Guidance Manual for the Selection and Use of Sorbents for Hazardous Substance Releases.* On-Scene Coordinators and their technical support personnel are the primary target audience for the manual.

To utilize the Manual, the user must first identify the spilled liquid. If it is one of the 200+ liquid hazardous substances addressed in the Manual, a reference is provided to one of 25 "Sorbent Selection and Use Guides." Each of the Guides enables the user to

rapidly identify generic sorbent classes, physical forms, and methods of application and collection that are most suitable for each of four different chemical release-control scenarios: 1) a spill onto land; 2) a floating release into water; 3) a non-floating release into water; and 4) immobilization for landfilling.

The Manual contains "Sorbent Data Sheets" for 13 generic classes of sorbents other than activated carbon. These data sheets contain information on manufacturers, acquisition costs, bulk density and sorbent limitations. The sorption capacity of 190 sorbent-chemical pairs was determined and recorded in the Manual. The Manual also includes cost and estimation procedures, test methods, hazardous liquid physical properties, and a description of the rationale for the release-control scenarios.

In Situ Treatment of Sodium Hydroxide Spills in Quiescent Water Bodies—An Experimental Program

Michael Borst
Mason & Hanger-Silas Mason Co., Inc.

In situ treatment of soluble hazardous material spills in quiescent water bodies has been advocated as an alternative to a withdrawal-treatment-replacement approach to avoid the necessity of transferring large volumes of water to a treatment facility. To document the practicality of this type of treatment, EPA conducted tests at the Oil and Hazardous Materials Simulated Environmental Test Tank in Leonardo, New Jersey. The program assumed from the start that the chemistry of the in situ treatment was not under examination; therefore, the selection of the contaminant and treatment chemicals was based on experimental needs and not requirements of a field (end-use) situation.

Acid/base chemistry was selected for this testing. The testing used sodium hydroxide as the contaminant because of cost and relative frequency of actual spillage. The treatment chemical selected was acetic acid because it is available in high concentrations, has a relatively low cost, and because the principal reaction product, sodium acetate, is highly soluble at the expected water temperature and biodegrades.

Session A-7
Contaminated Soil Treatment

Chemical and Microbial Stabilization Techniques for Remedial Action Sites

Janet Rickabaugh
University of Cincinnati

Highly contaminated soils at remedial action sites may require multiple technologies for successful on-site clean-up. One such example is the Chem-dyne site in Hamilton, Ohio. The site is located above a major aquifer which provides the water supply to many communities in southwestern Ohio. While this site was active, a large variety of chemicals were received in various containers. Subsequently, leaking containers and spillage caused heavy contamination to the soil in many locations on the site. Soil collected from one location on the site which contained hydrocarbons, chlorinated hydrocarbons, and organochloride pesticides was used in studies of biodegradation, surfactant scrubbing, followed by photolysis, and reverse osmosis. This paper discusses each technology and presents preliminary results from each study.

Treatment of Soils Contaminated With Heavy Metals

William D. Ellis
Science Applications International Corporation

The EPA's Hazardous Waste Engineering Research Laboratory has initiated a program to evaluate in situ methods for mitigating or eliminating environmental damage from releases of toxic and other hazardous materials to the soils around uncontrolled hazardous waste disposal sites. As part of this program, various reagents suitable for the in situ washing of heavy metal contaminants from soil were tested at laboratory scale. The work was performed on a soil from an actual Superfund site near Seattle, Washington. The soil contained five toxic heavy metals often found in hazardous waste site soils: cadmium, chromium, copper, lead, and nickel.

The tests demonstrated that sequential treatment of soil with ethylenediaminetetraacetic acid (EDTA), hydroxylamine hydrochloride, and citrate buffer was effective in removing metals from soil, and all were necessary for good cleanup. The best removals observed were: cadmium, 98%; lead, 96%; copper, 73%; chromium, 52%; and nickel, 23%.

Field Evaluation of In Situ Washing of Contaminated Soils With Water/Surfactants

James Nash
Mason & Hanger-Silas Mason Co., Inc.

Since 1981, the Releases Control Branch of the Hazardous Waste Engineering Research Laboratory has been developing techniques to wash contaminated soil in place (in situ). The project includes design and fabrication of the hardware to carry out the washing, evaluation of surfactants to do the washing, determination of which geological characteristics to use to judge the appropriateness of in situ washing, development of a monitoring and reporting system, evaluation of two candidate sites for the field testing of the hardware, and a pilot treatment study at a contaminated site.

This paper summarizes the desigr and development of the In Situ Contaminant/Treatment Unit (ISCTU) and the evaluation of surfactants for in situ soi washing. The emphasis is on work com pleted at Volk Air National Guard Base Camp Douglas, Wisconsin. The wor shows that surfactants will remov otherwise obstinate contaminants fron soil even without mechanical agitatio of the soil. However, subsequent trea ments of the surfactant laden leachate i an unresolved problem.

Session A-8
Control Technology for Superfund Sites

Effect of Freezing on the Level of Contaminants in Uncontrolled Hazardous Wast Sites—Part II: Preliminary Results

Iskandar K. Iskandar
U.S. Army Cold Regions Research and Engineering Laboratory

Artificial ground freezing has recen been identified as a potential meth for facilitating site decontaminatic This study was conducted to evalu the feasibility of using artificial grou freezing for dewatering slurries and contaminating soils at uncontrolled h ardous waste sites.

Preliminary column studies in the laboratory showed that freezing and thawing slurries significantly reduced their volume by as much as 40%. The effect of freeze/thaw on volatile organics was dependent on the number of freeze/thaw cycles and the octanol-water partition coefficient for the specific substance. For heavy metals, freeze/thaw cycling has a mixed effect.

Feasibility of Using Mined Space for Long-Term Control of Dioxin-Contaminated Soils

M. Pat Esposito
PEI Associates

The secondary use of mined space in Missouri for warehousing and other purposes strongly suggests that such spaces also could be successfully used for the long-term control of dioxin-containing soils and other hazardous wastes. This paper reviews the types of mines typically converted to secondary uses in the State and the advantages these mines offer over landfills as an alternative management option for hazardous wastes. Criteria for siting a mine for such purposes and costs for development and operation of the facility also are briefly discussed.

Session B
Incineration & Treatment Research Papers

Session B-1
Treatment Options for Non-Halogenated Organic Hazardous Waste

Review of Alternative Treatment Processes for Non-Halogenated Solvent Wastes

Benjamin L. Blaney
U.S. Environmental Protection Agency

There are both economic and regulatory incentives to treat wastes whose organic component makes them hazardous. This paper discusses management alternatives for the first set of non-halogenated wastes streams to be regulated under EPA's land disposal restriction program—the three spent solvent waste categories F003, F004 and F005. Three management alternatives for such wastes are addressed: recycle/reuse, destruction, and treatment followed by land disposal. The influence of physical waste characteristics and organic content upon the selection of waste treatment options is described.

Preliminary Assessment of Aerated Waste Treatment Systems at TSDFs

David A. Green
Research Triangle Institute

Aerated wastewater treatment unit operations are used for the removal of organic compounds from hazardous waste and industrial wastewater streams. In some operations, aeration is required to supply oxygen for aerobic decomposition of organics; in other operations, incidental air/water contact occurs to varying degrees. Methods for estimating emissions resulting from air stripping of volatile organic compounds that can accompany aerated treatment are reviewed and applied to full scale and pilot plant wastewater treatment plants.

Estimates of the fate of volatile organic compounds in waste treatment systems were made using available theoretical and semi-empirical mathematical models. The predications were compared with experimental measurements made at full-scale and pilot-scale treatment systems. It was concluded that reliable emissions estimates (i.e., estimates within the accuracy which is expected to result from variations in sampling and chemical analysis) can be made using selected mathematical models and correlations. Where plant operating conditions including residence times, aeration rates, dimensions, etc., are available, the limitations in applying the mathematical models result from lack of accurate biooxidation and partition (gas/liquid and liquid/solid) coefficient data.

An Evaluation of Batch Fractional Distillation for Removing Organics from Mixed Aqueous/Organic Wastes

C. Clark Allen
Research Triangle Institute

Batch fractional distillation was evaluated as a technique for removing volatile organics from mixtures of water and solvents. The tests were performed at a hazardous waste recycling firm. Two waste streams were chosen for study, both with high water content. One stream contained approximately 95% water, 3% methyl ethyl ketone; and 2% alcohols, chlorinated hydrocarbons, and other organics. The second stream contained 77% water, 21% acetone, and 2% other organics. Fractional distillation of both of these streams resulted in 99% removal of the organics from the aqueous bottoms, with resultant total organic concentrations in water of under 1,000 milligrams per liter.

Session B-2
Treatment Options for Halogenated Organic Hazardous Waste

Review of Alternative Treatment Processes for Halogenated Organic Waste Streams

Ronald J. Turner
U.S. Environmental Protection Agency

Many of the solvent and nonsolvent halogenated organic wastes exhibit high toxicity, mobility, persistence and bioaccumulation. The EPA's Office of Research and Development is conducting a research program to develop information on the applicability, effectiveness, capacity, cost and environmental impact of existing alternative (to land disposal) halogenated waste treatment technologies. Processes evaluated at commercial offsite treatment facilities include evaporation, distillation, steam stripping and fuel blending.

Management of Hazardous Wastes Containing Halogenated Organics

Douglas R. Roeck
GCA Technology Division, Inc.

The 1984 RCRA amendments direct EPA to study available treatment technologies for waste streams containing halogenated organic compounds. If it is determined that existing technology and capacity is sufficient for management of these wastes, then effective July 8, 1987, wastes containing halogenated organic compounds will be prohibited from land disposal. This paper presents estimates for volumes of halogenated wastes generated and managed in the United States and a brief overview of treatment technologies that have been demonstrated to be effective in handling these streams. Also presented are descriptions of and preliminary sampling results from two

treatment facilities evaluated by GCA during our continuing performance evaluation program for EPA's Hazardous Waste Engineering Research Laboratory.

Waste Minimization Case Studies for Solvents and Metals Waste Streams

Thomas J. Nunno
GCA/Technology Division

In response to the Hazardous and Solid Waste Amendments of 1984, the EPA Office of Research and Development, HWERL, initiated a program to develop case studies demonstrating waste minimization and recycling as options for improving hazardous waste management practices in the United States. The case study program is focused on solvents and metals waste streams from the metal plating and printed circuitboard industries. Specific waste streams being studied in this program include: 1) waste solvents from resist stripping and developing operations; and 2) plating baths and waste sludges from plating operations. The paper presents the progress of the facilities testing program in the early stages of this program. Technologies being tested range from small batch distillation units to continuous rinsewater treatment systems. Facilities studied are in the medium to large size range. The case study assessments being conducted under this program include a discussion of the process operations, waste streams, mass throughputs, economics of the technology, and process residuals.

Session B-3
Treatment Options for Dioxin-Bearing Wastes

A Review of Treatment Alternatives for Dioxin Wastes

Harry M. Freeman
U.S. Environmental Protection Agency

The 1984 Amendments to RCRA, called the Hazardous and Solid Waste Act amendments, direct the EPA to determine if dioxin bearing wastes should be prohibited from landfills. This determination is to be made by November 1986. Barring a determination by the Agency that the land disposal of dioxin wastes does not represent a threat to the environment, or that appropriate alternative treatment technology is not available, a land disposal prohibition would go into effect at that time. The purpose of this paper is to discuss the state of the art for several treatment processes for dioxin wastes that have been proposed for use instead of land disposal for disposing of solid and liquid wastes containing dioxins.

Evaluation of On-Site Incineration for Cleanup of Dioxin-Contaminated Materials

F. Freestone
U.S. Environmental Protection Agency

A project was initiated to evaluate the technical, economic, and administrative viability of on-site incineration of dioxin-contaminated materials in southwest Missouri. During 1984, the EPA Mobile Incineration System was extensively modified for field use.

Simultaneously, laboratory and pilot plant studies were carried out to establish optimum kiln conditions for decontamination of soils by fully volatilizing the organic contaminant, i.e., dioxin. The EPA system was judged to be more than adequate for detoxifying dioxin-contaminated solids and liquids, and could be reasonably expected to achieve a successful dioxin trial burn. Accordingly, the system was transported to the Denney Farm site in McDowell, Missouri.

From January to March 1985, extensive field shakedown activities were conducted, followed by a trial burn on dioxin-contaminated liquids and solids in April. Results indicated that destruction and removal efficiencies exceeding 99.9999% were achieved for 2,3,7,8-TCDD; no products of incomplete combustion were detected.

Session B-4
Engineering Options for Metals and Corrosives

Review of Alternative Treatment Processes For Metal-Bearing Hazardous Waste Streams

Douglas W. Grosse
U.S. Environmental Protection Agency

EPA has initiated measures to incrementally ban the land disposal of hazardous wastes generated in the United States. Wastes containing toxic metals and cyanide complexes have been selected as a group to be restricted. Many of these wastes have been identified as significant sources contributing to groundwater contamination when landfilled or land treated. EPA has been directed to identify and quantify applicable alternative treatment technologies which have the potential to treat, reduce or render nonhazardous these wastes. A review of existing alternative treatment processes is presented.

Field Evaluation of Treatment Processes for Corrosives and Metal-Bearing Waste Streams

Neville K. Chung
Metcalf & Eddy, Inc.

The 1984 amendments to RCRA require that EPA ban land disposal of certain hazardous wastes, and establish levels or methods of treatment. To implement the provisions of this legislation, EPA must determine whether adequate treatment technologies exist, what wastes can be treated and how effectively, what residuals and environmental discharges are produced, and what the associated costs are. As part of the program to develop this information, field evaluations of alternative technologies for treating or destroying wastes that have been listed for priority action were conducted. This paper reports on field evaluations of full scale processes as they are being applied at commercial hazardous waste treatment facilities for treating corrosive and metal-bearing wastes.

Recovery of Metal Values from Metal-Finishing Hydroxide Sludges by Phosphate Precipitation

L.G. Twidwell
Montana College of Mineral Science and Technology

A process for selectively recovering trivalent cations from electroplating hydroxide sludge materials has been developed. The process is based on phosphate precipitation. The advantages of the process are:

- Simple selective precipitation
- Easy solid/liquid separation
- Effective conversion of the precipitated phosphates to other products with the regeneration of phosphate reagent.

Application of the process to mixe

metal hydroxide sludges is discussed. Experimental results illustrating selective preparation, filterability rates, and conversion possibilities are also presented.

Treatment Technologies for Corrosive Hazardous Wastes

H. Paul Warner
U.S. Environmental Protection Agency

The 1984 amendments to RCRA, called the Hazardous and Solid Waste Act amendments, direct EPA to determine if corrosive wastes should be prohibited from landfills. This determination is to be made by July 1987. Barring a determination by the Agency that the land disposal of corrosive wastes does not represent a threat to the environment, or that appropriate alternative treatment technology is not available, a land disposal prohibition would go into effect at that time. The purpose of this presentation is to review the state-of-the-art for treatment processes for corrosive wastes that have been proposed for use instead of land disposal for disposing of solid and liquid corrosive wastes.

Session B-5
Engineering Analyses of Hazardous Waste Incinerator Performance

Engineering Analysis of Hazardous Waste Incineration; Energy and Mass Balance

W.R. Seeker
Energy and Environmental Research Corporation

A procedure exists for performing fast and accurate energy and mass balance calculations on the basis of limited input data using sound engineering principles. This procedure can be useful to incinerator designers and operators and especially to permit writers. Permit writers can use the procedure to evaluate the feasibility of incinerator designs and concepts to issue research, development and demonstration (RD&D) or construction permits and to evaluate the consistency of trial burn measurements and set appropriate operating limits on the basis of those measurements for operating permits of hazardous waste incinerators. Principles and applications of this procedure are discussed including the evaluation of data from two full-scale field tests and one hypothetical RD&D permit application.

The Formation of Products of Incomplete Combustion in Research Combustors

George L. Huffman
U.S. Environmental Protection Agency

Experiments were conducted in which various organic chemicals were burned, generally one at a time, along with a diluent fuel, heptane, in a pilot-scale combustor (the turbulent flame reactor, TFR) at EPA's Center Hill Facility. Excess air levels were varied in the TFR and Tenax trap samples were taken to determine the accompanying destruction and removal efficiencies (DREs) of the organic chemicals and the products of incomplete combustion (PICs).

Results showed that PICs did not always occur predictably, but that they were influenced by the principal organic hazardous constituent (POHC) being burned. When appreciable PICs were formed, however, their emission levels generally increased with increasing levels of excess air over the range of excess air levels investigated. Furthermore, the highest levels of PICs and unburned POHCs generally occurred at high excess air values.

Analysis of PIC and Total Mass Emissions from an Incinerator

Andrew R. Trenholm
Midwest Research Institute

The destruction of RCRA Appendix VIII compounds in hazardous waste incinerators and their residual stack emissions has been studied extensively. Complete characterization of organic compounds emitted in all effluents from an incinerator has not been conducted. This paper presents study plans and preliminary results of such a characterization, to the extent that the emitted compounds can be identified and quantified. Measurements will be made of both Appendix VIII and non-Appendix VIII compounds in all effluents (stack, ash, water, etc.) from an incinerator operating under both steady-state conditions and during typical transient conditions. A broad array of sampling and analysis techniques will be used. Sampling methods include Modified Method 5, volatile organic sampling train, and specific techniques for compounds such as formaldehyde. Analysis techniques include gas chromatography, gas chromatography/mass spectrometry, and high performance liquid chromatography. Continuous measurements will also be made for a variety of compounds including total hydrocarbons by flame ionization detector.

Session B-6
Innovative Hazardous Waste Technology

Concentration and Purification of Dilute Hazardous Wastes by Low Pressure Composite Membranes

D. Bhattacharyya
University of Kentucky

The use of membrane processes for waste purification and volume reduction is gaining considerable attention in many industries. For hazardous wastes containing priority organics and salts, reverse osmosis membranes can provide simultaneous separation of both organics and inorganics. The industrial development of non-cellulosic (aromatic polyamide, sulfonated polysulfone, etc.) thin-film composite membranes has provided a means for reverse osmosis treatment with high solute separations and minimal compaction problems. The low pressure reverse osmosis membranes have definite advantages in terms of energy savings, capital cost, and broad pH (2 to 12) operating ranges. Synthetic wastes utilized in this study include PAH compounds, phenol, chloro- and nitrophenols and phthalates. The polyamide (FT30-BW) membranes used in the study had 97 to 98% standard NaCl rejections and 24 to 30 gal/ft^2-day pure water flux at 300 psi. For ionizable organics such as phenol, chlorophenols, and nitrophenols, the rejections and flux drops were highly dependent on operating pH values. Membrane experimental results showed 99.5 to 99.8% rejections (at pH 11) of phenol, 2-chlorophenol, 2,4-dichlorophenol, 2,4,6-trichlorophenol, etc.

Trial Burns—Plasma Arc Technology

Nicholas P. Kolak
New York State Department of Environmental Conservation

A mobile plasma arc system for the destruction of liquid hazardous wastes has been designed and constructed, under a NYSDEC contract, by Pyrolysis Systems Inc. (Welland, Ontario, Canada). The (pyrolytic) destruction process produces acid gas, a fuel gas and finely divided carbon. The acid gas is removed in a caustic scrubber, which also captures most of the carbon; the fuel gas is flared. The system has a design feedrate of 4 kg/minutes.

The operation of the system has been tested in a series of short-term runs at Kingston, Ontario using MEK/MeOH, carbon tetrachloride, and PCBs as feed materials. DREs of greater than six "nines" were obtained for the chlorinated hydrocarbons, and the emissions from the system met environmental discharge criteria established by Canadian regulatory authorities.

Radio Frequency Enhanced In-Situ Decontamination of Soils Contaminated With Halogenated Hydrocarbons

Harsh Dev
IIT Research Institute

The techniques of radio frequency (RF) in-situ heating can be used for the treatment of soils containing hazardous chlorinated hydrocarbons. RF heating is used to rapidly heat the soil to the treatment temperature to facilitate decontamination. The feasibility of soil decontamination by thermal recovery of low boiling contaminants and chemical treatment of high boiling materials such as PCBs with dehalogenating agents has been established. In-situ RF heating is accomplished by inserting tubular electrodes into boreholes or by laying horizontal electrodes over the surface of the soil and by energizing them with an RF power source. The electrode pattern is selected based on the depth of penetration of the contaminant and the required temperature. The operating frequency is selected on the basis of the electromagnetic characteristics of the soil. Vapor and gas containment and collection systems are used to enclose the treated module.

Session B-7
Thermal Destruction Research

The Role of Rogue Droplet Combustion in Hazardous Waste Incineration

James A. Mulholland
U.S. Environmental Protection Agency

The trajectories of combustible liquid droplets injected in single, monodisperse streams into swirling, turbulent gas flames were measured in a 100 kilowatt combustor (50 centimeter internal diameter) as a function of the droplet injection parameters of size, velocity, spacing and angle. Cold flow tests were performed to measure droplet drag as a function of Reynolds number and droplet spacing. Using a general three-dimensional algorithm for modeling drag during the initial heating up and evaporation of a burning droplet, predictions of droplet trajectories are compared with the experimental observations. It is found that physical processes can dominate chemical kinetic effects during large droplet combustion, resulting in droplet bypassing and penetration of the flame zone. In the incineration of liquid hazardous wastes, where a destruction removal efficiency (DRE) of greater than 99.99% is required, lack of complete combustion of a very few individual droplets can result in an incinerator failure. Thus, predicting the fate of these rogue droplets is of paramount importance in understanding limits to DRE in the thermal destruction of hazardous wastes.

Characterization of Hazardous Waste Incineration Residuals

Carlo Castaldini
Acurex Corporation

EPA's Office of Solid Waste and Emergency Response is considering establishing a criterion for disposal of waste or residue into the land. This criterion is based on the achievement of residue quality equivalent to that from effective incineration. The purpose of this study was to provide data on the quantities and characteristics of solid and liquid discharges from hazardous waste incineration facilities. A total of 10 facilities were sampled comprising major incineration designs and flue gas treatment devices. All inlet and outlet liquid and solid streams were sampled and subjected to extensive analyses for organic and inorganic pollutant concentrations. Laboratory analyses for solid discharge streams also include leachate evaluations using standard EPA toxicity tests for metals and new EP III toxicity procedures for volatile and semivolatile organics and metals. Monitored data on incinerator facility operation was then used to determine the discharge rates of detected pollutants. This paper presents only the portion of the study associated with incinerator ash residuals.

Practical Limitation of Waste Characteristics for Effective Incineration

Edward J. Martin
PEER Consultants, Inc.

This report gives information which can be used to assess the incinerability of wastes which are subject to being banned from landfill disposal under the 1984 amendments to RCRA. Existing incinerator technology is evaluated and the characteristics of wastes which identify their incinerability are identified. Publicly accessible waste information data bases were reviewed and found to be deficient in requisite waste characterization. Commercial incinerator operators were interviewed to assess the costs of incineration and the characteristics of wastes which impact those costs.

Based upon published data from trial burns, a computerized thermodynamic model of incinerator systems with different air pollution control devices was developed which predicts the emission pathways taken by various metallic species. An extensive analysis of the potential risks to human health and the environment resultant from organic anc metallic emissions were calculated.

Incinerator and Cement Kiln Capacity for Hazardous Waste Treatment

Gregory A. Vogel
The MITRE Corp.

Estimates of incinerator and cemer kiln capacities for hazardous wast treatment are required to evaluate th impacts of banning land disposal of ha: ardous wastes. RCRA Part B permit ap plications were reviewed to obtain ir formation about incinerator desig capacity, utilization and the incinerate hazardous wastes. MITRE identified 2(incinerators within the RCRA regulato program that are presently destroyir approximately two million metric toı of hazardous waste annually. The u used potential capacity of these units estimated to be one million metric to of waste per year. The Congressior Budget Office estimates that 265.3 m

lion metric tons of hazardous waste are generated annually.

MITRE estimates that the annual hazardous waste treatment capacity available in cement kilns ranges between two and six million metric tons. Less than 5% of the potential hazardous waste treatment capacity in cement kilns has been permitted under RCRA. Factors affecting this low utilization include the large geographic distances separating some major waste generation sites from cement kilns, marginal economic benefits, and the uncertainty of some kiln operators about regulatory requirements.

Session B-8
Alternative Hazardous Waste Processes

Nonsteady-State Testing of Industrial Boilers Burning Hazardous Wastes

Carlo Castaldini
Acurex Corporation

Results from several field tests of industrial boilers burning liquid hazardous waste have indicated that these devices achieve destruction and removal efficiency (DRE) of principal organic hazardous constituents (POHC) in excess of 99.99% when operating under typical steady-state combustion conditions. Recent EPA-sponsored field tests have focused on the effect of nonsteady-state and transient boiler operation on DRE and product of incomplete combustion (PIC) formation. This paper presents test results on three industrial boilers cofiring liquid wastes spiked with hazardous organic compounds. The boilers tested comprise the major watertube design types: one gas- and oil-fired packaged boiler, one field-erected gas-fired boiler, and one coal-fired stoker. Emission sampling included detailed evaluations of volatile and semivolatile organic pollutants in the flue gas for POHC, DRE, and PIC determinations under several steady conditions and induced operational upsets. In the case of the coal-fired stoker, emission evaluations also included detailed organic and metal analyses of flue gas and flyash samples from collection devices.

Biodegradation of Chlorophenoxy Herbicides

D. Roy
Louisiana State University

Pesticides of all kinds as a broad class of man-made chemicals constitute approximately 2% of the total chemicals used by our society and herbicides make up about 50% of the quantities of pesticides used in the United States. Chlorinated phenoxy alkanoic acids, particularly 2,4-D (2,4 Dichlorophenoxy acetic acid) and 2,4,5-T (2,4,5 Trichlorophenoxy acetic acid) have maintained an important position in the herbicide market because of their widespread use. In our ongoing research on biodegradation of chlorinated herbicides and pesticides, we have isolated two new strains of *Pseudomonas* which can utilize chlorophenoxy alkanoic acids as their sole source of carbon and energy. These *Pseudomonas* isolates were obtained through the process of selective enrichment from a mixed microbial population of a municipal activated sludge treatment plant. This paper reports on the first phase of the study investigating the applicability of the two new isolates in detoxification and biodegradation of chlorophenoxy herbicides.

Session C
Combined HWERL Research Posters

The posters presented at the Symposium, and their primary authors, are as follows:

Earthen Liners: A Field Study of Transit Time
Karen Albrecht
Illinois State Geological Survey

Development of Process Monitors for Hazardous Waste Incineration
Sharon Nolen
U.S. Environmental Protection Agency

EPA Evaluation of In-Tank Methods for Detecting Leaks from Underground Storage Tanks
James Starr
Envirosponse Inc.

EPA Hazardous Waste Control Technology Data Base
C.S. Fore
DOE Hazardous Waste Management Program

The HWERL Chemical Detoxification Research Laboratory
Alfred Kornel
U.S. Environmental Protection Agency

Laboratory Evaluation of Model Slurry Walls
Richard McCandless
University of Cincinnati

Environmental Emergency Response Unit Technical Information Exchange
A.C. Gangadharan
Envirosponse Inc.

Hydrostatic Testing of FMLs for Determining Critical Failure Factors
David Shultz
Southwest Research Institute

Date Requirements for Remedial Action Technology Screening
Paul Exner
GCA/Technology Division

Development of Environmental Testing Chamber for Soil Reagent Testing
John Glaser
U.S. Environmental Protection Agency

Parametric Studies Delineating the Occurrence of Transient Puffs in a Rotary Kiln Simulator
W.P. Linak
U.S. Environmental Protection Agency

Canine Olfaction: A Novel Tool for Investigating Decontaminated Equipment and Leaking Underground Storage Tanks
Herbert Skovronek
New Jersey Institute of Technology

Data Base for Estimating Hazardous Waste VOC Emissions
John Harden
Radian Corporation

Applications of Catalytic Oxidation to the Treatment of Hazardous Waste
Howard Greene
The University of Akron

Thermal Decomposition Characteristics of Chlorinated Methane Mixtures
Philip Taylor
University of Dayton Research Institute

Weathering Effects on Exposed Soil Liners
David Anderson
K.W. Brown & Associates

Research Activities at the Hazardous Waste Research Center—An EPA Center of Excellence
Louis Thibodeaux
Louisiana State University

Hazardous Waste Research, Development, and Demonstration Permits
Nancy Pomerleau
U.S. Environmental Protection Agency

Center Hill Research Activities
Dept. of Civil & Environmental Engineering
University of Cincinnati

The U.S. EPA Combustion Research Facility
Larry R. Waterland
Acurex Corp. Combustion Research Facility

Automated Expert Assistance for RCRA Permit Reviews/Evaluation of Remedial Alternatives for Superfund Sites
Daniel Greathouse
U.S. Environmental Protection Agency

Prediction of Solubility of Hazardous Materials in Water
Frank R. Groves, Jr.
Louisiana State University

Removal and Recovery of Hazardous Organic Vapors by Adsorption onto Activated Carbon and XAD4 Resin
Kenneth Noll
Illinois Institute of Technology

QA/QC Support During Shakedown and Demonstration of Emergency Response Equipment
John Koppen
Princeton Aqua Science

Determination of Effective Porosity of Soil Materials
Robert Horton
Iowa State University

Hazardous Waste Research at the U.S. EPA Test and Evaluation Facility
Douglas Grosse
U.S. Environmental Protection Agency

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This Project Summary was prepared by staff of JACA Corporation, Fort Washington, PA 19034.
***Naomi P. Barkley** and **Harry Freeman** are the EPA Project Officers (see below).*
The complete report, entitled "Land Disposal, Remedial Action, Incineration and Treatment of Hazardous Waste: Proceedings of the Twelfth Annual Research Sumposium," (Order No. PB 87-119 491/AS; Cost: $42.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officers can be contacted at:
Hazardous Waste Engineering Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

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