waste management research Report

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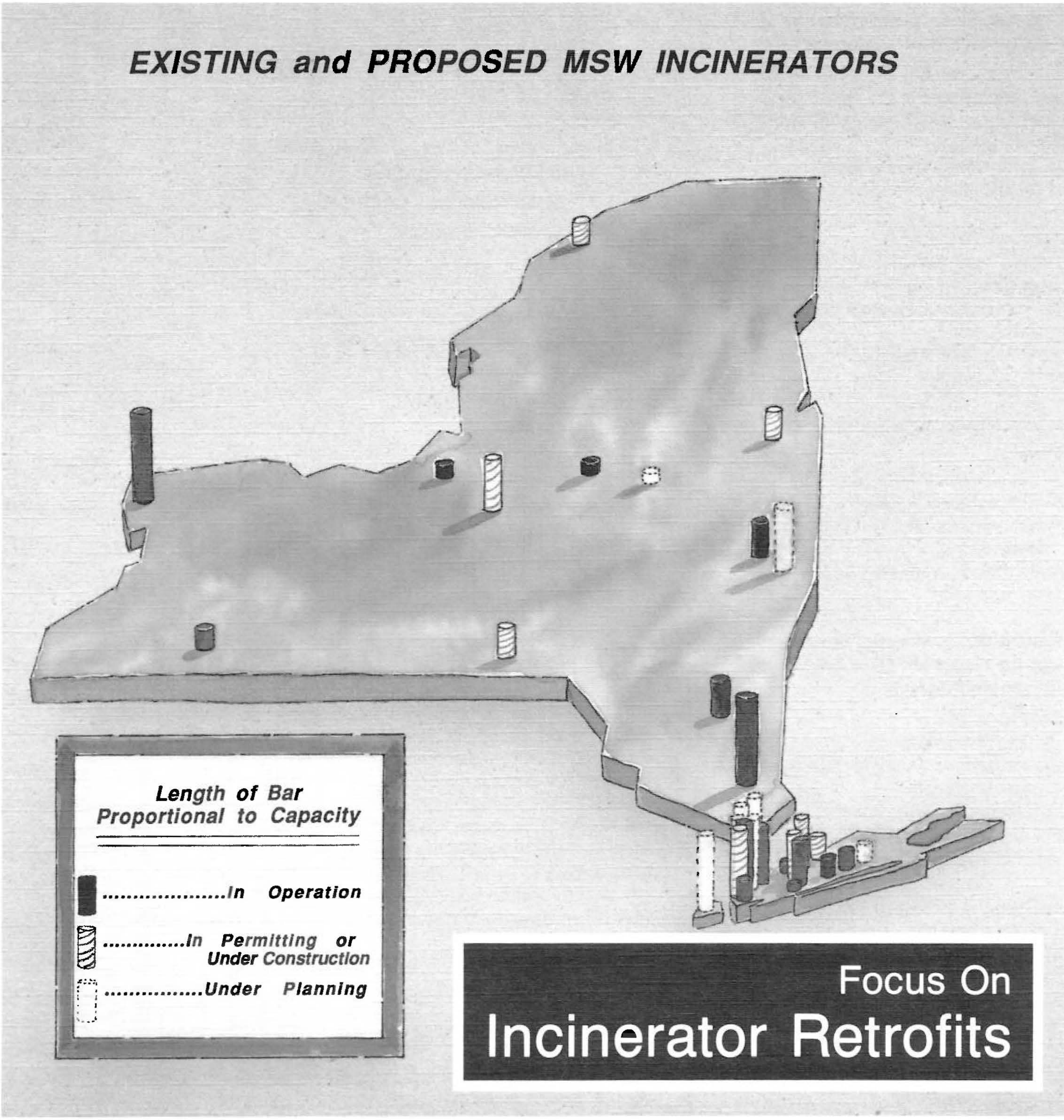

Focus On Incinerator Retrofits

Waste Management Research Report

Vol. 2, No. 1 Winter 1990

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CONTENTS

Commentary

Features

Announcements

About This Newsletter

Waste Management Research Report appears three times a year in order to share research from the publication's contributing institutions. Each issue focuses on one major area of waste management and highlights the contributing institution where researchers investigate the featured topic. The Cornell Waste Management Institute is responsible for this *Report*, with the emphasis on retrofit regulations for incinerators. The Waste Management Institute of the Marine Sciences Research Center at State University of New York at Stony Brook will be responsible for the Spring, 1990 issue which will focus on secondary materials. April 1 is submissions deadline. Mail all material to Louise W. Laughton at the editorial office address.

On the Cover

According to DEC's Draft Solid Waste Management Plan, 1989-1990 Update, *at least 31 municipal solid waste incinerators were operational, under construction, in permitting or in planning as of October 1989. (Figure courtesy of the Cornell Waste Management Institute.)*

Director's Comment

"Let's Make a Deal!"

Editor's note: Pollsters for the National Solid Waste Management Association recently asked residents of several communities in the Northeast to name the biggest problems facing their local officials. Sixty-seven per cent of respondents put disposal of community garbage at or near the top of the problem list, ahead of education, housing, and police and fire protection. Only drug abuse received more votes than solid waste disposal. Yet, according to a report in The Post Standard, *Syracuse, NY, November 28, 1989, poll respondents offered few solutions to the solid waste disposal problem that they defined as serious. More than half opposed new landfills. Forty-two per cent opposed waste-to-energy plants; only 36 per cent of respondents favored them. Dr. Richard Schuler suggests a possible way around the impasse.*

By Richard E. Schuler

Richard E. Schuler

The disposal of solid waste forces difficult decisions. In addition to evaluating the technical, economic, environmental, public health and safety, and social implications of disposal alternatives, we must make complex trade-offs when deciding where to put a disposal facility. The toughest decision of all can be deciding how to decide. Witness the pervasive American disease, Not In My Back Yard (NIMBY), that so often leads to institutional gridlock.

Public anguish surrounding siting decisions can be summarized by the charges, "Someone always loses!" "That's not fair!" "It makes me furious!"

What generates such strong emotion? Do our public officials offer us poor choices? Some choices are worse than others, but it is unlikely that every choice is a bad one. What, then, explains the public outrage?

Part of the answer is that we are running out of space. Not so long ago, the empty lot solved waste disposal problems, but, in our suburbanized nation, almost every vacant space has neighbors. We *are* dumping in someone's back yard. Another reason for the emotion surrounding siting decisions is the plethora of expert opinion available to us as an educated population in a democratic society. Finally, it is difficult to make siting decisions because we have made such excellent progress over the past 30 years in providing protection to affected third parties.

When a town needed a new dump 40 years ago, somebody inside the municipal power structure found a farmer, struck a deal on behalf of the town, bought the land, and that was the end of the story. The farmer's neighbors had to grin and bear it. The Constitution protected the farmer from government seizure of his property without fair compensation. Today, the concept of "taking property" has been extended, and the neighbors expect to receive compensation for "damages," too. Everyone who may be adversely affected can have a day in the hearing room.

How can we make progress in deciding where to site waste disposal facilities? Perhaps a few hard-nosed public officials could make the decisions. That, however, is not the answer if those officials want to be re-elected. Perhaps, we could wait for the solid waste crisis to get so bad that it forces a decision on the public. But, management of public issues by crisis precipitation rarely leads to good decisions.

Let's consider an alternative. I propose that we let politicians do what they do best: forge a consensus, or compromise. Return to our three laments for a moment. Enlarge the context in which people express them, and see if there is a basis for compromise.

Continued on page 2

Dr. Richard E. Schuler, a professor of economics and of civil and environmental engineering, is director of the Waste Management Institute at Cornell University.

Continued from page 1

"Somebody always loses." Does that mean that someone else always wins? Somebody had better win, or it is not worth doing. "That's not fair." So, suppose we share the winnings with you. "That's bribery. It makes me furious." Does the butcher get furious every time you bribe him for pork chops? "That's different." But is it different? In fact, there is little difference between paying a butcher for meat and having the public sector compensate people who may lose something if they become neighbors of a landfill, baling station, or incinerator. In this larger context, society may have a solid basis for "making a deal" when confronted by the solid waste crisis.

We must be certain that adequate environmental regulations are in place before we can employ a bargaining scheme. We must require municipalities and industry to use the best available solid waste disposal technologies to curb emissions and impose substantial penalties if they do not. But even with rules and regulations in place to protect the public, we still will hear laments about siting waste facilities. "Someone always loses!" "That's not fair!" "It makes me furious!" In these situations, it may be possible to make a deal.

In a satisfactory deal, benefits must far exceed costs. That is, the gains to the winners must be far greater than the losses to the losers. Application of the compensation principle (let's make a deal) determines simultaneously whether it is worthwhile to build a facility and where to put it. The compensation principle appears to be a simple model for decisionmaking. Its novelty lies in its application to public sector decisions in situations where the winners and losers cannot be identified easily.

Why should a few bear the brunt for the benefit of so many? *They don't have to, if a satisfactory deal can be struck.* The most difficult problem is determining the right amount of compensation. One solution is to ask people what magnitude of compensation would offset their anger. Previous experiments, and common sense, suggest that such a question creates a new dilemma. When people in the Southwest were asked how much their electric bills would have to be reduced before they could bear the visual insult of a new power plant and its smoke on the horizon, the average response was $10 per month. A similar group of customers, asked how much additional money they would be willing to pay each month to *avoid* seeing the new power plant, gave an average answer of 10 cents! The problem with the survey is failure to recognize the "public" nature of the insults.

The same is true when costs are shared. Some individuals can avoid paying and still receive the benefit, creating a tremendous incentive to exaggerate true feelings or to palm off the costs onto other individuals. In the case of new waste disposal facilities, more people have a real incentive to overstate their objections to a nearby site because they assume that the facility will be located somewhere ultimately, presumably not in their own back yards.

To diminish such exaggerated responses and bring them into line with social values, Prof. Howard Kunreuther at the University of Pennsylvania proposed a "truth-telling" auction that might be used to site waste disposal facilities. If there are 10 communities in a county where a new waste disposal incinerator is proposed, each municipality could receive an "opportunity" to bid for the incinerator. The low bidder would be the lucky winner, as in any competitive bidding process. Presumably, every town would submit an extremely high bid to avoid "winning" the incinerator. The second part of the auction offsets the advantage of bidding high.

All towns that did not submit the lowest bid would have to pay one-ninth of their bid to the winning community. Forcing the towns to pay in proportion to their high bids literally makes them "put their money where their mouth is." At the same time, it encourages them to submit estimates that reflect their true feelings.

I suggest that such a procedure should be implemented only when communities are totally gridlocked and unable to reach any decision. The auction game does, however, illustrate an important point: The process of reaching decisions on waste facility siting does not have to differ greatly from routine decisions about constructing a wide range of public facilities.

When dealing with waste disposal facilities, the entire community does not receive the same degree of adverse impact. A very small subset of neighbors close to the proposed facility usually "bear the brunt for the benefit of the many." Compensation packages should be targeted toward specific losers to be equitable.

How do we measure the extent of loss to the neighbor of a new landfill, when the potential damages are measured in probabilities expressed in units like one-in-a-million or one-in-a-billion? A simple rule for evaluation is the maxim that people vote with their feet. To the extent that a neighborhood is deemed less desirable, fewer people will clamor to live there and property values may fall.

A change in property values can be one measure of the perceived damage imposed on residents near the site of a proposed waste disposal facility, and that change can become the foundation for some minimum level of compensation. In New York State, Tompkins County recently implemented a property value guarantee in association with the announcement of a new landfill planned for the county. Nearby residents certainly would have preferred the facility to be sited elsewhere. Most residents of Tompkins County, however, judged property value assurances the fairest type of compensation.

Compensation programs address the lament, "That's not fair," by compensating those who are adversely affected. The losers don't lose quite so much as before, and the public ire may be reduced. I make no claims that such compensation procedures will please everyone or even succeed in bringing siting decisions to a conclusion. But, in the political climate in the United States, some type of compensation scheme seems necessary if there is to be any hope for a successful outcome. So, Let's make a deal!

WASTE MANAGEMENT EMPLOYMENT OPPORTUNITIES SURVEY

A nationwide survey of employment opportunities in consulting firms in the field of waste management engineering was conducted by the Cornell Waste Management Institute in the spring of 1989 on behalf of the School of Civil and Environmental Engineering at Cornell University. Almost all of the 51 firms that responded projected new employment opportunities for environmental and waste management engineers.

Key results from the Cornell survey, which asked consulting firms about recent and projected hires, salary increases and education requirements are:

- Nearly 60 per cent of the firms anticipate hiring more than 10 engineers in waste management in the next 5 years.
- In the past 2 years, 86 per cent of the firms had hired professionals in waste management engineering, with a quarter of the firms adding more than 50 employees in that field.
- The majority—60 per cent—of new hires in the past 2 years enter the job with a B.S. degree.
- The average starting salary for new hires at the firms surveyed by Cornell was $27,518 for a B.S. with 2 years or less experience and $30,403 for an M.S. with the same experience. By comparison, in 1988, starting salaries averaged $26,173 for a Cornell graduate with a B.S. in civil and environmental engineer ing and $31,300 for a B.S. in materials sciences.

Researchers at Cornell Investigate Impacts of Incinerator Retrofits

By Daryl W. Ditz and Jerry Zygmuntowicz

Daryl Ditz

Introduction

Approximately 2.6 million of the 20 million tons of municipal solid waste (MSW) managed in New York State are incinerated at 14 facilities that range in design from relatively modern to antiquated. In 1988, new state regulations established strict limits on emissions from new facilities. Existing facilities are not subject to these new rules. Instead, the New York State Department of Environmental Conservation (DEC) is proposing new standards for these facilities. These pending rules, sometimes referred to as "retrofit regulations" will have a significant impact on many existing solid waste incinerators. This report presents the results of an analysis of the magnitude and distribution of these impacts within New York State.

Meanwhile, the U.S. Environmental Protection Agency (EPA) is developing new national standards for municipal solid waste incinerators under the Clean Air Act. These regulations will require that States develop standards for existing facilities. Recent EPA analyses of the potential impacts of federal rules on MSW incinerators provide a basis on which to evaluate the impact of New York State retrofit regulations.

At the time of writing, these New York State regulations have not yet been released. Rather than speculating on their content, this analysis considers a variety of potential standards on several pollutants that are likely to be controlled. In this way, the costs and effectiveness of different standards may be evaluated. Based on the New York State regulations on future facilities and discussions with State and Federal regulatory staff, management at affected facilities, and others, it appears that retrofit regulations will include both design requirements, such as measures to improve combustion, plus a series of performance standards limiting the emissions of particulates, some acid gases, and selected organic pollutants.

Review of the literature indicates that compliance with such standards will involve process and operational changes. Interestingly, control of acid gases and particulates tends to drive the choice of retrofit options and the consequent capital and operating costs. As a result, estimates of costs and emissions are prepared on the basis of two alternative retrofit scenarios, one involving the adoption of spray dryers for acid gas control and fabric filters for particulate removal, the other relying on dry sorbent injection for acid gas neutralization and either fabric filters or electrostatic precipitators for particulate removal.

The eleven facilities listed in Table 1 are included in this analysis (some new facilities and several planned facilities that will be governed by the retrofit regulations are not considered). For each of these, the existing technology and emissions levels were reviewed to determine necessary technical changes, capital and operating costs of such changes, and reductions in the emissions of air pollutants. A number of possible standards were analyzed along with possible variations in compliance strategy for particular standards. A summary of the major findings follows.

On December 20, 1989, the U.S. Environmental Protection Agency proposed new guidelines for controlling emissions from existing municipal waste incinerators (54 FR 52209). Because of significant differences between these and DEC's preliminary drafts of retrofit regulations, efforts to promulgate new regulations on existing facilities in New York State have been suspended. EPA expects to issue final guidelines by the end of 1990 after which DEC will develop corresponding retrofit rules.

State Regulations on MSW Combustion

Combustion of municipal solid waste has received intense scrutiny in the last several years. This has motivated substantial design and operational improvements in the newest MSW incinerators. In fact, facilities built prior to the mid-1980s are now hard pressed to approach the lower emissions of the newest facilities. The disparity be-

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tween the performance of existing and new solid waste combustion facilities was underscored in New York State when regulations on "new" facilities entered into force on December 31, 1988 (Title 6 NYCRR Part 219).

One portion of these rules, Subpart 219-2, established strict limits on a variety of emissions, several of which were previously unregulated. These regulations apply to any new or modified facility issued a Permit to Construct after April 30, 1989.[1] Among other items, Part 219-2 specifies maximum emissions of particulates, hydrogen chloride (HCl), nitrogen oxides (NO_X), and tetrachloro-dibenzo dioxin (TCDD) equivalents (a weighted average of chlorinated dioxins and furans).[2] It also spells out a number of design and operational requirements. At the time of issuance, these regulations were among the most stringent emissions limits on new MSW incinerators to be found in the U.S. or abroad.

In anticipation of the pending federal guidelines and to complement the tightened standards on future MSW combustion facilities, DEC is in the process of developing regulations to govern existing facilities, replacing Part 219-5. At present, only particulate matter and opacity are restricted by regulation, although other pollutants are included in special conditions of operating permits on a facility by facility basis.

Federal Guidelines

In Section 102 of the Hazardous and Solid Waste Amendments of 1984, Congress directed the Environmental Protection Agency to report on the emissions of certain air pollutants from municipal solid waste (MSW) combustion and the resulting risk to public health. In response, EPA prepared the nine volume "Municipal Waste Combustion Study" (EPA, 1987).

On July 7, 1987, EPA announced its intention to regulate emissions from new or modified municipal waste incinerators under Section 111(b) of the Clean Air Act (52 FR 25399). New Source Performance Standards (NSPSs) will be proposed by EPA by December 1989. Since some of the pollutants to be regulated are not specified in pollutant-specific sections of the Act (Section 108-110 or 112), these forthcoming rules on new or modified facilities will trigger Section 111(d) requiring individual States to promulgate emissions standards for exisiting MSW combustion facilities based on guidelines from EPA.

In preparation for these new federal guidelines on existing facilities, EPA contracted with the Radian Corporation and the Energy and Environmental Research Corporation to investigate a wide range of technical and economic aspects of air pollution control. Their tentative results, contained in the draft "Retrofit Study," provided a starting point for this assessment of the likely impacts of retrofit regulations on existing MSW combustion facilities in New York State.

The draft Retrofit Study selected twelve U.S. facilities to represent a broad range of features, sizes, and designs. Twelve "model" facilities were created from selected features and performance characteristics of these actual plants. Then a set of alternative combustion and emission control strategies were considered which include relatively simple improvements in combustion control through much more ambitious and expensive installation of air pollution control equipment. For each alternative, the draft Retrofit Study proposed changes in design and operations at each facility and estimated capital and operating costs. These economic calculations were based on a combination of quotes elicited from equipment vendors, cost estimation formulas, and empirical relations.

Framework for Analysis

Even before the New York State retrofit regulations are proposed, two facilities in New York State, Occidental Chemical and Albany ANSWERS, have commissioned extensive engineering assessments of how potential regulatory changes will affect their facilities. Since such detailed analyses cost hundreds of thousands of dollars, it is clear why most of the existing MSW combustion facilities have chosen to wait for final regulations before undertaking similar studies. This delay may be prudent for individual facilities, but it deprives regulatory officials and others of valuable information on the economic implications of particular standards. In the meantime, there is a need for broader, if less precise, estimates of technical, economic, and en-

Continued on page 6

Table 1: New York State Municipal Solid Waste Incinerators Included in this Analysis

Design	Units	TPD*	Start-up	Facility
Refractory Wall				
Traveling Grate	4	1,000	1964	Betts Avenue (Queens)
Traveling Grate	4	1,000	1958	Greenpoint. (Brooklyn)
Rocking Grate	3	750	1960	SW Brooklyn
Mass Burn Water Wall				
Large	3	2,250	1984	Westchester Co. (Peekskill)
Small	2	250	1983	Glen Cove
Small	1	200	1984	Long Beach
Refuse-Derived Fuel (RDF)				
Large	2	2,200	1980	Occidental Chem. (Niagara Falls)
Small	2	600	1981	ANSWERS (Albany)
Modular, Starved Air				
Transfer Rams	4	200	1985	Oswego Co. (Fulton)
Transfer Rams	4	200	1985	Oneida Co. (Rome)
Grates	3	108	1983	Cattaraugus Co. (Cuba)

* TPD is the total design capacity of the facility in tons of MSW per day.

Retrofit Regulations

Continued from page 5

vironmental impacts on the remaining facilities.

This analysis considers the use of two different types of acid gas and particulate control for existing MSW incinerators in New York State. The combination of spray dryers and fabric filters represents the emerging state-of-the-art for both acid gases and particulates at new MSW incinerators. New facilities employing these units also tend to emit significantly lower levels of dioxins and furans, although the exact reason for this is in dispute. The second control scenarios envisioned in this analysis of retrofit regulations is dry sorbent injection (DSI). DSI is less effective at neutralizing acid gases, but has lower capital, operating and maintenance costs than spray dryers and fabric filters.

Either of these strategies is likely to affect the emission of dioxins equivalents, but there is insufficient evidence to support assumptions about specific relationships between acid gas control and dioxin removal. Therefore, this report does not estimate the degree to which either control option will aid in meeting any proposed limits on dioxin emissions. Also, this report does not attempt to estimate the costs of controlling NO_x emissions at existing MSW incinerators. New York State retrofit regulations are likely to require the application of "best available control technology" or BACT for NO_x control, but there is little support for requiring the installation of thermal $DeNO_x$ or other selective non-catalytic techniques on existing facilities. Clearly, if such a requirement does arise, this will add the costs of retrofit estimated in this analysis and reduce the overall emissions of this important criteria pollutant.

This report focuses on the impacts of the retrofit regulations only. The technical, economic and environmental consequences of facility expansion, compliance with other regulations, and changing prices of energy, materials and waste disposal are not considered. Within this limited scope, there are important questions about the inherent tradeoffs between the environmental and other benefits of the proposed regulations and the economic impact on facility operators and solid waste generators. This analysis permits the investigation of the relationship between different emissions standards and the costs at each facility on an annual basis and per ton of solid waste processed. In addition, attention is paid to the prospect of facility closure and waste diversion as a consequence of increased incineration cost.

Technical Analysis of Options

In this analysis, the facilities were described by type of combustion unit (i.e. mass burn, refuse-derived fuel, or modular), the number and nameplate capacity of the combustion units, annual throughput, type and quantity of energy recovery. In addition, the number and configuration of air pollution control equipment as well as current emissions of particulates, hydrochloric acid and sulfur dioxide were sought for all facilities. Unfortunately, not all of these parameters were available for the eleven facilities and in some cases there were conflicting estimates, especially in waste throughput and air emissions.

Annual throughputs of MSW were taken from DEC records. However, data from three facilities that have submitted monthly reports on waste receipt are in conflict with these permit-derived values. For the sake of uniformity, throughputs for all facilities were taken from the DEC records. A utilization factor, defined as the ratio of annual capacity to nameplate capacity, represents the fractional use of the facility including scheduled and other downtime. The utilization factor is used in the estimation of annual emissions from instantaneous measures.

Flue gas flow, typically recorded in actual cubic feet per minute, is another key parameter in sizing and costing retrofit options. Because concentrations of pollutants in the flue gas will vary with temperature, moisture, and the extent of dilution by excess air, it is necessary to correct the volumetric flow rate to a standard basis of dry gas at 68°F, 1 atmosphere pressure, and 7% oxygen by weight. Default values of 15% moisture and 11% oxygen were assumed.

For many facilities, several configurations of air pollution control equipment are possible. To maintain the ability to consider different numbers of ESPs, it was necessary to multiply the flow rate per flue, given by DEC, by the number of flues to establish a total plant flow rate. This value can be divided by the number of air pollution con-

Table 2: Primary Variables Included in this Analysis

Technical	Economic	Environmental
# of Combustion Units	Ash Disposal Costs	Particulate Emissions
Design Capacity	Bypass Disposal Costs	HCl Emissions
Actual Throughput of Waste	Prices of Utilities	SO_2 Emissions
# of Pollution Control Trains	Price of Sorbent, Filter Bags	HCl Removal Efficiency
Volumetric Flow of Flue Gas	O&M Labor Rates	SO_2 Removal Efficiency
Stack Temperature	Cost of Emissions Monitors	Particulate Standard
Energy Recovery Rate	Price for Recovered Energy	HCl Removal Standard

trol devices. The rationale for this feature will be apparent in the later discussion of retrofit costs.

Both the spray dryer and dry sorbent injection options considered in this analysis achieve some degree of acid gas control. The primary objective of acid gas control is to neutralize HCl with an alkali sorbent, forming salts that can be collected in the particulate control equipment. Several commercial sorbents are available, but this analysis assumes the use of hydrated lime that is comprised of 90% $Ca(OH)_2$ by weight and 10% solid impurities. HCl reacts with $Ca(OH)_2$ to produce insoluble calcium chloride, $CaCl_2$, and water.

The effectiveness of HCl removal is assumed to be 95% with spray drying and 80% with dry sorbent injection. The proposed regulations mandate HCl reductions, but sulfur dioxide (SO_2), the second most prevalent acid gas, also reacts with the sorbent. In this case, calcium sulfate, $CaSO_3$, is a product of the neutralization reaction. Other products can result including $CaSO_4$. The effectiveness of SO_2 removal is assumed to be 85% with spray drying and 40% with dry sorbent injection. The rate of sorbent feed is an important variable in determining the size and cost of acid gas control options. The sorbent feed rate was calculated as a function of the rate of MSW processed by the facility, the fractions of chlorine and sulfur in the waste, and the concentration of $Ca(OH)_2$ in the sorbent (assumed as 90% for hydrated lime). Because of incomplete mixing and kinetic limitations, the sorbent is usually fed at a rate that exceeds the stoichiometric requirements for neutralization. This "excess ratio" was taken at 1.5 for spray dryers and 2.0 for dry sorbent injection as given in the draft Retrofit Study.

As part of the dry sorbent injection scenario, specifications for retrofit of an ESP were calculated for each facility. For a particular application, the required particulate removal efficiency is simply the ratio of collected solids to total solids. Values for each facility were taken either from the Phase I Emission Study or, for six facilities not included in that stack testing, from DEC permits. The outlet particulate concentration corresponds to the emissions limit under the retrofit regulations. The physical size and cost of an ESP is primarily dependent on the total plate area available for particulate collection which is a function of the particulate collection efficiency.

For a given volumetric flow rate, the total plate area of the required ESP can be found from the inlet and outlet particulate concentrations only. Alternatively, when introducing additional particulate matter upstream of an existing ESP, as in the case of some dry sorbent injection retrofit scenarios, this algorithm can be reversed to determine the new particulate emissions from the existing equipment. If this fails to meet the required emissions standard, then this outlet loading can be considered the inlet loading to a new ESP whose total plate area can be calculated as above.

For the fabric filter retrofit option, an empirical relationship between filter size (in square feet) and particulate control efficiency was unavailable. The draft Retrofit Study assumed an outlet particulate level of 0.010 grains per dry standard cubic foot (gr/dscf), based on EPA tests at new facilities with fabric filters. Using this premise, fabric filters were sized and priced as a function of flue gas flow rate alone.

Economic Analysis of Options

Once the pertinent technical parameters have been identified and the overall control strategies specified, a detailed estimate of retrofit costs is possible. At the heart of this analysis is a model for calculating increased capital and operating costs of retrofit on a facility basis. The model was validated by comparison with EPA's analysis of the model plants. Preliminary results for the New York State facilities were shared with management at each of the affected facilities. Their comments and suggestions were incorporated and the results are presented in the following section.

The model divides costs into direct and indirect operating and maintenance (O&M) items. To obtain an estimate of total annualized costs of retrofit options, capital costs were amortized and included under indirect O&M. Major air pollution equipment is priced using empirical equations developed in the draft Retrofit Study on the basis of vendor quotes. The cost of dry sorbent injection is broken down into several components (e.g. storage silos and conveyor systems), but depends strongly on the sorbent feed rate. The draft Retrofit Study treats the spray dryer and fabric filter retrofit option as a single package. The cost of a spray dryer and fabric filter (SD/FF) system is given by EPA as a function of the volumetric flow rate.

The capital cost of other items was calculated in comparable ways. For example, the cost of new induced draft (ID) fans is a function of the volumetric flow rate, while flue gas ducting costs depend on both flow rate and length. Increased installation and fabrication costs resulting from site congestion and access restrictions are accounted for by escalating direct capital cost by a multiplier ranging from 1.1 for low congestion to 1.42 for more difficult installations. Allowances for indirect capital costs are each included at 30% of direct capital costs. The cost of new stack con-

Continued on page 8

Retrofit Regulations

Continued from page 7

struction and of demolition are difficult to predict without detailed information and are not included. The sum of the purchase price, installation, engineering and contingency costs is the total capital cost of retrofit.

Downtime, the other major one-time cost of retrofit, results from lost energy and waste disposal revenues. For each facility, a fixed period of 3 months was assumed to allow for equipment installation and tie-ins. During this period, the facility processes no waste, pays to bypass all incoming waste, and foregoes any revenues from steam or electricity sales. Lost energy revenues are calculated as the product of waste throughput during this period, the average energy content per unit of MSW, and the unit price of energy. Where facility-specific data are lacking, this analysis assumes that a ton of MSW can produce either 500 kilowatt-hours (kWh) of electricity or 5,000 pounds of steam. Prices for the electricity are assumed to be $0.06 per kWh and $5.50 per thousand pounds of steam except when actual values were given. The cost of bypass waste disposal for the downtime period is calculated as the product of MSW throughput during downtime and bypass cost. In some cases, bypass costs approach $100 per ton, but other municipal facilities with public landfills pay no cost.

The total capital and downtime costs were annualized using a simple formula for straight-line amortization. The capital recovery factor is a simple function of the annual interest rate and the equipment life. For an interest rate of 10% per year and a life of 15 years, the capital recovery factor is 0.1315. All costs are presented in 1987 dollars and no attempt was made to escalate costs over the anticipated life of the facility or to include inflation.

Direct O&M costs include labor, materials, utilities, and ash disposal. Labor costs are estimated by assuming the number of hours per day required to operate and maintain retrofit equipment. For example, 4 hours for operation and 2 hours for maintenance is assumed for the spray dryer/fabric filter retrofit per shift. A default wage of $12 per hour is used for operating labor, with a 10% premium assigned to maintenance labor. Supervision cost is included as 15% of the operating labor cost.

Material costs include lime and other materials. Lime costs for the acid gas control system are equal to the annual sorbent feed times the lime cost, assumed at $80 per ton. General maintenance materials are taken to be 8% of the total capital costs. For the fabric filter, bag replacement costs assume a cost of $1.35 per square foot, a gross air-to-cloth ratio of 3:1, and a one-year bag life. Utility costs include water (for lime slurry preparation) and compressed air (for sorbent injection). Electricity for ESPs, pumps, and ID fans, the largest utility cost for retrofit, was based on a number of empirical equations.

Waste disposal is the final component of direct O&M costs. Estimating the solid waste generated as a byproduct of the retrofit action requires a mass balance on the acid gas/particulate control system. The mass flow of alkali salts (i.e. $CaCl_2$ and $CaSO_3$) produced by the acid neutralization reactions and the remaining, unreacted $Ca(OH)_2$ are estimated as functions of the sorbent feed rate. The additional particulate matter collected is determined from the efficiency of the retrofit particulate control device and the flue gas flow rate per device. The waste disposal cost is simply the product of the additional solid waste generated (in tons/year) and the unit price of ash disposal. Specific prices were available for some facilities. For those facilities that did not report a price for ash disposal, a default value of $25/ton was assumed.

Indirect O&M costs are estimated as the sum of overhead, business expenses, and capital recovery. Overhead is assumed to be 60% of all labor costs including operating, supervisory, and maintenance. Business expenses, including taxes, insurance, and administration, are taken as 4% of total capital costs. These are added to the annualized capital recovery to determine total indirect O&M costs.

The sum of direct and indirect O&M costs represents the total annual cost of the retrofit. Retrofit costs per ton are calculated as the ratio of total annual cost to total facility throughput of MSW. It represents the required increase in tipping fee if a plant passes the cost of retrofit on to the municipalities it serves, and can be a crucial factor in whether an existing MSW incinerator can compete economically with waste management alternatives.

Environmental Analysis of Options

Ironically, while the retrofit regulations are driven by concern over air emissions, three difficulties stand in the way of estimating the positive effects of retrofit. First, there is a very incomplete record of current emissions from existing facilities. Of the eleven facilities included in this assessment, stack test data are available for only six. Even those results are based on very short duration sampling. In the case of dioxins and furans, samples are collected over a period of hours. To consider these point estimates indicative of average emissions requires nothing short of a leap of faith. For the other facilities for which no data on metal and organic emissions exist, this analysis has relied on the current permitted emissions. Obviously, lacking actual data, there is no assurance that allowable emissions match actual releases.

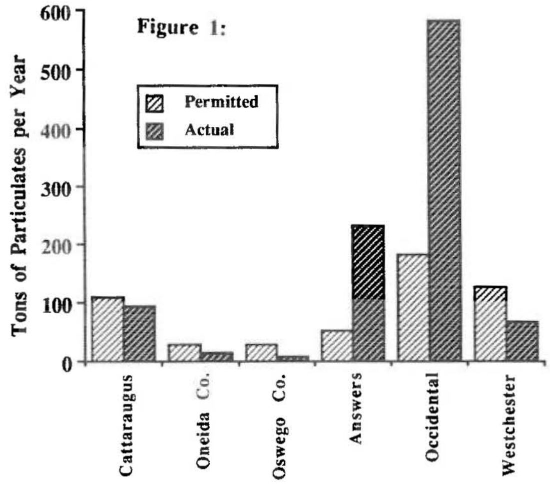
The second problem frustrating the estimation of environmental benefits is the lack of reliable information on the effectiveness of various rettrofit alternatives in practice. That which exists is largely empirical and cannot be readily translated to facilities of different design. While control of particulate and acid gas emissions can be estimated with some certainty, there is no reliable way to determine the effect of various acid gas and particulate controls on the host of metals and organic pollutants in incinerator exhausts. As a result, the benefits that presumably result from reduced air emissions of these materials are not considered here. Finally, even if current emissions, control efficacy, and the composition of solid residues were known with certainty, there remains the problematic issue of how to translate these into a meaningful measure of benefits.

The most recent series of DEC stack tests were performed on six facilities in 1984 and 1985.[3] During these tests, emissions of particulates, ten metals, HCl, SO_2, NO_x, and several organic compounds including chlorinated dioxins and furans were measured.[4] No stack test data are available for Long Beach, Glen Cove, or the three New York City incinerators (Betts Avenue, Greenpoint, and Brooklyn Southwest.)
the three New York City incinerators (Betts Avenue, Greenpoint, and Brooklyn Southwest.

These data provide important insights into the relative as well as absolute loadings to the environment from existing facilities. For example, the magnitude of particulate releases as given by stack tests and by permit is shown in Figure 1 for each facility. Note that for some facilities, actual emissions are substantially below permitted levels while for others, permitted limits are exceeded. While specification of a new particulate standard (e.g. 0.010 grains/dscf) allows calculation of post-retrofit emissions, estimating the amount of emissions reduction is problematic. In this analysis, actual stack results were used where available. For other facilities, reductions are calculated as the difference between the new and existing standards.

Fortunately, not all measurements introduce the same ambiguity. Recall that the determination of sorbent feed rate depends on the fraction of chlorine and sulfur in the waste stream. The use of a single value for chlorine and sulfur content suggests a uniform waste composition. This is not

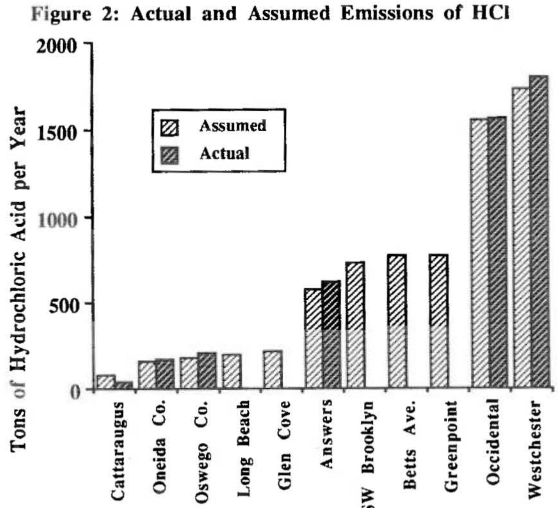
Actual and Permitted Emissions of Particulates (adapted from DEC Phase I Report, 1989)



valid, nor is it true that all chlorine and sulfur found in MSW is converted to HCl and SO_2. For the purposes of this analysis, data from the six New York State facilities on uncontrolled emissions of HCl and SO_2 were used to back-calculate the fraction present in the waste stream. Average values of 0.264% and 0.079% were determined for chlorine and sulfur content, respectively.

The relationship between actual and predicted emissions is depicted in Figure 2 which shows the annual release of hydrochloric acid according to stack tests along with the amount estimated using the aggregate value. In the case of HCl emissions, there is good agreement between actual measurements and an aggregate estimate of chlorine per ton of MSW.

Figure 2: Actual and Assumed Emissions of HCl



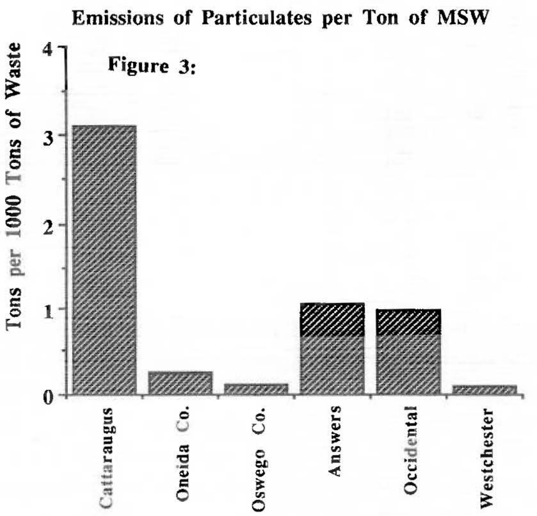
The stack tests for particulate emissions reveal other interesting features when adjusted for the total quantity of waste processed. This per-ton measure of emissions can be considered an indication of the relative "cleanliness" of the facilities. Figure 3 demonstrates rather large dif-

Continued on page 10

Retrofit Regulations

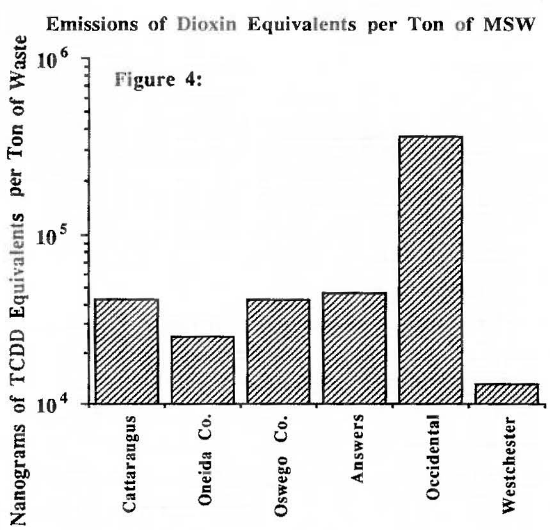
Continued from page 9

ferences in this measure for particulates among the existing facilities for which data are available. Not surprisingly, Cattaraugus, the sole facility without particulate control, appears as the largest emitter per ton of MSW processed.



Data describing the emission of dioxin equivalents can be portrayed in the same manner. Of this limited sample of existing facilities, the emissions from the RDF facility at Occidental clearly dominate. Westchester achieved the lowest per-ton emissions of dioxin equivalents. It should be stressed that these values are based on stack tests conducted over three years ago.

The retrofit of existing MSW combustion facilities will impact solid waste disposal on land in two ways. The countervailing effects of transferring organic and inorganic residues from air emissions to land disposal are only treated in aggregate in this analysis. Additional solids in the form of neutralization products and excess sorbent from acid gas control are calculated on the basis of the sorbent feed, SO_2 and HCl produced,



and the effectiveness of acid gas removal techniques. Similarly, additional particulate matter from improved collection efficiency is readily estimated as the difference between pre- and post-retrofit particulate emissions. However, more subtle effects on the composition of this residual are not considered in this analysis.

Temporary or permanent facility closure constitute the second class of solid waste impacts due to retrofit regulations. It seems clear that landfills would receive a significant burden of these wastes. While downtimes were estimated at three months for the purposes accounting for lost revenues, in reality this could vary widely depending on the ease of retrofit at each facility, the ability to construct new pollution control equipment without interrupting availability, and the potential for accommodating waste in one unit while others are being modified. There is a possibility that retrofit costs could lead to permanent closure at some facilities.

Discussion of Results

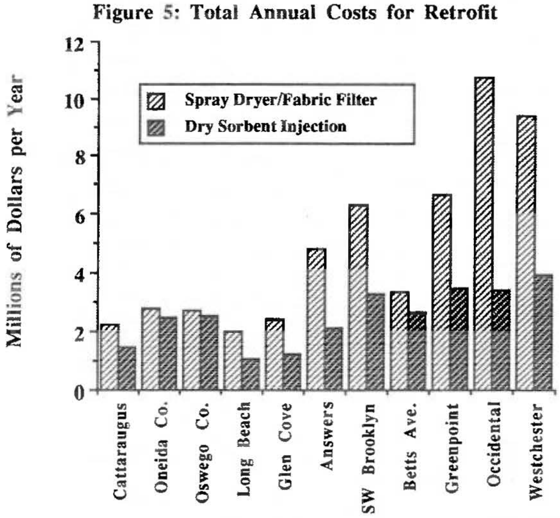
Economic Impacts of Regulations

The results of the economic analysis demonstrate that the retrofit regulations are likely to have significant cost impacts and that these impacts are not felt equally by all facilities. Figure 5 demonstrates the range of total annual costs at the eleven facilities, listed in order of total capacity, for both spray dryer/fabric filter and dry sorbent injection scenarios. In the first case, total annual costs vary from $1.9 million per year at Long Beach to $10.8 million at Occidental. If all facilities were to install such units, the total annual cost would exceed $53 million per year. In contrast, dry sorbent injection with particulate control retrofit is less expensive, but also less effective in reducing air pollutants. Total annualized costs vary from $1.0 million per year at Long Beach to $4.0 million per year at Westchester. For all eleven facilities together, the dry sorbent injection option amounts to $28 million per year. As one might suspect, these costs depend strongly on the overall throughput of the facility.

However, consideration of the costs of retrofit per ton of MSW leads to quite different conclusions about which facilities are most severely impacted by the proposed retrofit regulations. Figure 6 presents the per-ton costs for the two retrofit alternatives. Again, the spray dryer/fabric filter option is more expensive than dry sorbent injection. The spray dryer/fabric filter scenario could cost as little at $11 per ton at Brooklyn SW or as much as $75 at the Cattaraugus facility. For dry sorbent injection, the lowest unit cost is expected at Occidental with $5.7 per ton to as high as $50 per ton at Cattaraugus. Averaged over the total capacity of these eleven facilities, the spray dryer/fabric filter alternative amounts to slightly more than $20.2 per ton, while dry sorbent injection is roughly half that, $10.4 per ton.

Because of the high fixed costs of acid gas and particulate control equipment, the smallest facilities bear the greatest costs per ton of MSW. Thus those facilities with the highest total annual costs tend to face the lowest per-ton costs. Expressing the economic impacts of these retrofit scenarios on a per-ton basis also provides an indication of the effect of retrofit on the economic attractiveness of combustion at existing facilities. Large increases in the per-ton cost could force the closure of some facilities when less expensive alternatives are available or when retrofit changes cannot be financed. The decision to make retrofits rather than close a facility depends on a number of factors including the price and availability of alter-

Figure 5: Total Annual Costs for Retrofit

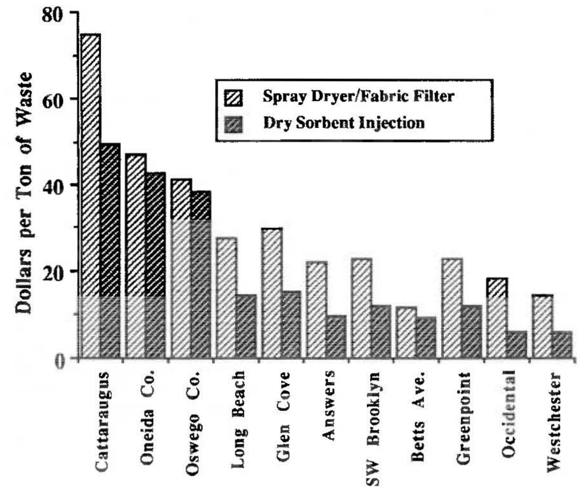


natives, the remaining life of existing plant and equipment, whether the facility is owned by a public or private entity, costs required by other changes in law, and so on. It is impossible to predict which plants would choose to make the changes required by new regulations.

However, it is possible to draw some insights into the magnitude of capacity affected by varying costs. For example, if costs above $30 per ton were sufficient to cause closure, three facilities accounting for 5.8% of the existing capacity would be affected. If retrofit costs of $20 per ton led to closure, dry sorbent injection would affect the same three facilities. But, with the spray dryer/fabric filter scenario, a total of eight facilities would close removing 64% of the existing capacity. If a retrofit cost of $10 per ton were large enough to close existing facilities, then no plants would retrofit with spray dryers and fabric filters. At this level, four facilities representing 67% of the existing capacity could afford dry sorbent injection.

These results are represented in Figure 7 as capacity remaining as a function of the retrofit cost at which facilities choose to close. To use this graph, one would first determine the cost

Figure 6: Total Costs Per Ton for Retrofit



above which retrofit is deemed uneconomical. Then for each of the two retrofit alternatives, one can estimate the net impact on existing MSW incineration capacity. It is important to remember that the private or municipal owner of any given facility might choose to close even though costs appear high or that they could close even though these costs appear rather modest.

Environmental Impacts

Estimating the environmental benefits is complicated by incomplete data on current emissions and uncertainty over the effectiveness of various control measures. However, lower emissions of a variety of air pollutants are likely to yield some improvements on the local and regional scale. It is assumed that hydrochloric acid emissions from these facilities, which currently total about 6,900 tons per year, will be reduced 95% through the use of spray dryers with fabric filters and 70% by dry sorbent injection. Sulfur dioxide emissions from these eleven facilities, currently around 4,200 tons per year, are assumed to decrease by 85% with spray dryers and fabric filters and by 40% with dry sorbent injection. A particulate emissions standard of 0.010 grains per dry standard cubic foot (gr/dscf), results in total emissions of 223 tons per year, an estimated reduction of 74% over permitted emissions and 87% over actual emissions based on DEC stack tests. While the additional particulates and products of acid gas neutralization will add to the total residues requiring disposal, these quantities average less than 1% of the total MSW throughput.

Because existing facilities in New York State differ widely in their level of air pollution control, these regulations will result in greater environ-

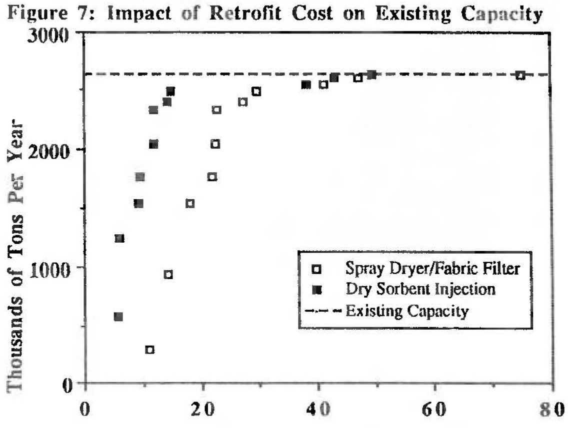
Continued on page 12

Retrofit Regulations

Continued from page 11

mental benefits at some facilities than at others. The cost effectiveness of emission reductions indicated by the tons of particulates removed per dollar of retrofit cost. The per dollar improve-

Figure 7: Impact of Retrofit Cost on Existing Capacity



ments in particulate removal are greatest at the larger plants and at Cattaraugus which has no particulate control to date. Topping the list of cost effectiveness are the Occidental and Albany RDF facilities and the New York City facilities at Betts Avenue and Brooklyn Southwest. Under the spray dryer/fabric filter scenario, 35 to 48 tons of particulates are removed per million dollars at five facilities, while dry sorbent injection results in 60 to 150 tons of particulates removed per million dollars. Interestingly, Westchester, which is the largest facility in the state, is near the lowest in cost effectiveness with only 2.7 to 6.4 tons removed per million dollars. This is a reflection of the already high level of particulate control relative to other facilities.

Since the two retrofit options achieve much more than particulate control alone, it is somewhat misleading to measure cost effectiveness on this basis. For comparison, consider the reduction of HCl, which is not currently controlled at any of the eleven facilities. Since the chlorine content of MSW is essentially uniform from one facility to another, these findings correspond to the per-ton costs of retrofit. In this case, 110 to 220 tons of HCl are removed per million dollars at the six largest facilities using spray dryers and fabric filters. Under the dry sorbent injection scenario, results for the same six facilites vary from 180 to 370 tons of HCl removed per million dollars.

New York State regulations on future facilities restrict emissions of dioxin equivalents to 2.0 nanograms per dry standard cubic meter, but the proposed retrofit rules specify 5.0 ng/dscm. DEC stack tests at several New York State facilities indicate that most existing facilities do not meet either standard. In any event, both new and existing facilities are compelled by the New York State regulations to develop strategies for achieving emissions of dioxin equivalents below 0.2 ng/dscm.

In conclusion, the retrofit regulations are likely to substantially reduce the air emissions of certain pollutants from existing solid waste incinerators, but these improvements will carry significant costs. The magnitude of the costs and benefits of these regulations depend heavily on a few standards which drive the selection of control strategies. For any given standard, the impacts will not fall equally on all facilities. The larger facilities will bear the largest annualized costs, but this impact is offset by the throughput over which these costs can be spread. From the standpoint of cost effectiveness, dry sorbent injection achieves greater reductions of emissions per dollar of control. However, spray dryers and fabric filters will achieve a greater total reduction in air emissions. Faced with the choice of retrofit or closure, some facilities may choose to cease operations. Those which are most heavily impacted contribute relatively little to the total waste management capacity. However, waste which would otherwise have been burned at these plants will be a burden on the existing waste management infrastructure and may be routed to less desirable treatment alternatives.

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Notes

[1] *These regulations are currently under legal challenge in* New York Public Interest Research Group, Inc. (et al.) v. New York State Department of Environmental Conservation, *Request for Judicial Intervention, Article 78, Supreme Court, Albany County, Index No. 2558-89, May 1, 1989.*

[2] *The definition of toxic equivalent factors, and hence dioxin equivalents, employed by New York State differ slightly from those used by EPA. Care should be exercised in attempting to compare results calculated on different bases.*

[3] *Testing has been completed at the Dutchess County facility, but results were not available.*

[4] *Metal included arsenic, beryllium, mercury, cadmium, chromium, lead, manganese, nickel, vanadium, and zinc. Organic chemicals included mono- through octa-chlorinated dibenzo dioxins and dibenzo furans, benzo a-pyrene, chrysene, and polychlorinated biphenyls.*

NETAC To Evaluate Bioremediation For Oil Spills

The National Environmental Technology Applications Corporation (NETAC) at the University of Pittsburgh recently assembled an independent panel of scientists from industry, academia, and applied research organizations to recommend criteria for evaluating bioremediation technologies offered for oil spill cleanup. The group will submit its recommended criteria to the Environmental Protection Agency (EPA), which asked NETAC to develop an evaluation system.

The panel, chaired by Dr. Edgar Berkey, executive vice president of NETAC, also will review information from bioremediation companies seeking to help clean up the oil spill in Prince William Sound, Alaska, and rank the proposed technologies against the criteria. Dr. John H. Skinner, acting deputy assistant administrator for research and development for the EPA, said that development of a bioremediation protocol will enable his agency to compare technologies proposed to the EPA, the Coast Guard, and other federal agencies for cleaning up the oil spill in Alaska and spills that may occur in the future. And, said Dr. Berkey, an evaluation system will help move innovative biological approaches to oil spill cleanup more quickly into the marketplace.

Metal-Plankton Interaction Focus Of Research At Stony Brook

By Dr. Nicholas S. Fisher

Nicholas S. Fisher

Introduction

The Waste Management Institute at the Marine Sciences Research Center at SUNY, Stony Brook is unique because it is situated within a research center devoted to the marine sciences. It is therefore well placed to investigate the behavior of important waste products in ocean systems, particularly coastal and estuarine waters. Many of the wastes under consideration contain high levels of metals known to be toxic to marine organisms and to man. It is important to understand their behavior in marine ecosystems so that the toxicological implications of their presence in seawater can be assessed.

Consideration also is being given, on a national and international basis, to the disposal of long-lived radionuclides in the oceans, particularly the seabed, as one possible option for the ultimate disposal of these wastes generated in the nuclear fuel cycle. Currently, there are no options that are generally deemed acceptable for the disposal of radioactive wastes, particularly high-level wastes. Models examining the implications of radioactive waste disposal in the sea have underscored the need for studies on the extent to which these wastes can be accumulated and influenced by marine organisms. This report describes a series of studies addressing some of these points, focusing on the interactions of metals, some of which are of interest from a radiological protection standpoint, with organisms at the base of marine food webs.

Metal in Phytoplankton

Interest in the study of phytoplankton interactions with metals stems in part from the fact that phytoplankton concentrate some metals up to a million fold out of seawater (Table 1) and are known to be very sensitive to some toxic metals. Since they lie at the base of most marine food webs, they can introduce these metals into food

Continued on page 14

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Metal-Plankton Studies

Continued from page 13

chains, potentially leading to man. Moreover, phytoplankton can sink, either as intact cells or packaged into fecal pellets or marine snow, thus mediating the vertical transport of metals in marine systems.

The flux of particulate matter in marine and freshwater systems has been recognized as a major vector in regulating metal concentrations in natural waters. Since phytoplankton and planktonic debris are major components of natural suspended particulate matter, they can play significant roles in mediating the vertical transport of metals, particularly out of surface waters, consequently affecting oceanic residence times of the metals. It is of interest to assess the accumulation of metals by phytoplankton in the context of geochemical cycling of metals.

The degree to which metals are concentrated out of seawater by phytoplankton is a function of their speciation in water and their affinity for available surface ligands. Metal affinity for various ligans, including hydroxides, is correlated with the polarizing power and the charge density of the metals and should determine the reactivity of metals for suspended particles, including phytoplankton, in natural waters. Attempts have been made to formulate predicitive models of the surface chemistry of marine particles and particle-metal interactions, both to explain field and laboratory observations and to help model the behavior of contaminants in the sea.

Hydroxyl groups in inorganic and organic matrices in particular have been investigated as potentially important ligands in models of metal scavenging by marine particles. Fisher (1986) showed that concentration factors of a diverse array of metals in marine phytoplankton also correlate well with metal affinity for hydroxyl groups, and significantly less so with metal affinity for sulfur, suggesting that oxygen ligands dominate the surfaces of algal cells with respect to metal binding. The algal concentration factors plateau between 10^5 and 10^6 for metals with a very strong propensity for hydrolysis.

Metals generally associate with phytoplankton cells in accordance with Freundlich adsorption isotherms, living and dead cells concentrating metals to the same extent from seawater. Since phytoplankton have much greater surface: volume ratios than do larger organisms, their concentration factors for metals are correspondingly higher (Table 2). The similarity of response of many types of algae (diatoms, green algae, dinoflagellates, coccolithophores, etc.) in metal accumulation suggests that the uptake process is similarly determined in these cells.

Table 1

Volume/Volume Concentration Factors in Marine Phytoplankton

	Diatom (*T. pseudonana*)	Green (*D. tertiolecta*)	Coccolithophore (*E. huxleyi*)	Prasinophyte (*T. chuii*)	Dinoflagellate (*H. pygmaea*)	Blue-green (*O. woronichinii*)	Blue-green (*Synechococcus sp.*)
Co	1.0 E3	nd	nd	nd	nd	nd	4.0 E3
Zn	1.2 E4	1.0 E4	4.6 E3	nd	nd	5.2 E3	3.2 E4
Tc	1.0 E1	<1.0 E0	<1.0 E0	2 E0	1.7 E1	8.0 E0	nd
Cd	3.0 E2	1.0 E3	3.7 E2	nd	nd	1.0 E3	nd
Ag	3.4 E4	1.3 E4	2.4 E4	nd	nd	6.6 E4	nd
Sn	1.1 E5	nd	nd	nd	nd	nd	7.9 E5
Hg	9.3 E4	3.2 E4	9.5 E4	nd	nd	7.6 E4	1.3 E6
Pb	3.7 E4	8.2 E4	4.1 E4	nd	nd	1.6 E4	1.8 E6
Po	1.2 E5	4.3 E4	nd	nd	nd	nd	nd
Ra	<3 E2	nd	<3 E2	nd	nd	<6 E1	nd
Th	3.9 E5	4.1 E5	3.1 E5	nd	nd	1.1 E4	1.9 E6
U	<2 E2	<2 E2	<1 E2	nd	nd	<2 E1	nd
Np	< 1.5 E2	<1.5 E2	<1.5 E2	<1.5 E2	nd	<1.5 E2	<1.5 E2
Pu	6.3 E5	2.2 E5	1.6 E5	4.0 E4	nd	1.7 E5	1.0 E6
Am	6.9 E5	1.8 E5	1.1 E5	3.0 E4	3.8 E5	3.0 E4	5.8 E5
Cm	6.4 E5	1.2 E5	2.1 E5	nd	1.2 E5	2.6 E5	nd
Cf	6.2 E5	4.1 E5	3.2 E5	9.0 E4	nd	1.3 E5	nd

Metal Flux, Biogenic Debris

Sinking phytodetritus and other biogenic debris may strongly influence the vertical profiles of metals in marine systems. Decomposing cells, marine snow, and degrading fecal pellets may release some of these substances back into the dissolved phase, although possibly in altered chemical form. Generally, in marine systems, the primary forces (biological and physicochemical) mediating this phenomenon have not yet been identified. Yet, this is essential information in understanding the cycling of metals and various anthropegenic substances in the sea. Sinking particulate matter, including phytoplankton aggregates and zooplankton fecal pellets, may also carry pollutants to sediments, where they may enter detrital food chains. The eventual fate of phytoplankton-bound pollutants in seawater and the degree to which they become incorporated in benthic or pelagic food webs is largely unknown at present.

One area regarding metal-particle interactions which has received comparatively little study is the degree to which metals, once associated with biogenic particulates, are retained by these particles as they sink through the water column. To what extent can we consider the association of different metals with biogenic debris irreversible? What are the rates of release of different metals from particulate matter, and how are these rates influenced by environmental factors? It is self-evident that this information would have direct bearing on our understanding of the particle-mediated flux of metals in marine systems.

There are, of course, several possible scenarios, which may be of varying importance for each metal/particle combination:

(1) Particles may remain essentially intact as they sink, and any release of metal from the particulate to the dissolved phase would proceed by desorption of the metal or ion exchange processes.

(2) Particles (e.g., fecal pellets, phytodetritus, marine snow, exoskeletons of crustaceans, larvacean houses, etc.) may degrade, and metals bound to specific ligans may be released into the water, or they may continue to sink, bound to that fraction of the particle that remains intact.

(3) A particle may be ingested by an animal during its descent in the water column and the metals may remain attached to the ligands on the ingested particle as it passes through the animal's gut, or they may be released. The ingested metal may be assimilated into the animal tissue, packaged into fecal pellets, or released in the dissolved phase.

Previous studies have not examined desorption of metals from biogenic debris and, at the same time, measured the bacterial decomposition of the debris. Sediment trap studies have indicated the release of many metals into the dissolved phase at the mid-depth by decomposing organic matter. While distinct patterns of metal flux can

Continued on page 16

Table 2

Concentration Factors*

	Element	Phytoplankton	Zooplankton	Macroalgae	Molluscs	Crustaceans	Fish
	Sr	3 E 0	1 E 0	5 E 0	1 E 0	2 E 0	2 E 0
Fission	Tc	5 E 0	1 E 2	1 E 3	1 E 3	1 E 3	3 E 1
Products	Sn	1 E 5	5 E 4	2 E 4	5 E 4	5 E 4	5 E 4
	I	1 E 3	3 E 3	1 E 3	1 E 1	1 E 1	1 E 1
	Cs	2 E 1	3 E 1	1 E 1	3 E 1	3 E 1	1 E 2
	Fe	8 E 4	1 E 4	3 E 4	3 E 4	5 E 3	3 E 3
Activation	Co	2 E 3	2 E 3	1 E 4	5 E 3	5 E 3	1 E 3
Products	Ni	5 E 3	1 E 3	2 E 3	2 E 3	1 E 3	1 E 3
	Zn	8 E 3	2 E 4	2 E 4	3 E 4	5 E 4	1 E 3
	Pb	5 E 4	1 E 3	1 E 3	(1 E 3)	1 E 3	2 E 2
Natural Series	Po	8 E 4	3 E 4	1 E 3	(1 E 4)	5 E 4	2 E 3
Radionuclides	Ra	(1 E 2)	1 E 2	1 E 2	(1 E 3)	1 E 2	5 E 2
	Th	2 E 5	1 E 4	2 E 2	1 E 3	1 E 3	6 E 2
	U	3 E 1	5 E 0	1 E 2	3 E 1	1 E 1	1 E 0
	Np	1 E 1	(1 E 2)	5 E 1	4 E 2	(1 E 2)	1 E 1
Transuranic	Pu	2 E 5	1 E 3	2 E 3	3 E 3	3 E 2	4 E 1
Elements	Am	2 E 5	2 E 3	8 E 3	2 E 4	5 E 2	5 E 1

* *Compiled from Bewers et al. (1985)*

Metal-Plankton Studies

Continued from page 15

be surmised for different metals from their particulate and dissolved profiles in the field, the rates at which metals are scavenged and released by different particles can best be determined under controlled conditions with laboratory experimentation. It appears that retention half-times increase inversely with temperature, possibly as a result of enhanced microbial degradation of the debris at elevated temperatures or greater desorption rates at greater temperatures. By combining data on radionuclide retention in planktonic debris with the sinking rates of this debris, Fisher and Fowler (1987) modeled the impact of each type of debris on mediating the vertical transport of particle-reactive elements like americium in the sea. They concluded that crustacean molts and large fecal pellets would deliver these elements to deep waters and sediments, whereas small fecal pellets, sinking algal cells, appendicularian houses, and marine snow would transport these elements a maximum of only a few hundred meters.

Comparison of predicted and observed values for the vertical flux of five different radionuclides in different water columns.

While it is possible to model the impacts of sinking biogenic debris on the vertical flux of some particle-reactive radionuclides in ocean waters (Figure 1), there is an insufficient data base to model the roles of sinking debris in the transport of many other metals in marine systems. Critical missing information includes desorption rates from particulates and decomposition rates of the debris. Furthermore, there have been comparatively few studies on the assimilation in animal tissue of metals ingested in contaminated food or accumulated from a dissolved source term. Thus, it is difficult to assess the importance of biological cycling of many metals in surface waters. There is evidence that some metals such as polonium may be recycled extensively in surface waters via assimilation in animal tissue while other metals such as lead may undergo significantly less recycling in the same waters.

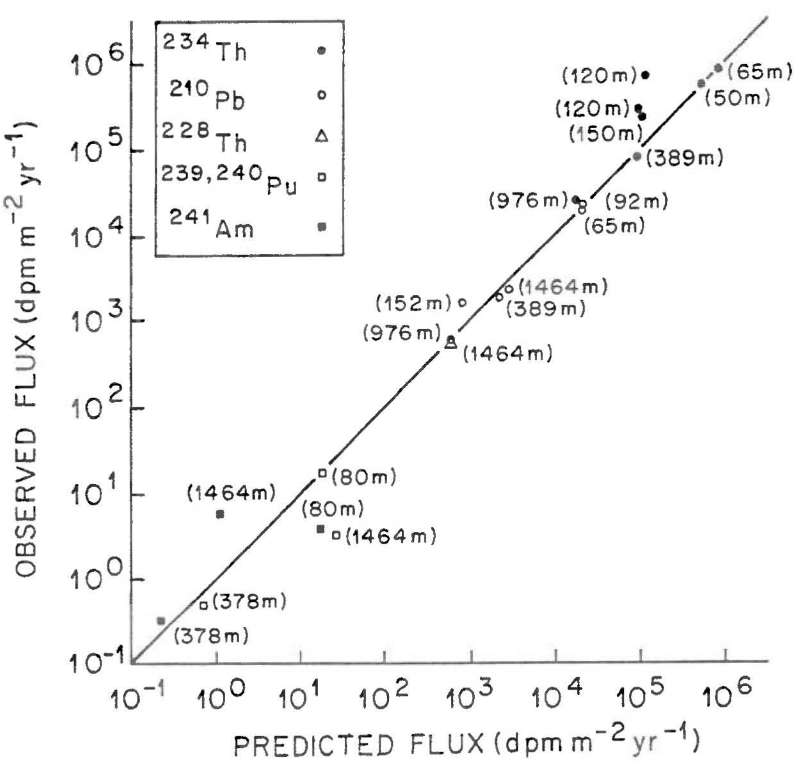

Fig. 1. The model for flux predicitions considered oceanic new production values in specific water columns, dissolved surface radionuclide concentrations, and mean concentration factors of these radionuclides in marine phytoplankton. Observed fluxes are from sediment trap measurements in different regions, with depth (m) of sediment trap indicated in parentheses. Solid line indicates hypothetical perfect match of predicted and observed fluxes. Good agreement between predicted and observed flux of these radionuclides suggests that essentially all vertical flux of these radionuclides (and presumably other particle-reactive elements) in the open ocean can be accounted for by sinking biogenic debris. From Fisher *et al.*, 1988.

Current Experiments

Fisher's group has established an active research program at the Marine Sciences Research Center at Stony Brook to address the fate of metals associated with phytoplankton or phytoplankton-based biogenic debris. The following specific questions are being considered in a series of experiments incorporating the use of gamma-emitting radiotracers.

(1) Once associated with phytoplankton cells, at what rates are metals released back into the dissolved phase from intact cells? Does this differ among class A, class B, and borderline metals and between essential and non-essential metals?

(2) As algal cells die and lose their structural integrity, what are the release rates of different metals into the dissolved phase?

(3) What are the release rates of selected metals from zooplankton debris (fecal pellets, crustacean molts, appendicularian houses) to the dissolved phase?

(4) To what extent are metals excreted from pelagic animals? Could metal assimilation in these animals significantly influence the recycling and residence time of those metals in surface waters?

(5) Can a simple model be constructed with these data to understand and predict roles of biogenic debris in mediating the flux of metals in the sea? Are predictions confirmed by analyses of debris caught in sediment traps?

Experiments now underway address these questions, focusing initially on the interactions of a wide variety of metals with phytoplankton and with copepods and their debris. To date, Se, Cr, Mn, Ag, Co, Cd, Sn, Pu, Am, Zn, Eu Ce, and Hg have been examined. In all cases, metal detection takes advantage of gamma emissions of metal radionuclides, which enables experimentation with metal concentrations down to the femtomolar range. Metal assimilation in copepods has ranged from essentially zero for such metals as americium to 95 percent for selenium. Algal and fecal pellet retention of metals has been determined for a variety of different bacterial degradation regimes and temperatures, simulating natural conditions; retention times range from hours for some metals (e.g., Cd) to months for others (e.g., Hg).

Significance

The results of these studies will help to quantify the kinetics of uptake of many metals of geochemical interest in marine plankton and the roles they play in vertically transporting them in the oceans. A model will be developed to assess the significance of each type of debris in the vertical transport of metals to depth. The model's approach, which considers sinking rates of debris together with metal retention times under different conditions of microbial degradation, should be extendable to the study of other metals and even organic contaminants which enter the ocean via atmospheric deposition.

Results of these studies will also be used to understand the fate of many long-lived radionuclides emanating from the nuclear fuel cycle which enter the ocean either through accidental release or intentional discharge. Through critical pathway analysis, it has been determined that, from the radiological protection standpoint, the greatest risk to man from radioactive substances in the oceans is via consumption of seafood. These studies will enable an evaluation of the extent to which certain long-lived radionuclides (e.g., isotopes of Pu, Am, Sn) can accumulate in the food chain.

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Organo-metallic Complexes Treated by Adsorption

By Mark R. Matsumoto

Mark R. Matsumoto

The availability of metals as a natural resource was a key impetus to the rapid development of human civilization. There are few aspects of modern society that do not rely on metals. Besides the obvious use of metals in construction, cars, planes, and appliances, metals also are widely used in inks, in batteries, in the production of organic chemicals, and in the textile industry. The standard of living that we enjoy could not have been achieved without metals.

Along with their benefits, however, metals present a potential hazard to society. Many soluble metals are extremely toxic, and people can experience severe, acute and chronic toxic effects as a result of exposure to them. Therefore, the discharge of metals into the biosphere from mining, refining, manufacturing, and other use must be minimized.

Many, if not most, of the industries that use or manufacture metals generate aqueous waste streams that contain soluble metals. Because of the wide assortment of metal-bearing waste streams, numerous types of metal recovery and/or treatment systems must be synthesized to cope with the various situations. No single process yet has been developed that can recover and/or remove metals from all of the various waste streams.

Particularly difficult to treat are wastes that contain both soluble metals and organics. Soluble metals by themselves are generally easily removed by the addition of a chemical precipitant such as hydroxides or sulfides. Most organics by themselves are generally easily removed during biological treatment. However, when organics are present together with soluble metals, the organo-metallic complexes which form inhibit the effectiveness of precipitation. Additionally, the presence of soluble metals in a biological

Continued on page 18

Dr. Mark R. Matsumoto is an associate professor of civil engineering at State University of New York at Buffalo.

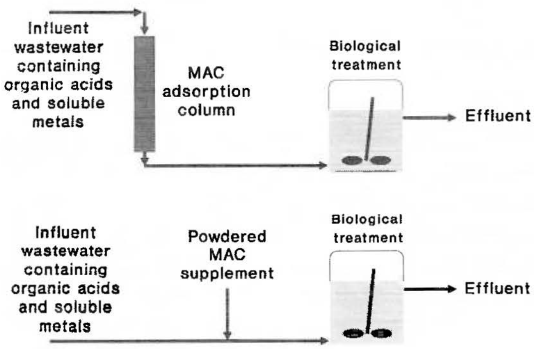
Treatment Tested

Continued from page 17

treatment process inhibits bacteria from degrading the organics. Thus, when soluble metals and organics are together, neither precipitation nor biological treatment (the conventional techniques) are effective. Alternative treatment processes must be employed.

Two variations for the use of metal adsorbing compounds (MACs) in conjunction with biological treatment.

Scheme A

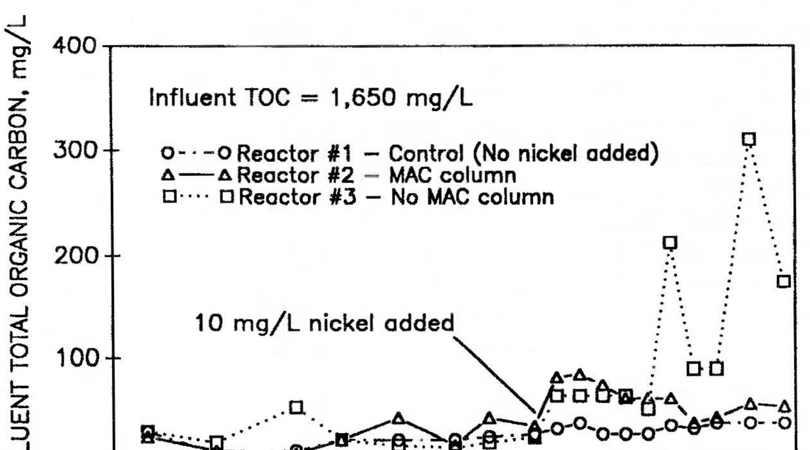


Scheme B

One alternative technique under investigation at the State University of New York at Buffalo (SUNY-Buffalo) for treating wastes that contain both soluble metals and organics is the use of metal adsorbing compounds (MACs) in conjunction with biological treatment. (Adsorption is a surface phenomenon in which a chemical species is removed from solution by attachment to a solid surface.)

Two variations for the use of MACs in conjunction with biological treatment (Figure 1) are being tested at SUNY-Buffalo. In the first scheme, a column of MAC material is placed ahead of the biological process. The purpose of the MAC column is to remove both free and complexed metals from the solution before the waste is introduced into the biological reactor in order to preclude poor organic removal.

Effectiveness of MAC column to minimize deterioration of biological treatment as a result of nickel toxicity.



During this study, parallel biological treatment systems, sequencing batch reactors (SBRs), were used to treat a synthetic hazardous waste that included high concentrations of phenol, acetic acid, sodium acetate, and ammonium chloride, and a soluble nickel concentration of 10 mg/L. One system operated with a MAC column (Reactor 2); another system operated without a MAC column (Reactor 3), and a third system operated as a control without a MAC column and without soluble nickel in the synthetic wastewater (Reactor 1).

The effectiveness of the MAC column in preventing poor organic removal is shown in Figure 2. The effluent concentration of total organic carbon (TOC) from Reactor 3 varied considerably shortly after soluble nickel was introduced into the wastewater. In contrast, the effluent TOC from Reactor 2 remained relatively stable when compared to the control reactor. The soluble nickel concentration remaining after passage through the MAC column was found to be less than 1 mg/L. More than 90 percent of the soluble nickel was removed in the MAC column. Less than three percent of the influent TOC was removed through the MAC column.

Based on these results, the use of MACs in conjunction with biological treatment seems to be a viable alternative for the treatment of aqueous waste streams that contain both organic and soluble metals. Experiments using MACs in the second scheme (see Figure 1) are also being conducted at Buffalo.

ESF Offers Course

The State University of New York College of Environmental Science and Forestry (ESF) will present a 40-hour course, "Integrated Hazard Management," from 7 to 10 p.m. Tuesdays, February 20 through May 13, in 215 Bray Hall on the ESF campus in Syracuse. The objective of the course is to train supervisors and managers of facilities regulated by the Resource Conservation and Recovery Act (RCRA) so that they can meet or exceed compliance with federal OSHA 29 CFR 1910.120 standards at the facilities they administer.

The four major topics will be: Creating Hazard Communication Programs, Industrial Health and Safety, Community Right-to-Know, and Waste Management. Instructors will come from the SUNY Health Sciences Center in Syracuse, the Syracuse Fire Department, the state Department of Labor, a private laboratory, and a Syracuse law firm as well as from ESF.

Registration deadline is February 5, and the cost is $695 per person, payable to the SUNY Research Foundation. Interested persons may call ESF Continuing Education at (315) 470-6891.

Surfactant Process Offers Promise For On-Site Groundwater Remediation

By John Fountain and Dennis Hodge

Many common groundwater pollutants have high densities and low solubilities in water and thus form a separate, dense nonaqueous phase liquid (DNAPL) when they enter the subsurface. Common pollutants that form DNAPL include trichloroethylene, perchlorethylene, dichloroethane, PCBs, and most other halogenated liquids. Because of its low solubility, DNAPL cannot be removed efficiently by conventional pump-and-treat methods.

Research underway at the State University of New York at Buffalo by the authors evaluates the use of surfactants to extract organic contaminants. The work, supported by a grant from the New York State Center for Hazardous Waste Management, is based upon the ability of surfactants to increase the solubility of organic liquids in water.

Surfactants Injected

A dilute aqueous solution of surfactants is injected into a contaminated aquifer, flushed through the contaminated zone, and extracted from recovery wells. The pollutants are brought into solution by the surfactants and recovered with the treatment solution. Once on the surface, the pollutants are separated from the treatment solution, which is reinjected. Results of lab-scale tests suggest that the high solubility of the pollutants in the surfactant solution will result in much more efficient extraction than is currently possible.

The first objective of this research was to identify a mixture of surfactants that could effectively solubilize common pollutants. Both kinetic and equilibrium parameters must be considered in the surfactant selection. Goold solubilization ability is, however, only one of several parameters that must be considered in surfactant selection.

Emulsions Form

Surfactants that are good solubilizers tend to form spontaneous emulsions of DNAPL in water. Some form a dense layer of emulsions on the surface of the DNAPL which inhibits further reaction. Others form a fine, highly mobile emulsion which aids solubilization through an increase in surface area. Thus, the character of emulsion also must be considered.

Dr. John Fountain is a geochemist and Dr. Dennis Hodge a geophysicist at the State University of New York at Buffalo.

Surfactants lower the interfacial tension between groundwater and DNAPL. The lowered interfacial tension reduces the capillary forces that inhibit horizontal flow of DNAPL under normal conditions. The increased mobility may create potential problems at some sites by allowing the DNAPL to move farther down through small pores and cracks on the floor of the aquifer. We thus consider interfacial tension in our surfactant selection, avoiding those that greatly increase DNAPL mobility.

Toxicity and biodegradability also are important factors in the selection of surfactants. The investigators plan to use only those surfactants known to be non-toxic and biodegradable.

John Fountain

100 Surfactants Tested

Almost 100 surfactants representing approximately 20 chemical types have been screened at this time, and several candidates for possible use have been identified. Geology graduate students Andrew Kilmek and Michael Beikirch conduct experiments that compare promising surfactants in extraction of trichloroethylene and tetrachloroethylene from horizontal, sandpacked, glass columns. The experiments simulate aquifer flushing on a very small scale.

Dennis Hodge

Proposed Field Test

The initial field test of the process is planned for spring, 1990. We have been invited to test the process at the Borden Canadian Forces Base test site in Ontario. The Borden site is used by the University Consortium Solvents-in-Groundwater Research Program, an international consortium directed by Dr. John Cherry of the University of Waterloo (Ontario).

A small cell in the unconsolidated-sand aquifer at the site will be isolated with sheet piling walls. Contaminant will be introduced and the cell will then be treated with the surfactant solution. A network of monitoring wells will be used to evaluate the remediation process.

Efforts are underway to identify a suitable inactive hazardous waste disposal site, either a Superfund or a Resource Conservation and Recovery Act (RCRA) site, where the technology can be demonstrated under actual field conditions. It is hoped that this demonstration can be undertaken through the Environmental Protection Agency (EPA) SITE program.

Notes and Announcements

Cornell Waste Management Institute Offers Publications

The Waste Management Institute and Solid Waste Combustion Institute publish the following variety of informational reports. Copies are available, free, upon request. Bulk copies of fact sheets and viewpoints can be obtained by calling the Institute at 607-255-7535.

Fact Sheets
Viewpoints

—plastics
—Municipal composting

Technical Papers

—Retrofit of Municipal Solid Waste Incinerators: Impact on Costs and Emissions in New York State
—Chemical Kinetic Limitations on NO_x Emissions from Waste Incinerators

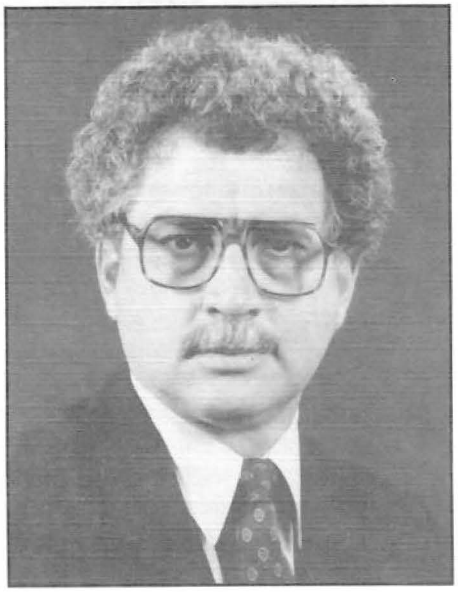
Educational Resource List
Waste Management Newsletter

Buffalo Center Offers Report On R&D Survey

The New York State Center for Hazardous Waste Management offers a report on hazardous waste research taking place at 17 research centers in the United States. The report categorizes 370 projects according to primary and secondary areas of research (*e.g.*, biodegradation, transport and fate of waste, policy studies, waste characteristics, facility siting).

Each project is identified by project title, name of investigator(s), affiliation, and contact telephone number. Descriptions of the 17 centers make up the report's appendix.

Interested persons may write the New York State Center for Hazardous Waste Management, State University of New York at Buffalo, 207 Jarvis Hall, Buffalo, New York, 14260, or call (716) 636-3446.



Roger D. Cohen

Cohen Appointed To Buffalo Board

D. Bruce Johnstone, Chancellor of the State University of New York (SUNY), recently named Dr. Roger D. Cohen, SUNY'S Associate Provost for Health Sciences, his designee on the executive board of the New York State Center for Hazardous Waste Management at SUNY at Buffalo.

Cohen is responsible for academic relationships within the SUNY health professions education system and develops management/oversight structures for SUNY teaching hospitals and related clinical academic programs.

Cohen previously held faculty and administrative positions at Tufts University, SUNY at Stony Brook, and Dartmouth Medical School. He earned bachelor's and advanced degrees at Syracuse University and participated in the Harvard University Executive Program in Health Policy and Management.

Alternative Technologies Workshop Topic

The New York State Center for Hazardous Waste Management at State University of New York at Buffalo and the state Department of Environmental Conservation (DEC) recently sponsored a workshop on the use of alternative technologies in the remediation of inactive hazardous waste disposal sites in New York State.

The 45 workshop participants represented state and federal agencies, industry, public interest groups, engineering consultants, lawyers, technology vendors, and legislative staffs.

Workshop goals were to (1) identify obstacles and impediments that must be resolved in order to facilitate the use of appropriate alternative technologies and methods in New York State's remediation program and (2) determine the measures necessary to facilitate the use of alternative technologies.

A summary of the January, 1990, discussions and findings will appear in a future issue of this publication.

Bonhotal Joins Cornell Staff

The Cornell Waste Management Institute recently named Jean Bonhotal staff coordinator for youth programs. She will develop a youth curriculum that will broaden outreach to schools, 4-H groups, BOCES, and other educational agencies that serve young people. Bonhotal's appointment responds to the growing interest in solid waste issues among teachers and pupils in both elementary and secondary schools.

Law Course Scheduled For March

Government Institutes, Inc. of Rockville, MD, will sponsor a course, "New York Environmental Laws and Regulations," March 26 and 27 in the Albany, NY, Marriott Hotel. Course content defines ways in which state laws differ from both federal legislation and Environmental Protection Agency (EPA) regulations.

To register or acquire more information, contact Lori P. Cannon, Government Institutes, Inc., 966 Hungerford Drive, #24, Rockville, MD 20850, or call (301) 251-9250.

Guest Comment

Waste Separation Necessary

By Maurice D. Hinchey

New York's Solid Waste Management Act of 1988 established a hierarchy: waste reduction, reuse and recycling, energy recovery or combustion, and land burial. Policy discussions too often focus on the **bottom** of the hierarchy, the choice between energy recovery (combustion) and land burial. Retrofit requirements for the state's older incinerators provide an opportunity to redirect our focus to the broader dichotomy between reuse/recycling and waste disposal.

Under the hierarchy, energy recovery as a form of waste control may occur only "from solid waste **that cannot be economically and technically reused or recycled.**" As we deal with the environmental and economic aspects of the state's new retrofit requirements for solid waste incinerators, decisions for each plant—whether to upgrade or to cease operation—must move away from the incineration of wastes that are not appropriate for combustion.

Maurice D. Hinchey

In 1988, 16.5 million tons, 82 per cent, of the state's solid waste was landfilled. Approximately 2.5 million tons, 13 per cent, was incinerated, with and without energy recovery. With increased source separation and recycling, growing reliance on out-of-state disposal, and new waste-to-energy capacity, the percentage of waste going to in-state landfills decreased and combustion increased. In 1989, 71 per cent was landfilled and 19 per cent was incinerated, more than half at waste-to-energy (WTE) plants subject to the proposed state Department of Environmental Conservation (DEC) retrofit requirements.

Facility operators face difficult decisions about the cost and feasibility of meeting more stringent emission and operating standards, and solid waste processed at existing plants still must be managed during retrofit downtime or following a facility's closure. The cost to municipalities that use the facilities as their primary or sole means of waste management could increase substantially. Prior removal of non-combustible and other troublesome elements of the waste stream must be a primary consideration. Owners of existing disposal capacity must better manage an increasingly valuable state resource, and use WTE capacity only for wastes that cannot be recycled or landfilled.

"Guest Comment" provides a forum for debate of complex waste management issues. The opinions expressed are those of the authors. The editors reserve the right to edit for length.

Yard waste, a capacity "eater" high in nitrogen and low in heat value, acts as a heat sink in WTE plants. Municipalities must divert yard waste, as well as glass and metals, from the front end of the waste stream. Some New York jurisdictions pursuing WTE projects have banned yard waste and recyclables. Others, however, have proposed plants sized to accommodate yard waste or to provide for metals recovery **after** combustion.

A number of developments suggest that both new and aging plants must address the composition of their feedstock. New laws in Wisconsin, Minnesota, and New Jersey prohibit the disposal of yard waste. Resource recovery operators in Pennsylvania must formulate plans to divert recyclables in order to operate after 1990. In New York, the DEC's new regulations identify "untreatable wastes," including household and vehicle batteries, that may not be incinerated.

The state's ANSWERS facility in Albany, operated by the Office of General Services, recently underwent a feasibility study funded by the state legislature. Consulting engineers defined improvement in the quality of "fuel" as fundamental for improved emission and operating conditions at the refuse-derived-fuel (RDF) plant. Separating glass, aluminum, and newspapers from the waste stream also could produce an increase in the heat quality of the RDF plant. Almost half the cost of necessary retrofit improvements would be incurred **outside** the RDF plant at the facility where solid waste is prepared for combustion.

We must ensure that in-state disposal capacity is used only for materials that **require** disposal, and, in the case of combustion, that can be incinerated efficiently. With no expansion of the DEC's definition of "untreatable wastes," legislation to prohibit incineration of yard waste, glass, and metals will emerge as a top priority in the 1990 legislature.

Maurice D. Hinchey (D. Ulster County) represents the 101st District in the New York State Assembly. He is joint chairman of the Legislative Committee on Solid Waste Management and chairman of the Assembly Committee on Environmental Conservation.

Waste Management
Research
Report

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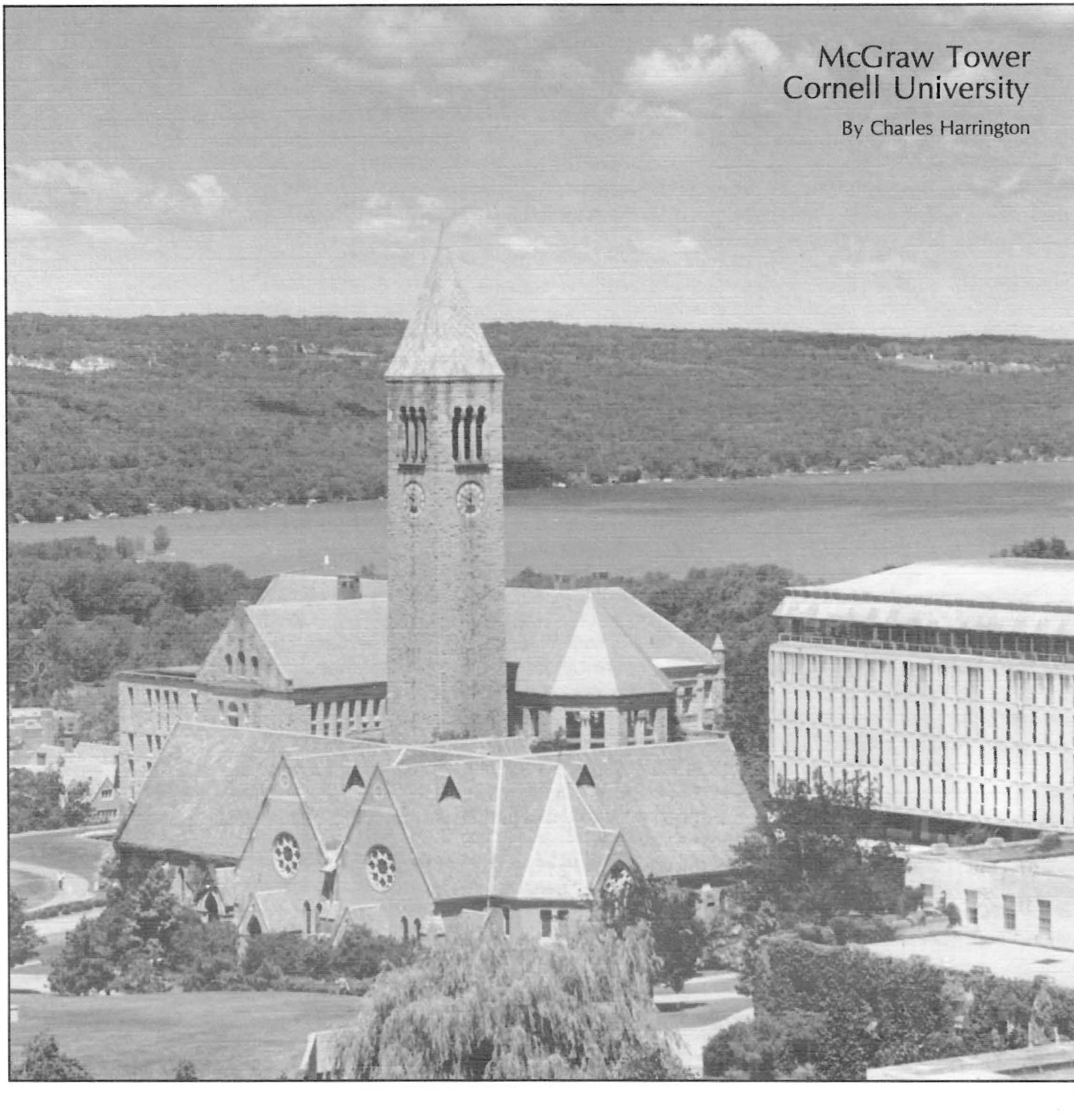

McGraw Tower
Cornell University
By Charles Harrington