MUNICIPAL SOLID WASTE POLICY FORUM
Results and Conclusions

Co-Sponsored by
Stony Brook's
Waste Management Institute

and

The Long Island Regional Planning Board

J.R. Schubel, L.E. Koppelman, and H.A. Neal
Conveners

23 May 1986

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marine sciences research center
state university of new york

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INTRODUCTION

The Municipal Solid Waste Policy Forum held on 23 May 1986 was the third in a series of such forums sponsored by Stony Brook's Waste Management Institute. This forum was co-sponsored by the Long Island Regional Planning Board. The Agenda for the Forum is contained in Appendix A; the list of participants in Appendix B; and a report on ash research presented by Rene Surgi of Signal Environmental Systems in Appendix C.

The Municipal Solid Waste Policy Forums are designed to bring together small groups of knowledgeable people to explore a wide range of municipal solid waste management issues. This particular Forum was designed for Long Island decision makers, specifically for town supervisors and their staffs. The objectives were (1) to present a clear, concise and well-balanced overview of the advantages and disadvantages, real and perceived, of modern resource recovery technology; (2) to explore other important components of a town's comprehensive municipal solid waste management program; and (3) to examine the course we have embarked upon for municipal solid waste management on Long Island, to assess our present position relative to the goal, and to determine whether any mid-course corrections are called for.

This report summarizes those major findings and recommendations which emerged from the discussion which are particularly pertinent to Long Island and the Metropolitan New York City area. Since not all participants had the opportunity to review and comment on this document before printing, it does not necessarily follow that all participants endorse all of the findings and recommendations presented here. There was broad consensus, however, on all statements.

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FINDINGS AND CONCLUSIONS

General

- The management of municipal solid waste is one of the most pressing and difficult problems Long Island faces.
- It probably is not an exaggeration to say that Long Island faces a municipal waste crisis.
- Long Islanders have the dubious distinction of producing more garbage and trash per capita than any other region in the World. The statistics are:

Long Island:	6-6.5	pounds/person/day
U.S. (average):	5	pounds/person/day
Europe:	4	pounds/person/day
China:	2	pounds/person/day

- Municipal solid waste is a very heterogeneous mixture. The materials are organic and inorganic; naturally-occurring and anthropogenic. The average composition of municipal solid waste is shown in Figure 1.
- Solution of Long Island's municipal solid waste problem will require inter-town and bi-County cooperation and collaboration, and cooperation and collaboration of these units with the State.
- At least for most of Long Island, the preferred technological approach to reduce the magnitude of the problems is the modern resource recovery facility (i.e. mass burn waste-to-energy incinerators).
- Other non-technological solutions--particularly source reduction and recycling--can contribute to the resolution of the municipal solid waste management problem.

- The need for landfills on Long Island will persist, although the amount and character of material placed in them will change.
- The present regulatory requirement of the 1990 Landfill Law that a landfill with a 10-year lifetime must be identified before beginning construction of a resource recovery facility may need to be changed.
- Acceptable solutions to the municipal waste problem must be found promptly. As tipping fees continue to rise, the incentives for illegal dumping increase and with them the potential risk to the environment.
- The 1990 Landfill Law emerged from the findings and recommendations of the Long Island 208 Study, but it went farther and faster than that study had advocated. The 208 Study proposed that Long Island's East End Towns have more time to phase out landfilling since they are not in the deep recharge area. The landfill Law does not distinguish the special character of the East End Towns from the remainder of Long Island.
- There are alternative municipal solid waste management strategies which may be as, or more, appropriate than incineration in resource recovery facilities for certain segments of Long Island, particularly East End Towns.
- Among the alternative strategies are recycling, composting, and even landfilling. Distillation and Refuse-Derived Fuel facilities may be alternatives in the future, but are undeveloped at present.

Resource Recovery Technology

- o Until very recently the U.S. resource recovery industry has lagged far behind that of Europe and Japan. There were few incentives in the U.S. to improve technology or to utilize the best technology available in other countries. The problems in the U.S. were primarily socio-political.
- o In countries where energy was expensive and natural resources scarce, there were incentives to view municipal solid waste as a resource; to remove recyclables, and to use the remainder as a fuel to generate steam for heat or electricity.
- o Many plants in Europe and Japan were built in densely populated sections of major cities. Some had contiguous recreational areas (e.g. Switzerland and West Germany).
- o Until very recently, the design specifications for municipal incinerators in the U.S. were prepared by city engineers and the major components were contracted for on an individual basis through the low bid process. The result: a low bid plant with all the accrued benefits.
- o There was a further problem in the U.S. There were no incentives to operate these plants to design specifications.
- o All this has changed.
- o The resource recovery facilities now being constructed in the U.S. represent the best technology available anywhere in the world today.
- o Typical municipal solid waste has a heating value of 3800-5000 BTU per ton; about one-third the energy (12,000 BTU/ton) of coal, and one-fourth that of oil (18,500 BTU/ton). This

translates into 2-3 pounds of steam per pound of trash. The energy content of a ton of municipal solid waste is approximately equal to that of a barrel of oil.

- Although municipal solid waste does not age gracefully, there are essentially no odors or dust associated with the proper operation of well-designed, modern resource recovery facilities. All garbage is stored inside until it is burned and the storage pit is kept under slight negative pressure.
- Emissions from a resource recovery facility may result from (1) the material itself before burning, (2) incomplete combustion, (3) complete combustion and (4) over (excessive) combustion.
- Some of the materials which contribute to undesirable emissions can be removed before combustion; but not all.
- Most of products of complete combustion--the acid gases and particulates--can be controlled satisfactorily with scrubbers and electrostatic precipitators or baghouse filters.
- The emissions of major concern--the furans, dioxins, PCBs and PAHs--result primarily from incomplete combustion. The data indicate that these compounds and other cyclic, thermally refractory organic materials tend to increase when there is incomplete combustion in the secondary firing zone above the grate.
- This observation is not limited to solid waste-fired systems. It applies also to those systems in which coal, lignite, wood, bagasse and even heavy fuel oils are burned.
- The available information indicates that when the temperature of the flue gas just above the secondary firing zone is maintained at approximately 1800°F for a second, or two, and when there is

good mixing of the flue gas rising from the fire bed with an adequate amount of secondary air, the emission of dioxins, furans and related materials is quite low.

- The levels of dioxins and furans emitted from municipal solid waste incinerators vary widely among the plants tested, Table 1.
- The levels of emission of dioxins and furans from mass burning of garbage and trash can vary from plant to plant by a factor of more than 1000 depending upon plant design, construction, and operation (Table 1).
- The differences in emissions shown in Table 1 can be attributed to a variety of factors. Some plants are old; others new. Some have furnaces with refractory walls; others have water-cooled walls. Some were field erected; others were not. Some are small; others are large. Some recover heat; others do not.
- The data in Table 1 indicate that facilities which recover heat tend to have lower emissions of dioxins and furans than those that do not. One exception is the Hamilton (Ontario) plant. This plant is of an old design and had been poorly maintained. A second exception is the Hampton (Virginia) plant which also is poorly designed and was poorly operated.
- Most effective control of emission of dioxins and furans from resource recovery facilities can be achieved through a combination of good combustion and effective removal of particulates from the flue gas. Scrubbing and low temperature particulate control have been shown to be particularly effective.
- The available data indicate that properly designed and operated resource recovery facilities can meet the emissions criteria

Table 1

DIOXIN (PCDD) STACK EMISSION DATA*

FACILITY (Country)	EMISSION RATE (ng/m^3) ALL PLANTS	HEAT RECOVERY PLANTS
STAPELFELD (Germany)	31	31
CHICAGO N.W. (USA)	42	42
ESKJO (Sweden)	73	73
STELLINGER MOOR (Germany)	101	101
PEI (Canada)	107	107
ZURICH (Switzerland)	113	113
BORSIGSTRASSE (Germany)	128	128
COMO (Italy)	280	280
ALBANY (USA)	316	316
DANISH RDF (Denmark)	316	316
ITALY 1	475	
ITALY 6	569	
BELGIUM	680	680
ITALY 5	1020	
ZAANSTAD (Holland)	1294	
VALMADRERA (Italy)	1568	1568
HAMILTON (Canada)	3680	3680
HAMPTON (USA)	4250	4250
ITALY 4	4339	
TORONTO (Canada)	5086	
ITALY 3	7491	
ITALY 2	48808	

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*Source: Kay Jones, Roy F. Weston, Inc., Courtesy BFI, Inc.
Plants are arranged in increasing order of emission of PCDD

being considered by New York and the EPA for dioxins and furans.

- Application of state-of-the art combustion technology in modern resource recovery facilities can reduce emissions of dioxins and furans to levels below the most stringent guidelines now in effect, or anticipated at this time.
- The residual wastes from modern resource recovery facilities are ash--bottom ash and fly ash. Bottom ash accounts for about 95% (by mass) of the total ash, fly ash for the remaining 5%.
- The levels of some metals, dioxins and furans in fly ash are greatly enriched relative to their concentrations in bottom ash.
- In general, bottom ash is not viewed by scientists as a potential threat to human health or to the environment. Fly ash is of much greater concern.
- Bottom ash can be mixed with fly ash to reduce the concentrations of contaminants.
- If the mixture is solidified, the availability of contaminants in ash to leaching decreases substantially. The stabilization of ash into blocks appears to lock up the associated metals, dioxins and furans.
- Cadmium and lead in fly ash behave as surface-bound metals and leach in a predictable way from loose ash.
- When ash is stabilized cadmium and lead behave as matrix metals and leach much more slowly.
- Incineration in modern resource recovery facilities reduces the original volume of material to about 10-15% and the original mass to about 25-30%.

- No matter how effective our programs are in source reduction, in recycling, and in promoting incineration in modern resource recovery facilities, Long Island will still need landfills.
- Under a worst possible case scenario, about 17% of the surface-bound lead (Pb) and 50% of the cadmium (Cd) in the fly ash are available for leaching.
- There are a variety of potential creative uses for resource recovery ash. These include: as landfill cover; as a substitute for typical aggregate in asphalt. If shown to be structurally sound and environmentally safe, blocks made from ash could be used in building construction, in creation of artificial fishing reefs, in shore protection, and in offshore island construction.
- The Long Island Regional Planning Board will be the focal point for developing a comprehensive research program for ash from resource recovery facilities and coordinating the results of these studies.

Uncertainty Concerning Dioxins and Furans

- There still is disagreement within the scientific community as to how and where dioxins and furans are formed during the entire combustion process in resource recovery facilities--from introduction of the waste to the furnace to discharge of flue gas to the atmosphere. This disagreement was found among the forum participants.
- There is some evidence that dioxins and furans are formed post furnace since levels of dioxins and furans in the stacks appear to be higher than in the flue gas when it leaves the furnace. The data are inconclusive, however.
- There is less disagreement as to what levels of dioxins and furans can be expected in the flue gas of modern, well-designed, well-operated resource recovery plants.
- The forthcoming EPA National Dioxin Study, Tier IV Report, may reduce the level of uncertainty surrounding the conditions which promote the formation of dioxins in the resource recovery facilities, the contribution of this source relative to other sources, such as coal-fired power plants, utility boilers, etc., and the effects of dioxin on human health.

A Potential Problem

- If the toxicity leaching test procedures proposed in the January 14, 1986 Federal Register, Part III, Environmental Protection Agency (40 CFR part 260 et al.) are implemented, fly ash from resource recovery facilities would probably be classified as a hazardous waste. This might eliminate the potential for creative uses of unprocessed ash and lead to the requirement that unprocessed ash be placed in a hazardous waste facility.
- If resource recovery residue were classified as a hazardous waste, resource recovery probably would not be a viable municipal solid waste management alternative for Long Island and perhaps not anywhere in the U.S.
- Failure to distinguish between industrial hazardous wastes and municipal solid wastes would cause enormous economic and environmental problems, not only to Long Island, but to New York, and indeed to the entire Nation.

Other Components of a Comprehensive Waste Management Program:

Source Reduction and Recycling

- One can't begin to solve a problem until one formulates it.
- Forums such as this one can be of great value in bringing together the spectrum in interests and expertise needed to formulate problems in tractable forms and to begin the search for solutions.
- The question is not whether we should recycle; only how much.
- It is the policy of the New York State Department of Environmental Conservation (NYDEC) to promote recycling.
- The New York Department of Environmental Conservation believes that a 25% reduction in the municipal solid waste stream could be achieved through an appropriate recycling program. The goals are a 10% reduction by 1988 and 20% by 1990.
- Commissioner Henry Williams has declared that NYDEC's policy will be to include in all permit-to-construct applications for resource recovery facilities, the condition that the town must study and evaluate its solid waste stream and develop a plan for a recycling and source separation program... and a plan to implement the program.
- The benefits of source reduction and recycling are clear.

  They conserve energy.
  They reduce pollution.
  They conserve valuable natural resources.
- Implementation of effective programs of source reduction and recycling would require significant changes in the lifestyle of the typical U.S. citizen.

- Approximately 30-40% of all municipal solid waste is in packaging of one form or another.
- New Jersey is more aggressive than New York in promoting recycling. New Jersey has programs to provide low interest loans to support recycling initiatives, educational grants to promote recycling, and education programs from K to 12 to emphasize the societal benefits of recycling. These efforts are funded through a per ton disposal tax charged at landfills.
- Recycling is receiving relatively little attention today by the federal government.
- It appears that a number of recycling efforts around the U.S. were designed to fail--or at least not to succeed.
- Approximately one-third of all household waste potentially are recyclable.
- An aggressive program of source reduction and recycling is not incompatible with a program of incineration in resource recovery facilities. Indeed, the two are complementary. Source reduction and recycling could improve the quality (BTU content) of the fuel for resource recovery facilities, decrease the abrasion and corrosion it causes to the plant, and reduce the amount of residual ash.
- The New York State Energy Research and Development Authority (NYSERDA) is preparing a draft solicitation for "Development of Recycling Systems for Increasing the Recycling of Materials Found in Municipal Solid Waste".
- Through this NYSERDA Program funding for up to 50% of eligible costs will be provided for (1) development of innovative

recycling systems, including demonstrations, system development work and feasibility studies for innovative industrial processes and other activities that would result in greater use of recyclable materials; and (b) analysis of environmental impacts of recycling systems.

The Need For Citizen Participation

- Citizen participation is critical in developing and implementing effective municipal solid waste management plans. Citizens must be involved from the outset and on a continuing basis.
- There are a large number of ways in which citizens can be involved. More of these techniques should be used in developing municipal solid waste management plans, and in gaining acceptance of them.
- The Long Island Regional Planning Board has involved self-appointed citizen advisory groups in all of its major planning initiatives. They observed that while citizens may have come to the process with predetermined positions, most were willing to change those positions as new information was gained, and to support the ultimate policies with vigor.

The Role of Science

- There is growing distrust by the public concerning our ability to solve all of society's problems through technology.
- Science and scientists do not have all the answers. They never will. Through properly designed and conducted research and development programs the levels of scientific and technical uncertainty can be reduced, but not eliminated.
- Good policies must be rooted in the best scientific and technical information available--but this information while necessary, is not sufficient.
- The tone and cosmetic quality of technical presentations by scientists and engineers are often the key factors in establishing public perceptions.
- We must do a better job of presenting technical information to the public.
- To the extent possible, technical evaluations--judgements--should be separated from value judgements. As Lewis Thomas has observed, "There are some things about which it is not true to say that every man has a right to his own opinion".
- David Noble, an historian at MIT has observed "Technical imperatives define only what is <u>possible</u>, not what is <u>necessary</u>; what <u>can</u> be done, not what <u>must</u> be done. The latter decisions are social in nature. Unfortunately, this distinction between possibility and necessity is lost on most contemporary observers, and with it a large measure of imagination and social vision".

The Role of Public Education

- An ambitious and extensive program of public education must be developed to deal with all aspects of the management of municipal solid wastes--the sources and magnitude of the problem, the alternative ways of dealing with it, and the advantages and disadvantages of each alternative. The program needs to be targetted at all levels: K through 12, and at adults.
- Appropriate educational materials need to be prepared for each of these audiences. The materials need to be presented as clearly and objectively as possible.

The Role of the New York State Energy Research and Development Authority

- The New York State Energy Research and Development Authority is supporting research and education to improve the design and operation of resource recovery management systems and develop creative uses for the residuals from these facilities. (Their research program was described in detail in the report of the Second Waste Management Forum held on 24 January 1986).

The Role of the New York State Environmental Facilities Corporation

- The New York State Environmental Facilities Corporation can provide communities with technical assistance, can finance loans for construction of resource recovery facilities, can help communities to plan resource recovery facilities, and can even plan and operate resource recovery facilities and hazardous waste facilities. The range of activities of the N.Y. State Environmental Facilities Corporation are summarized in Table 2.

New York State Environmental Facilities Corporation
50 Wolf Road, Albany, N.Y. 12205 / (518) 457-4100

Table 2

Summary of Existing Powers

	Sewage Treatment Works	Sewage Collecting Systems	Solid Waste Disposal Facility	Solid Waste Processing Pilot Projects	Air Pollution Control Facility	Water Management Facility	Industrial Hazardous Waste Treatment Storage, Exchange and Disposal	Inactive Hazardous Waste Disposal Site Remedial Program	Storm Water Collecting System	Resource Recovery Facilities	Industrial and Hazardous Materials
Advice, Technical Assistance	M, P, A	M, P,A	M, P, A		M, P, A	M, P, A	M, P, A	P, O, M, A	M, P, A	M, P, A	P,OS, S M, A, I
Plan	A, M	A, M	A, M	E	M, A	M, A	X	O	M, A	M, A	
Design	M, A	M, A	M, A	E	M, A	M, A	X	O	M, A	M, A	
Construct	M, A	M, A	M, A	E	M, A	M, A	X	O	M, A	M, A	
Operate and Maintain	M, A	A	M, A	E	M, A	A	X	O	A	M, A	
Own	M, A	M, A	M, A		M, A	A			M, A	M, A	
Acquire Real Property	M, A	M, A	M, A	E	M, A	M, A		O	M, A	M, A	
Financing General/ Special Obligation	M, A, P	M, A, P	M, A, P		M, A, P	M, A, P	P	P	M, A, P	P, M, A	
Lease/Rent	P_1	P_1	P_1		P_1	P_1	P_1	P_1	P_1	P_1	

KEY:

A—State Agency
E—EFC may initiate the Project and Contract for the Work
M—Municipality
O—Owner
O S—Other States

P—Person
P_1—Lease/Rent to Person
S—State of New York
X—Client not Defined
I—Interstate Body

Revised April 1985

THE MODERN RESOURCE RECOVERY FACILITY:
ITS DESIGN AND OPERATION

This section is taken largely from Chapter VI of the forthcoming book--GARBAGE: CAN WE TURN MOUNTAINS INTO MOLEHILLS--by Homer A. Neal and J.R. Schubel which will be published by Prentice-Hall in the fall of 1986.

CHAPTER VI

RESOURCE RECOVERY

INCINERATION TECHNOLOGIES

INTRODUCTION

There are at present approximately 350 resource recovery incinerator facilities operating in over 15 countries in the world.[1] The shared feature of these facilities is that garbage is placed in huge furnaces and incinerated at high temperatures, usually from 1650 to 1850 degreees Fahrenheit. In these installations arrays of tubes carry water to recover the heat generated from burning the waste. Heat transferred to the water from the burning trash and garbage causes the water to boil and to produce steam. The steam is used to turn turbines which produce electricity. In other cases, the steam is transported to nearby industries or homes for direct heating.

The residue (ash) from the incineration process normally contains significant amounts of metals, including iron and aluminum. These materials can be separated from the ash and sold to dealers for recycling. This recovery of resources--energy and useful materials either before or after burning--gives rise to the term "resource recovery". This concept clearly will become more and more relevant in dealing with garbage disposal in the future.

Ideally a resource recovery facility accepts garbage for incineration and captures energy from the combustion process for use as electricity or heat and, either before or after incineration, extracts all materials that can be recycled. The incineration temperature should be sufficiently high to break down any chemicals that would be harmful if released into the atmosphere, but not so high that heavy metals, which are themselves harmful, are vaporized and released into the atmosphere. Nor should the temperature be so high that the reliable long term mechanical operation of the facility is compromised. Using technologies developed in Europe starting in the 1920s there are now a number of resource recovery facilities operating throughout the world which come close to these ideals.

Communities considering solid waste disposal options must take into account the relative economics of mass incineration and landfilling, as well as the environmental and public health impacts these two options may have on the region. For landfills the primary issues are the possibility of groundwater contamination and the cost of land in highly populated regions of the country. For resource recovery facilities, the primary issues have to do with the extent to which emissions may pose health hazards, and the capital costs of the construction project.

In this chapter we review the design and operation of resource recovery facilities, the nature of the emissions, possible impacts of the operation of these facilities on surface water and groundwater, a comparison of the emissions that would result from a standard fossil-fuelled power plant producing the same amount of energy as a resource recovery plant, and strategies contemplated for dealing with disposal of the residual ash. In Chapter VII a comparative summary is made of the economic and environmental considerations applicable to the landfilling and resource recovery disposal options.

OPERATION OF RESOURCE RECOVERY FACILITY

Table VI-A at the end of this chapter summarizes a selected list of resource recovery facilities in operation, under construction or planned in the U.S.

Normally a resource recovery facility is designed to handle the garbage disposal requirements of a county, bi-county, or regional area. To take a specific case of an operational facility, we will focus on the Pinellas County resource recovery facility serving the greater St. Peterburg, Florida, area. A photograph of this facility is shown in Fig. VI-1. A schematic drawing of a typical modern resource recovery facility is shown in Fig. IV-2. The Pinellas County facility, which was put into operation in 1983, handles 2100 tons of garbage per day and serves a population of about one million.

Garbage trucks in Pinellas County pickup in residential and commercial areas and transport their roughly 10 ton loads to the resource recovery facility. On entering the facility, each truck is weighed and the driver questioned about the contents of the load to insure that no highly flammable items are included, and to anticipate the presence of any large items (e.g., refrigerators) that might best be separated out before incineration. The driver then takes his load to the tipping floor of the facility and backs up to a large pit. In the Pinellas facility, this pit is 50 feet wide by 250 feet long and has a depth ranging from 35 to 65 feet. It is capable of holding up to three days worth of garbage deliveries, or 6000 tons of garbage; the equivalent of approximately 600 standard truck loads.

Garbage is removed from the pit by cranes controlled by operators situated in cabins high above the pit. A crane's huge sectored-clawed mechanical hands can lift over one ton of garbage in a single bite and deposit it in a chute leading to the furnace. The garbage is gravity fed into the furnace where it is hydraulically rammed onto the moving grate system.

As fresh garbage enters the stoker it is pushed on top of burning garbage from deeper in the furnace which has been returned close to the entrance chute by action of the reciprocating grate--a characteristic of the patented Martin

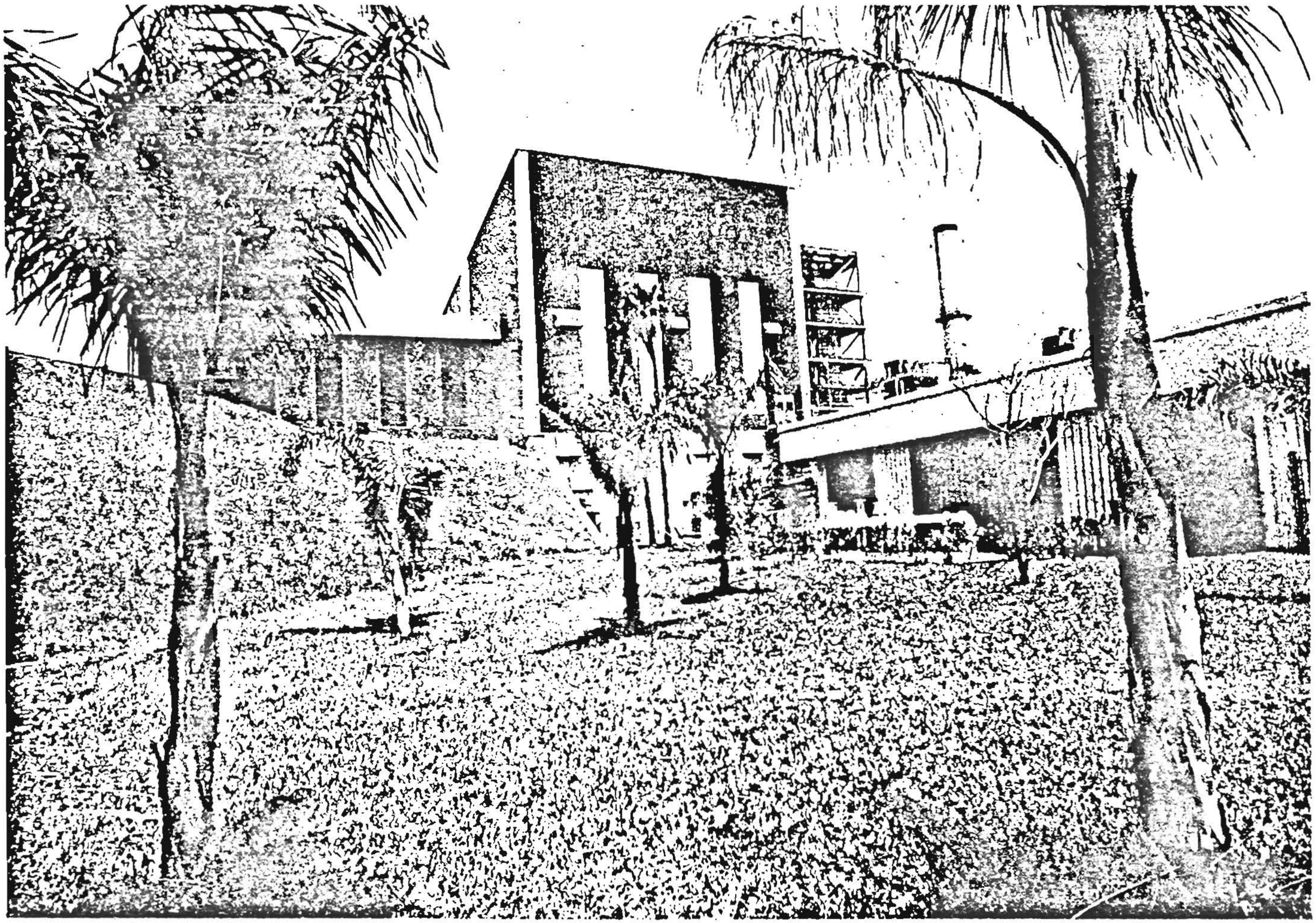
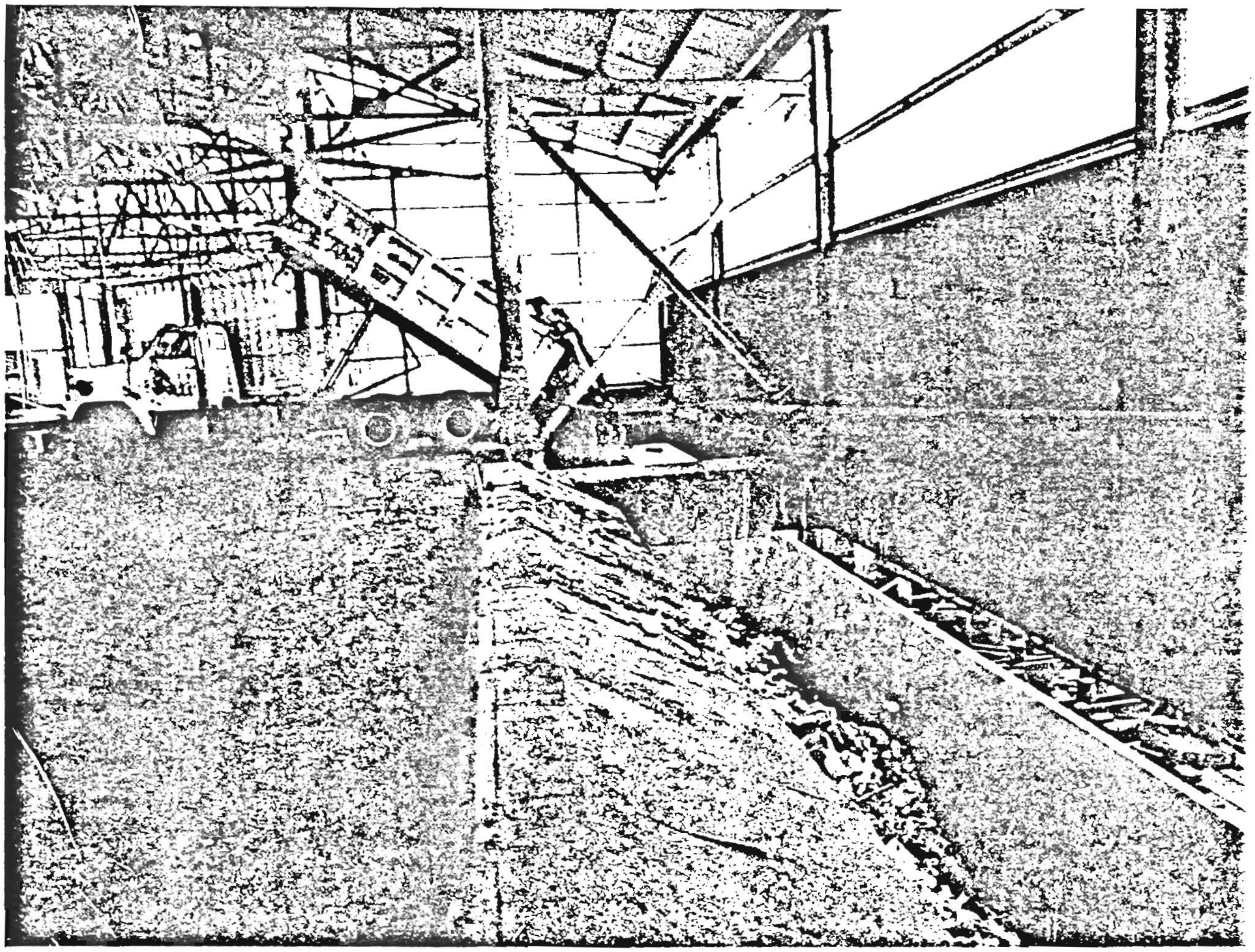


Fig. VI-1. Photograph of Pinellas County (Florida) Refuse-to-Energy Facility.



Photograph of garbage truck unloading in a resource recovery facility.

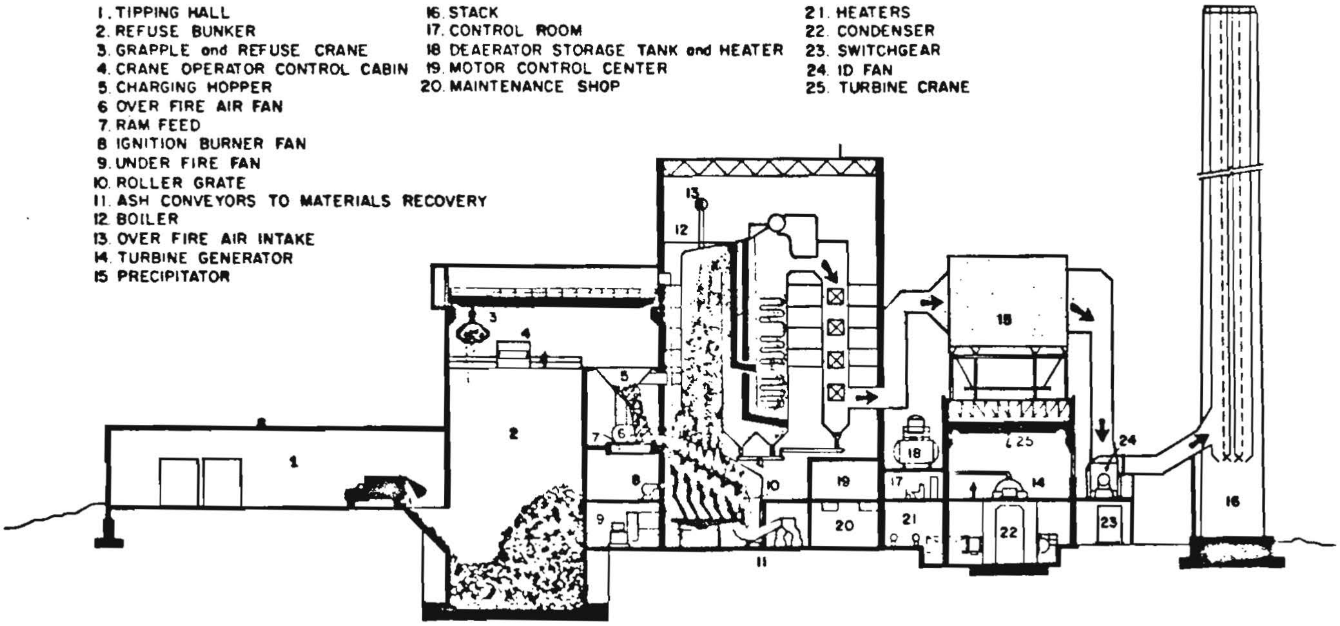


Fig. VI-2. Schematic of resource recovery facility.

process described later in this chapter. In this way garbage entering the furnace for the first time is quickly dehydrated and combusted.

The ash which represents the solid residue of the combustion process collects at the bottom of the grate. It falls onto conveyor belts which carry it to other locations within the facility where it is automatically sorted by size of the particles in the residue. A stone of a size that survives the incineration process will fall onto one conveyor belt, the remnants of a refrigerator onto another. Bottom residue within a given size range is then passed near a magnet which removes the ferrous pieces for sale to iron dealers. The bulk of the other metal is aluminum from beverage cans. This residue also can be sold for recycling. In Chapter VIII we review the economics of recycling activities.

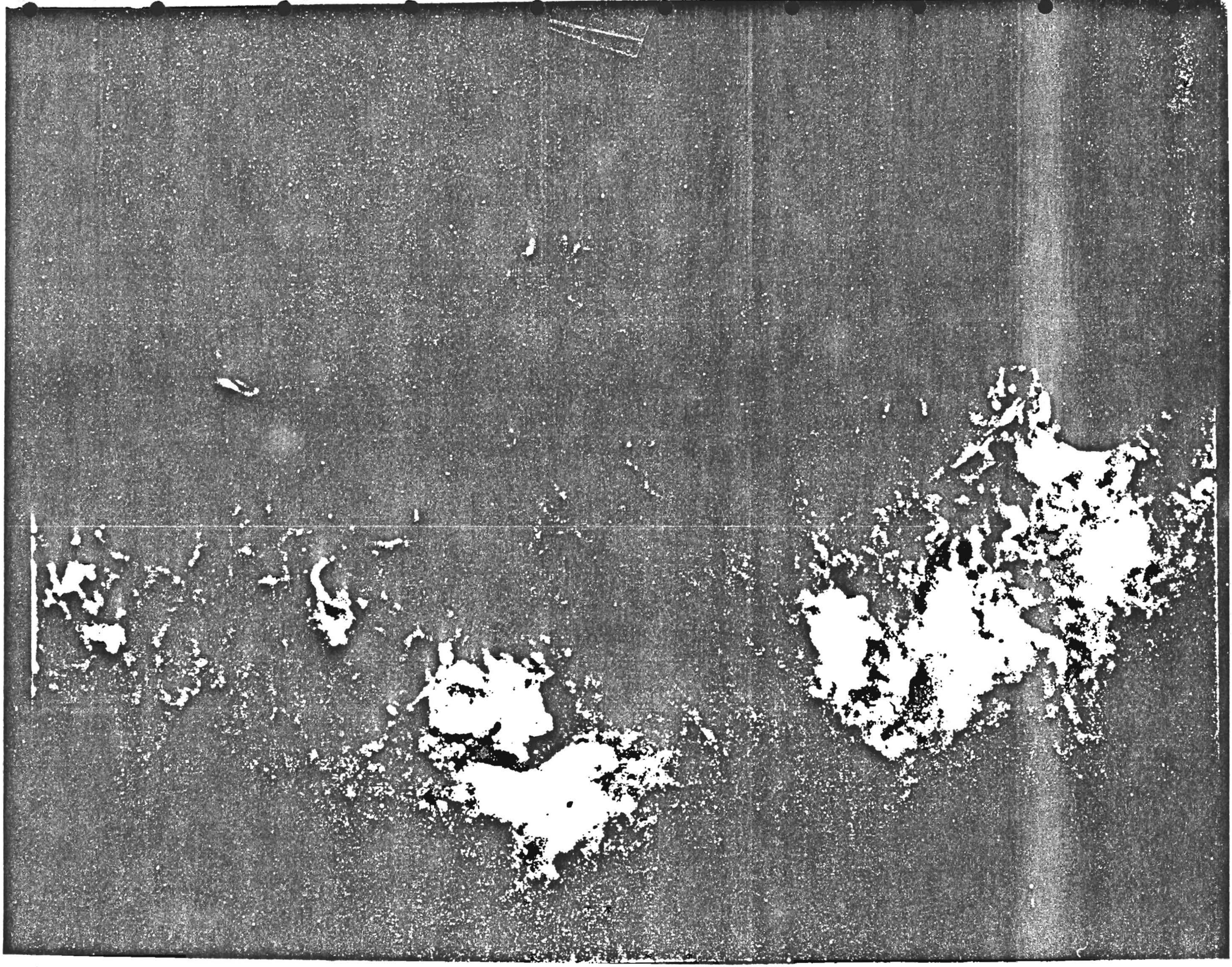
In addition to bottom ash, fly-ash--made up of particles suspended in the gas--is generated by the combustion process. Normally fly-ash is collected in devices called electrostatic precipitators. In these large devices, placed in the path of the gaseous flow of the emissions enroute to the smoke stack, fly-ash is given an electrical charge and is attracted to plates in the precipitator, where it is trapped. It accumulates on the plates and is removed periodically. Usually it is mixed with bottom ash and disposed of. (Other devices called baghouses or fabric filters are also being used today in resource recovery facilities. These devices function somewhat like a nylon stocking placed over the exhaust of a household clothes dryer.

Fly ash is very fine-grained, not unlike soot from fireplaces. For every ton of garbage burned, approximately one-quarter ton ends up as ash.[2] Fly-ash accounts for about 5-10 percent of the total ash residue; the remaining 90-95 percent is called bottom-ash. The ash from most resource recovery facilities is buried in landfills, or used as landfill cover. There are general concerns that, since ash contains metals, dioxins, furans and other contaminants, burying the ash in landfills may hasten the entry of these contaminants into the environment and the water supply. Though EPA toxicity tests have concluded that resource recovery ash is not to be classified as a hazardous waste, it is clear that continued research on ash disposal options and its creative uses is highly desirable. Various options for the utilization of ash, including use as aggregate in concrete blocks, are discussed below.

When present upgrades of the Pinellas County facility are complete, it will provide 75 megawatts electric power to the Florida Power Corporation. This electric power will serve the equivalent of 56,000 homes. The turbines which generate this electricity are driven by steam from the heated water in the walls of the furnace.

COMBUSTION PARAMETERS

The efficiency with which garbage is incinerated in a furnace depends upon a variety of combustion parameters, including the furnace temperature, the amount of air injected into the furnace, the degree of turbulence, the uniformity of the



Photograph of interior of resource recovery furnace.

burning bed and, the time period each element of garbage is exposed to high temperatures. An improperly designed and operated furnace can simultaneously have regions where insufficient air is being provided to sustain burning and nearby regions which receive so much air that torch-like hot spots exist. It is important that such conditions be avoided for a variety of reasons. On the one hand, incomplete combustion leads to the emission of excess quantities of a variety of compounds ranging from the components of black smoke to potentially harmful hydrocarbons. On the other hand, excessive temperatures in isolated hot spots can lead to grate damage and slag formation. The capability for avoiding such conditions is one of the features which distinguishes good and bad furnace designs.

A well-designed furnace should quickly dry the garbage and bring it to combustion, should vigorously mix air uniformly throughout the garbage during combustion and should ensure that each element of garbage and its combustion products are held at a temperature above $1800^{\circ}F$ for at least one second. Laboratory data indicate that these conditions of good combustion destroy more than 99.9 percent (by weight) of many of the effluent compounds, including dioxins and furans. Data supporting this conclusion are shown in Fig. VI-3. It is believed that the wide range of furnace designs in use is responsible for the widely varying rates of dioxin emissions from the plants listed in Table VI- 1. The Chicago plant, for example, emits only 42 billionths of a gram of dioxin per cubic meter of gaseous effluent from the stacks, while the Hampton (VA) plant emits over 4250 billionths of a gram per cubic meter of gaseous effluent. Clearly, such tremendous differences suggest the advisability of studying the design and operating conditions of such plants in an attempt to determine what design and operating parameters should be incorporated into future plants.

In a paper by Licata[8] the value of the three-T's rule is stressed. The three T's are time, temperature, and turbulence. The longer an element of garbage is subjected to high temperature, the more complete is the combustion. The higher the temperature for a given exposure time, the better the combustion. For a given temperature and exposure time the more turbulence the garbage is subject to, the more complete the combustion. Good furnaces must therefore ensure a high temperature, a high degree of turbulence and a sufficiently long exposure time.

Given the varied composition of municipal solid waste and the need for resource recovery facilities to operate reliably throughout the year, it is important that there be an effective monitoring of furnace conditions. Three such methods are employed in modern facilities. One is the monitoring of emissions of carbon monoxide, certain hydrocarbons and oxides of nitrogen. Another is the monitoring of the amount of carbon or combustible material remaining in the ash residue. A third is the monitoring of the efficiency of the boiler surrounding the furnace. The better the combustion, the lower is the emission of the foregoing gases, the lower the carbon and combustible material in the ash, and the greater is the boiler heat generated.

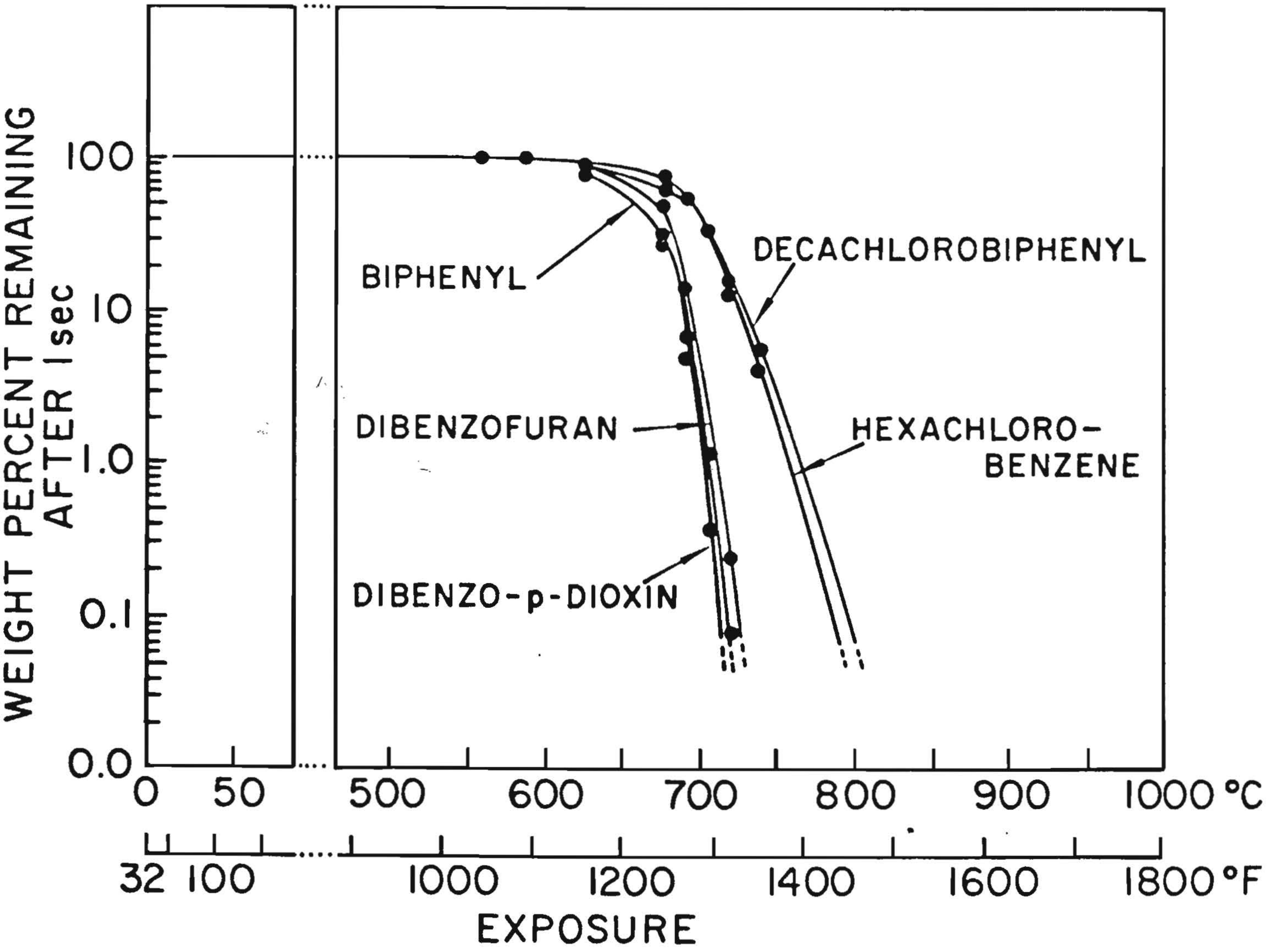


Fig. VI- 3 Destruction efficiencies of various compounds as function of temperature.

TABLE VI-1

DIOXIN (PCDD) STACK EMISSION DATA*

FACILITY (Country)	EMISSION RATE (ng/m^3) ALL PLANTS	EMISSION RATE (ng/m^3) HEAT RECOVERY PLANTS
STAPFLFELD (Germany)	31	31
CHICAGO N.W. (USA)	42	42
ESKJO (Sweden)	73	73
STELLINGER MOOR (Germany)	101	101
PEI (Canada)	107	107
ZURICH (Switzerland)	113	113
BORSIGSTRASSE (Germany)	128	128
COMO (Italy)	280	280
ALBANY (USA)	316	316
DANISH RDF (Denmark)	316	316
ITALY 1	475	
ITALY 6	569	
BELGIUM	680	680
ITALY 5	1020	
ZAANSTAD (Holland)	1294	
VALMADRERA (Italy)	1568	1568
HAMILTON (Canada)	3680	3680
HAMPTON (USA)	4250	4250
ITALY 4	4339	
TORONTO (Canada)	5086	
ITALY 3	7491	
ITALY 2	48,808	

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*Source: Kay Jones, Roy F. Weston, Inc., Courtesy BFI, Inc.
Plants are arranged in increasing order of emission of PCDD

Of all of the surrogates for monitoring the performance of a furnace, perhaps carbon monoxide (CO) is the most useful. The presence of high levels of CO in the flue gas of an incinerator indicates the presence of a significant amount of unburned carbon in the furnace. Moreover, there is evidence that the amount of CO in the effluent is correlated positively with the amount of dioxins/furans emitted. Good furnace design and operation should keep[3] CO levels in the effluent below 100 parts per million (mg/m^3).

The following general guidelines are given for design concepts that foster good combustion[4]:

1. The grate (stoker) should be covered with fuel(trash) at a uniform depth across its width. The depth at any given location on the grate should be consistent with the air deliverable for combustion at that point.

2. There must be an air distribution system that will apportion air to the proper burning rate of waste along the entire breadth and width of the grate.

3. Underfire air should be introduced in a carefully controlled manner. Depending upon the particular technology it may be concentrated in a small area or spead over a large area. Zones of high pressure air and "blowtorch" effects should be eliminated. Bursts of air in one section of the fuel bed prevents the even mixing of air into the burning refuse in other areas.

4. Air must be introduced into the burning refuse both above and below the burning bed. At least 70 percent of the total combustion air required is provided through the underfire system, with the remainder provided through a high pressure overfire system. In some systems the underfire system may account for a larger fraction of the combustion air. Oxygen provided through the overfire system helps to complete the combustion of any hydrocarbons that were not oxidized near the fuel bed.

5. Steps must be taken to prevent the buildup of slag within the furnace. Slag can damage the boiler system, and also result in poor combustion by preventing proper air mixing into the fuel bed.

6. Gases generated in the incineration process should experience maximum mixing, to enhance the chances that oxygen will come into close proximity to any unburned particles, as well as to provide maximum dwell time of the gases before release to the atmosphere.

EUROPEAN INITIATIVES IN RESOURCE RECOVERY TECHNOLOGY

The methods chosen by a country for dealing with societal problems are determined as much by the economic realities as by the state of technology. In Europe, where the costs of energy historically have been high relative to those in the United States and where land for dumping purposes has been scarce, there has been a much more agressive adoption of resource recovery incineration methods for disposing of garbage.

A critical element in the efficient operation of a resource recovery facility is the design of the stoker-grate system used in the furnace. It is not difficult to see how important the grate structure is, since clearly, it is not sufficient to form a massive pile of garbage, strike a match, and stand back and watch complete combustion take place. This is especially true because of the complex mix of materials in the typical solid waste stream, ranging from material with high moisture content, to grass, carpets and even large chunks of metal from items such as furniture and washing machines. The keys to a hot and uniform combustion are the constant mixing of air into the material being burned, and the use of partially combusted material to heat and ignite the new material introduced into the combustion chamber.

Three primary European grate designs have found world-wide application. One system, the Martin System, has a reverse reciprocating grate system, another, the VKW System, has a series of rotating drums as a grate, and the third, the Von Roll System, has a reciprocating grate.

Figure VI-4 shows the Martin process. In this design the grate has a reciprocating action: it moves alternately down and back to provide continuous motion of the refuse. The net motion of the refuse is downward toward the bottom of the furnace but the agitation caused by oscillation of the grate causes considerable mixing of burning refuse with newly introduced refuse, leading to rapid ignition and uniform burning.

In the VKW process illustrated in Fig. VI-5 the large rotating drums slowly move the refuse toward the bottom of the furnace. This system also utilizes the ruffling of the garbage and the injection of air to enhance combustion.

Fig. VI-6 illustrates the Von Roll system. There are three grate sections in this design: the first to dry the newly-introduced refuse and ignite it; the second to serve as the primary combustion grate; and the last as the stage on which the refuse is reduced to ash. Grate elements move in such a way that at a given time for any pair of elements, one is moving and one is stationary. Such a design results in the refuse moving slowly toward the bottom of the furnace but, because of the shuffling action of the grates, the agitation of the fuel bed aids significantly in the combustion process.

Older American incinerator systems did not involve the agitation-generating features found in the European systems. Instead, a series of two or three traveling grates were employed; drying takes place on the first section and full or partial combustion on the second section and, if present, on the third section. Refuse enters the grates from a charging chute and is slowly carried through the various stages of drying and combustion with the residual ash discharged on a belt collection system. There now are a number of American systems of design similar to that of the European systems but, in general, they are not yet as sophisticated.

In another technique employed at some United States

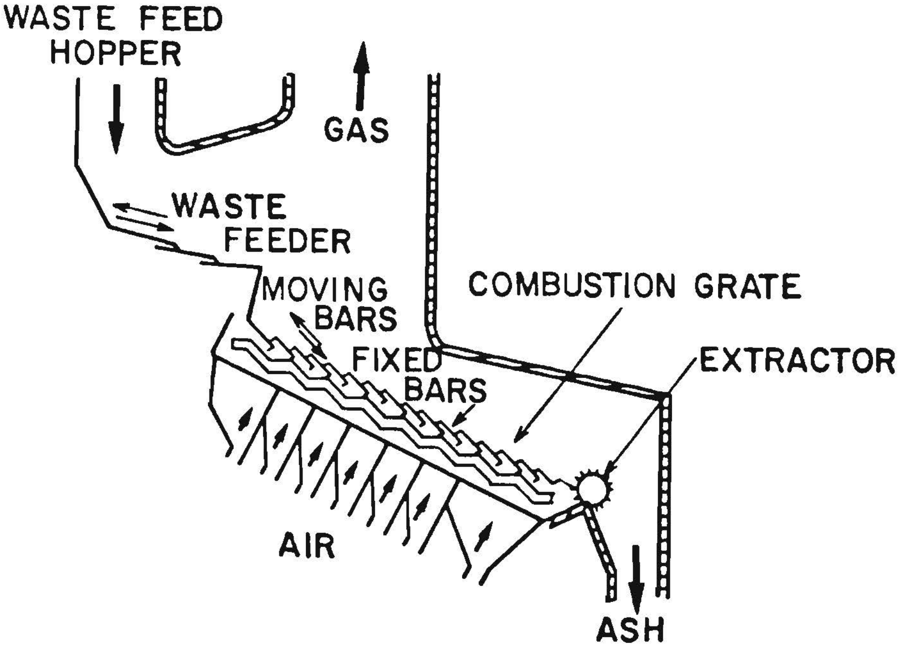


Fig. VI-4. Illustration of Martin grate system.

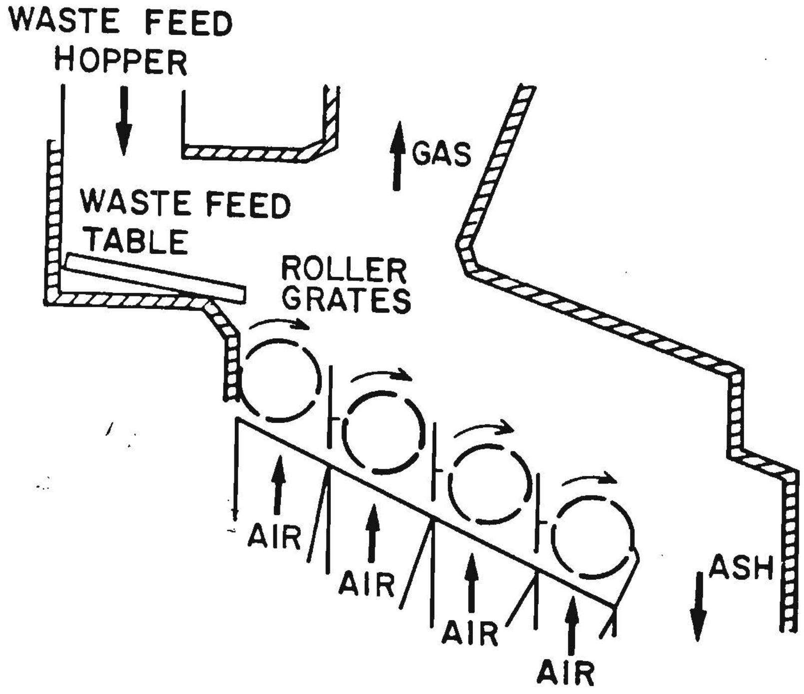


Fig. VI-5. Illustration of VKW grate system.

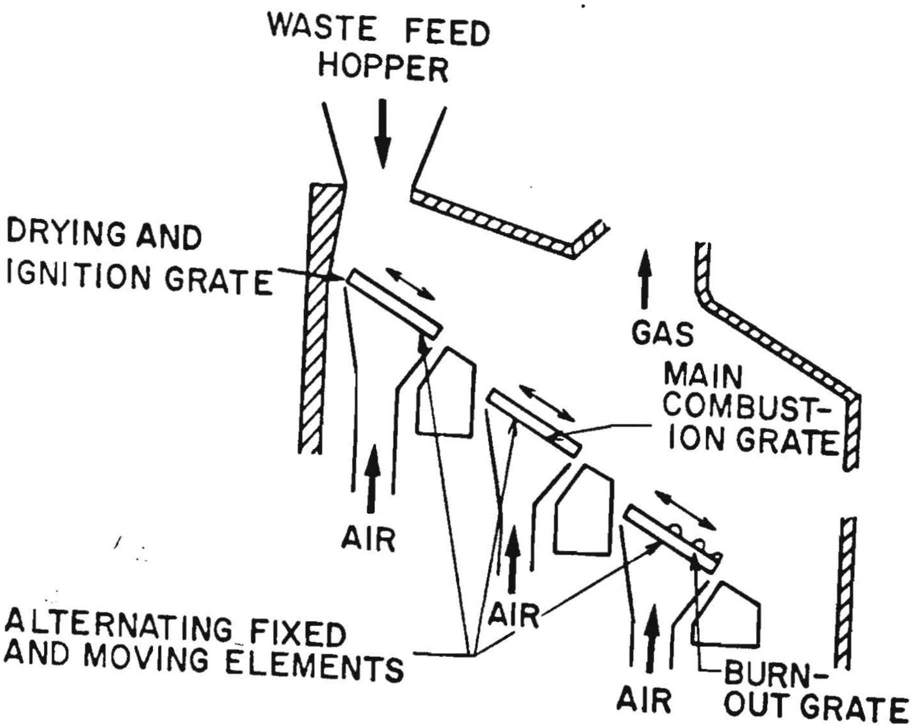


Fig. VI-6. Illustration of Von Roll grate system.

facilities, waste is pneumatically injected into the furnace system and burned while suspended in the furnace chamber, rather than being burned completely on a grate. To make this process efficient, the injected refuse must be largely free of noncombustible material and reduced to relatively fine elements, since large sections of any material introduced into the furnace will not burn before falling to the floor of the furnace. Thus, the refuse must be processed to be used in such facilities. The product of the processing step is known as refuse-derived fuel (RDF). In particular, some method of shredding material must be employed before the refuse is fed into the combustion chamber. Shredding can be problematic, since many items do not lend themselves to this process and, in addition, danger to the operator exists when shredding potentially explosive items. Processing normally includes magnetic extraction of bulk furrous metals, and a screening step to remove fine glass particles and grit, which can cause slagging in the furnace. In contrast, European systems are designed to accept essentially all items without any processing. The shredding concept has not had a great deal of success in the U.S. and only a few plants of this type remain in operation. Many have been closed due to insurmountable mechanical and economic problems.

AMERICAN ENTRY INTO RESOURCE RECOVERY FIELD

It is interesting to review the origins of the growing U.S. utilization of mass incineration methods for disposing of solid wastes. In the 1970's a growing consensus developed that something had to be done to identify new methods of disposing of municipal wastes to replace or, at least, to augment the use of landfills and small-scale volume-reduction incinerators. Landfills, which were at the time, as in many cases now, little more than open dumps were growing ever higher in elevation, leading in many cases to the poisoning of surface and ground water supplies. Apartment-type incinerators then in use were emitting large quantites of smoke and noxious odors, making life in heavily populated areas less and less desirable.

Against this background the then recently formed U.S. Environmental Protection Agency set about to determine which direction should be taken by the country in dealing with its solid waste disposal problem. In order to make sure that the technology so identified represented the state-of-the-art, the agency decided to fund a number of research/demonstration projects. There was very little attention paid to the systems already operating in Europe. It was assumed that since the European systems were designed many years before, they were essentially irrelevant in the selection of designs for the future decades. Millions of dollars were assigned by the EPA for a R/D effort that led to the development of systems such as those used in Hempstead, New York; Bridgeport, Connecticut; and Hampton, Virginia; Franklin, Ohio; Baltimore, Maryland; San Diego, California; and St. Louis, Missouri. These systems were essentially failures, although the nature of their design flaws became known only after millions of dollars in construction and operation had been spent. Because of the lack of ongoing, solid research in the years before, the pressures to identify quick solutions to the mounting garbage disposal problem led some municipalities to adopt technologies that were far from proven, and indeed, were far inferior to the European systems which had evolved over the decades before.

Many of today's operating resource recovery plants which are experiencing various emission and combustion efficiecy difficulties are based on designs developed during the past decade in the foregoing effort to find an improved incineration method. The lessons we have learned in this process again underscore the stubborness of the waste disposal problem, and the need for long range research, development and planning.

AIR POLLUTANTS IN INDUSTRIALIZED SOCIETIES

In any urban environment the atmosphere contains many pollutants, some are relatively innocuous but unpleasant, and some pose potential health hazards. In considering the impact of a routine, ongoing process such as mass incineration of solid waste, it is important to examine the extent to which the resulting emissions may add to the existing burden of atmospheric pollution, both in absolute and in relative terms.

In defining the quality of air one normally refers to the National Ambient Air Quality Standards (NAAQS) estblished by the federal government under the Clean Air Act. These standards, described in more detail in Appendix II, utilize the levels of sulfur dioxides, nitrogen dioxides, lead, photochemical oxidants, carbon monoxide, and particulate matter as criteria in assessing air quality and are thus called the "criteria pollutants". There are other pollutants regulated by the Clean Air Act, but since these are not utilized as criteria for defining the quality of air, they are referred to as "non-criteria pollutants" and they include asbestos, beryllium, mercury, fluorides, vinyl chloride, sulfuric acid mist, hydrogen sulfide, and reduced sulfur and sulfur compounds.

Major Atmospheric Pollutants

One of the principal pollutants of the atmosphere is carbon monoxide, a gas produced whenever any material containing carbon is burned. Carbon monoxide is more than 10 times as prevalent in the atmosphere as any other single pollutant. Of the 180 million metric tons of pollutants emitted into the atmosphere in the United States each year, almost half of this total is carbon monoxide.[6] Approximately two-thirds of the total comes from automobile exhaust. In the city of Los Angeles alone, over 9000 metric tons of carbon monoxide are generated and released into the atmosphere from automobiles every day.[6]

The primary health effect of carbon monoxide is a result of its ability to pass easily into the lungs and then directly into the blood stream. Once there, it attaches to hemoglobin, the carrier of oxygen, and greatly reduces the efficiency of hemoglobin in fulfilling its tasks. The body senses a reduction in the oxygen being delivered by the blood; the heart rate is elevated to compensate, and the breathing rate is stimulated. If, in the process, more and more carbon monoxide is inhaled, life support mechanisms can degenerate quickly. Indeed, at carbon monoxide concentrations of 1500 parts per million, human life is threatened.

The Brooklyn Navy Yard (BNY) 3000 TPD resource recovery facility described in Ref. 7 is expected to produce approximately 366 tons of carbon monoxide per year (See Table VI-2). This sum is to be compared with the New York City total carbon monoxide emissions of 644,208 tons per year. An industrial coal boiler producing the same amount of electricity as the BNY resource recovery facility would emit approximately 187 tons of carbon monoxide per year.

The next major pollutants, in order of abundance in most cities, are the sulfur compounds. In industrial areas the concentration of sulfur dioxide is commonly in the range of 1.7 to 3.0 parts per million--close to the threshold level for human detection by smell. The effects of inhaling sulfur dioxide can range from discomfort as a result of the production of sulfuric acid in the throat and lungs by the chemical reactions of the dioxides with moisture in the respiratory system, to more serious complications which arise when sulfur dioxide is adsorbed onto the surfaces of particulates in the air which then are inhaled and succeed in penetrating into lung tissue. Such deep penetration is thought to be capable of causing emphysema and bronchitis.

For the Brooklyn Navy Yard facility the sulfur dioxide emission level is projected to be 1,177 tons per year, compared to the total New York City production level of 56,336 tons per year. An industrial coal boiler producing the comparable electricity output would produce approximately 1,847 tons per year, or 670 tons per year more than the corresponding resource recovery facility.[8]

Another class of criteria pollutants is the nitrogen oxides. Overall, these are produced at much greater rates by natural sources than by human activities. But in heavily populated areas, the anthropogenic production can dominate, because combustion of fossil fuels is one of the primary mechanisms for production.

The typical level of nitrogen dioxide in an industrial area is 1 part per million. Exposures to levels of 50 ppm are quite hazardous, and methemoglobinemia, a change in blood chemistry, occurs at exposure levels of 100 ppm.[9]

Although sulfur dioxide and nitrogen dioxide cause illness in similiar ways the absence of the warning smell which sulfur dioxide provides makes nitrogen dioxide especially dangerous. Individuals unaware of the impending danger may remain in areas of high concentrations of nitrogen dioxide longer than they otherwise would.

Nitrogen dioxides also have been implicated in the formation of smog and acid rain. In the atmosphere, NO_2 may be oxidized and combined with water vapor to form nitric acid (HNO_3), which contributes to acid rain.

COMPARISON OF PROJECTED EMISSIONS FROM BROOKLYN NAVY YARD INCINERATOR, STEAM GENERATING FACILITY AND COAL BOILER

(IN UNITS OF TONS PER YEAR)

POLLUTANT	BROOKLYN NAVY YARD RESOURCE RECOVERY	HUDSON AVE. STEAM GENERATING FACILITY	INDUSTRIAL COAL BOILER
PARTICULATE MATTER	161	128	486
SULFUR DIOXIDE	1177	1435	1847
NITROGEN DIOXIDE	2973	1300	3403
CARBON MONOXIDE	366	132	187
HYDROCARBONS	65.7	26.4	56.1

Table VI-2

The Brooklyn Navy Yard facilty is expected to produce 2,973 tons of nitrogen oxides per year, compared to the total New York City production of 191,205 tons per year. The emission from a industrial coal boiler producing the same electricity output is 3,403 tons per year. [10]

Lead is used in a wide variety of applications: plumbing pipes, radiators and batteries, paints, printing, glass, pottery, and electronic components, to mention just a few. A primary source of lead in the atmosphere comes from the combustion of gasoline in automobiles, and this is the basis for the targeted attention that has been given to the regulated use of unleaded gasoline in newer model cars. Lead in the environment is a source of public health concern because it compromises the ability of the body to form hemoglobin and it can seriously damage the central nervous system, the kidneys and the reproductive system. Comparison with archaeological studies indicates that the lead level in bones of "modern industrial man " is more than 100 times higher than that of humans who lived 4500 years ago.

The concentration of lead in the blood of the average human is about 10 to 15 micrograms per deciliter of blood. Estimates of the blood level at which lead poisoning can occur are about 50 micrograms per deciliter. Urban air contains lead in concentrations normally much less than 0.001 ug/deciliter (10 ug/m^3) and is not believed to pose any significant threat to adults even when exposed over long periods of time. However, individuals who work in certain jobs such as lead smelting and battery manufacturing are known to be exposed to levels ranging as high as 900 ug/m3 and have been known to develop lead blood levels of 90 ug/deciliter.[11]

The Brooklyn Navy Yard resource recovery facility is expected to emit 14.5 tons of lead annually.[12] Data on lead emissions citywide are not available at this time. The principal sources of lead to the urban atmosphere are automobiles and industrial processing. Emissions from a coal-fired power plant producing the same electricity output as the Brooklyn Navy Yard and equipped with modern emission control technology would be approximately ______ tons of lead per year.[13]

Specific Emission Issues For Resource Recovery Facilities:

Metals

Metals that are emitted in relatively high levels on fly ash particles from resource recovery plants include lead, cadmium, zinc, copper, manganese, silver, mercury, and tin.[14] Most metals are enriched on the smaller flyash particles (less than 2 microns in diameter). This observation can be explained by the volatilization of metals during the combustion of refuse, and subsequent condensation at lower temperatures onto the finer-sized particles, which have greater surface area per unit volume available for adsorption than larger particles. Furthermore, the presence of a higher density of fine particles in the flue gas will favor a higher probability of a volatilized metal condensing onto a particle. Of the heavy metals, mercury is the only one that does not show a high degree of affinity for adsorption onto fine particles. This behavior is the result of the high vapor pressure of mercury. Approximately half of the mercury in the flue gas is in the vapor phase at temperatures characteristic of flue gas.

Identification of the sources of some of the more toxic metals in the refuse, and removal prior to combustion may decrease the emissions of some of these metals.[15,16] Trace elements found in urban refuse are listed in Table VI-3. Printing inks have been found to be sources of lead, cadmium and zinc. Other metals used extensively in publishing are titanium, molybdate, magnesium, iron, and barium. Paints contribute lead, titanium, and chromium to emissions.

Table VI.3. Trace elements found in urban refuse

Element	Concentration (ppm dry weight)
Silver (Ag)	7
Aluminum (Al)	5,978
Barium (Ba)	130
Calcium (Ca)	6,848
Cadmium (Cd)	9
Cobalt (Co)	7
Chromium (Cr)	65
Copper (Cu)	250
Iron (Fe)	1,630
Mercury (Hg)	1
Potassium (k)	913
Lithium (Li)	2
Magnesium (Mg)	1,087
Manganese (Mn)	250
Sodium (Na)	3,152
Nickel (Ni)	54
Lead (Pb)	674
Antimony (Sb)	22
Tin (Sn)	98
Zinc (Zn)	1,087

Source: Lowes, S., B. Hayne and W.J. Campbell. 1978. Pre-burn separation should limit metal emission. Waste Age 9:51-59.

Cadmium and copper are concentrated in heavy combustibles like heavy-guaged plastics. Also, plastic stabilizers are sources of tin, lead and cadmium. Those metals in emissions that appear to be contributed in roughly equal amounts by the combustible and noncombustible fractions of the refuse include cadmium, chromium, lead, manganese, silver, tin, and zinc. These metals are associated with coatings of galvanizing materials, solders, pigments, and other surface agents, or with thin foils or wires in the noncombustible fraction. Metal emissions believed to be derived largely from the combustible fraction are copper, cadmium, mercury and magnesium. Lead in emissions is believed to be significantly derived from noncombustible sources (e.g. bulk metals). Therefore, removal of the noncombustible sources before incineration could effect some reduction in the emission levels of cadmium, chromium, lead, manganese, silver, tin, and zinc.

Major reductions of metal emissions can be accomplished by efficient collection of fly ash, particularly the finer-size fraction, with electrostatic precipitators or baghouse filters. Reduction of the flue gas temperature to below 500°F (260°C) promotes condensation of many volatilized metals onto fly ash particles, which then can be removed by pollution-control devices--electrostatic precipitators and baghouse filters. Temperatures of 250°F are even more effective.

The primary atmospheric pollutants described above are of direct concern to residents of urbanized regions and usually are monitored by the appropriate agencies. It has been demonstrated repeatedly that well-designed resource recovery facilities can meet the extant regulations governing the criteria polutants and, as discussed below, the technology exists for satisfactorily controlling metal emissions. There are other important concerns, however, associated with the possible release of minute quantitites of highly toxic chemicals such as furans and dioxins as a result of the incineration of municipal solid wastes and other processes. Though there are no present U.S. regulations governing such emissions, and the official position of the U.S.E.P.A. is that emissions of such hydrocarbons from properly operating resource recover facilities pose no health hazards, public concern remains. Some of the elements of the concern are discussed below.

The incineration and combustion processes and the byproducts of combusting a diverse waste stream consisting of paper, wood, metals, glass and plastics is chemically very complicated. Though the mechanics of these processes are known, the science is not fully understood. Certain gases can be created directly by the chemical breakup of items during incineration. Other compounds may be created through the interaction of various compounds present in the burning environment. We review below issues regarding the production of some compounds of special interest -- PCBs, dioxins and furans.

PCBs

Special concern has been expressed about the incineration of materials containing polychlorinated biphenyls (PCBs) because low concentrations of these chemicals have been shown to cause cancer in laboratory animals. This concern has extended to the incineration of municipal wastes which are known to contain numerous items fabricated with PCBs.

PCBs present an interesting example of the way in which products with potential adverse effects can become almost ubiquitious in society. Through research with hydrocarbons, scientists discovered that chains of molecules of hydrocarbon coupled with chlorine produced material that had unique electrical insulating properties and good stability as a plastic. Almost immediately these chemicals, PCBs, found their way into adhesives, fireproofing materials, electronic components, and paints, as well as carbonless paper. The carbonless paper contained PCBs in Aroclor 1242 microcapsules. Although the discovery of the potential health hazards of PCBs led to suspension of manufacture in 1971, they are distributed widely in the environment and will be with us for a very long time; at least for decades. As an example, the rapid market success of PCB- laden carbonless paper, and the recycling of this paper after use, has led to PCBs being present in essentially all paper products using recycled paper. Thus, there are clear reasons for being concerned about what effects landfilling and incineration will have on the further dispersal of PCBs in the environment.

Studies of limited scope have been conducted to determine what occurs when material containing PCBs is incinerated. One paper reported that the level of PCBs measured in the effluent of an incineration facility was essentially unrelated to the PCB content of the material incinerated.[17] Instead, the measured PCB levels were consistent with their origination in the ambient atmosphere within the plant. Other observations have indicated that indoor residential PCB levels were higher than those outside because of outgassing of caulking compounds, small electrical equipment, and ballasts of faulty flourescent lights. In any case, the existing data also indicate that at least 99.99% of the PCBs are destroyed by the high temperature incineration process characteristic of modern resource recovery facilities.[18]

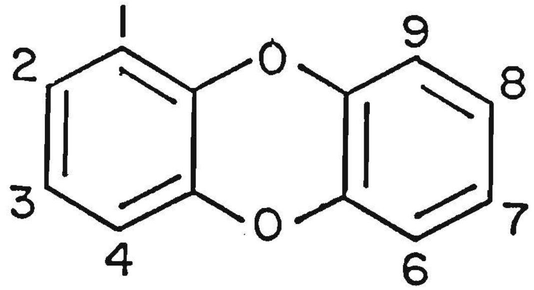
Dioxins

A chemical compound having two benzene rings coupled with two oxygen bridges in the presence of specific chlorine atom arrangements is called a polychlorinated dioxin. The term "bridge" is used here to denote the fact that an atom of oxygen being divalent (i.e., being able to form two electron bonds) provides a linkage between two different benzene molecules. Diagrammatic models of benzene rings and dioxins are shown in Figure VI-7. An important characteristic of these dioxins is that there must be at least two chlorine atoms at two or more of the eight marked sites on the structure in Figure VI-7. The complete family of dioxins and their molecular formula are shown in Figure VI-8.

Another related group of compounds are the dibenzofurans (frequently called simply furans). Their chemical structure is shown in Figure VI-9. The principal difference between them and the dioxins is the presence of one oxygen bridge, rather than two. Examples of members of the furan family are shown in Figure VI-10.

Dioxins appear to retain their chemical integrity up to temperatures of 1300 degrees Fahrenheit; above that they disintegrate through the breaking of the various bonds (see Fig. VI-10a). At standard atmospheric temperature and pressure, the solubility of dioxins in water is quite low, and the vapor pressure is also low (less than one millionth of a millimeter of mercury at STP), indicating that very little of the material volatizes at ambient temperature and pressure.

Note that in Figure VI-11 chlorine atoms occupy the sites 2,3,7, and 8. This Tetrachloro-bidenzo-p-dioxin (TCDD) is the most toxic dioxin discovered so far. Although there has been no known case of long-term human disability, or death,



DIBENZO-P-DIOXIN

Fig. VI-7.

PCDD

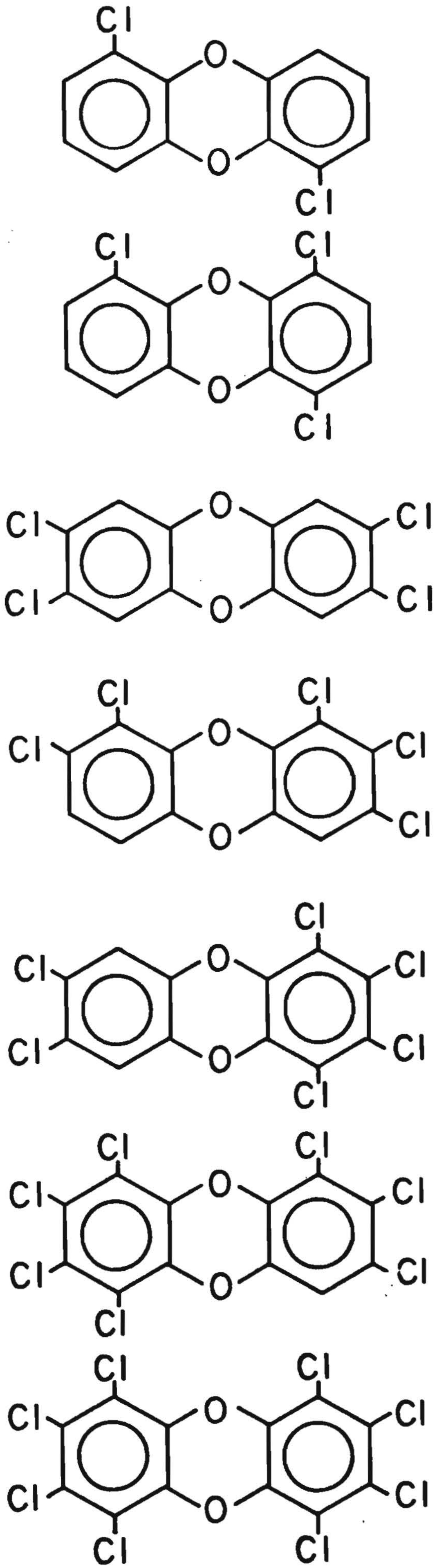


Fig. 8. Family of Dioxins.

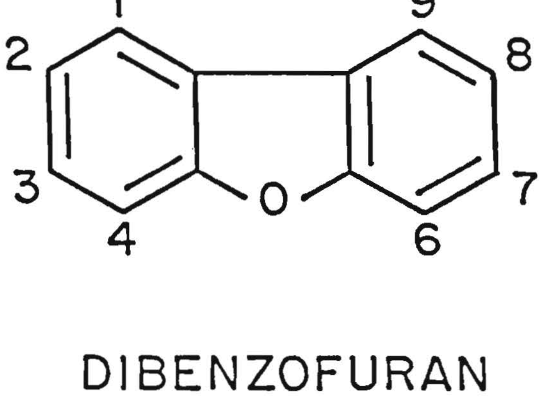


Fig. VI-9. Chemical structure of furans.

Tetrachloro
dibenzo-furan

Pentachloro-
dibenzo-furan

Hexacloro-
dibenzo-furan

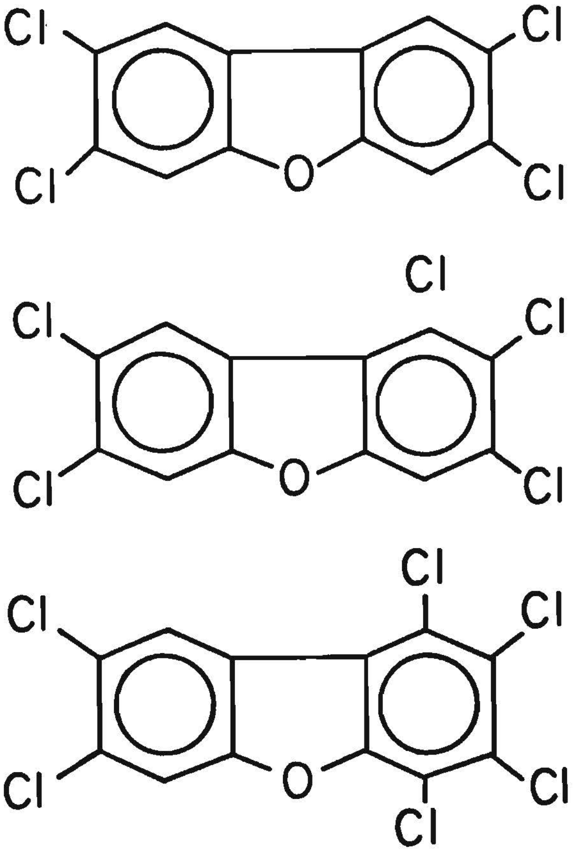
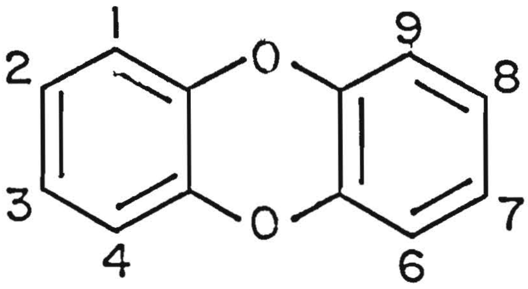


Fig. VI-10. Examples of members on the furan family.



DIBENZO-P-DIOXIN

Tetrachloro-
dibenzo-p-dioxin

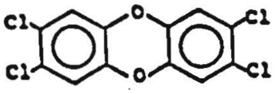


Fig. VI-11. Illustration of chemical structure of TCDD dioxin resulting directly from exposure to dioxin, there is a body of research which indicates that this compound is very toxic to small animals. Indeed, it currently is the most toxic of all synthetic chemicals tested on animals. Table VI-4 indicates the toxicity of 2,3,7,8 TCDD in comparison with other known toxins. In terms of lethal effects for each gram of toxin per kilogram of body weight, it is 10,000 times as potent as cyanide. In comparison with the dreaded Botulism Toxin A, however, it is less than one-ten-thousandth as potent.[19]

Carcinogenicity of TCDD, as well as effects on the reproductive systems and the fetuses, has been demonstrated in small laboratory animals. There are no experimental data on the effects of dioxins on humans. Since dioxins are not naturally occuring, the epidemiology of effects over time is not available. Industrial accidents have been infrequent and have not led to diagnostic insights of the precise effects of exposure. The incidents that have been examined indicate that exposure is followed by the skin disorder, chloracne, and short term liver damage.[20] Longer term studies and detailed analyses will be required to assess the true carcinogenic effects on humans.

Dioxins are released in the environment by residential fireplaces and grills, incinerators, diesel truck mufflers, and the soil. Table VI-5 shows approximate levels of dioxin in parts per billion in various sites.[21]

Parameters that influence the rate of dioxin emission include combustion temperature, air mixture and exposure time. Observations of municipal solid waste incinerators indicate that increasing the temperature of combustion generally decreases the total amounts of dioxins and furans produced. These observations at operating plants are consistent with the belief that greater thermal and oxidative destruction of PCDDs, PCDFs, and precursor compounds occurs at higher temperatures. An extensive analysis on dioxin emission rates versus a number of combustion characteristics revealed a strong positive correlation betwen PCDD/PCDF emission rates and minimal combustion temperature, and a weaker correlation with average furnace temperatures.[22] When temperatures fall below 932 ^{o}F (500 ^{o}C), emission rates appear to be greatly enhanced, perhaps indicating a change in the production process such as the generation rate of organic precursor compounds. At temperatures at and above 1832 ^{o}F (1000 ^{o}C), dioxins and furans are still detected, but levels are significantly reduced. It is surprising that the results of laboratory studies are more equivocal.

Many laboratory studies have been used to examine the production of dioxins and furans, and their precursors, from the combusting and pyrolyzing of both chemically related and unrelated substances. There does not seem to be general agreement on a correlation between PCDD/PCDF production and temperature. Some investigators believe it is very difficult to relate laboratory reaction analyses to dioxin and furan generation from the incineration of heterogeneous refuse. More useful information may be obtained by analyzing particular chemicals (i.e. chlorine and chlorinated aromatic compounds) in municipal solid wastes to determine how they influence the production of dioxins and furans. The apparent

Acute Toxicities Relative to 2,3,7,8 TCDD

	Dose (g/kg body wt)	Relative Toxicity
Botulism toxin A	30E-12	35,000
Tetanus toxin	1E-10	10,000
2,3,7,8 TCDD	1E-6	1
1,2,3,4 TCDD	1E-4	.01
Strychnine	5E-2	.002
Sodium Cyanide	1E-2	.0001

Source: A. Poland and A. Kende, "2,3,7,8 TCDD: Environmental Containment and Molecular Probe," In Air Pollution Control, *Federation Proceedings*, 35, no. 12 (October 1976), San Francisco, CA. 2404–11.

Table VI-4a. Comparison of TCDD toxicity relative to that of other known toxins.

Dioxin Dosage In Animal Species

Animal	LD_{50}, μ/kg body weight
Guinea pig	1
Rat (male)	22
Rat (female)	45
Monkey	<70
Rabbit	115
Mouse	114
Dog	>300
Bullfrog	>500
Hamster	5,000

Source: A. Poland and R. Knudsen, *Annual Review of Pharmacology and Toxicology* (1982), Unpublished Report.

Table VI-4b. Dioxin dosage in various animal species.

Chlorinated Dioxins in the Enrivonment

Sample	Apparent Dioxin Content, ppb			
	TCDD	HCDD	H_7CDD	OCDD
Soil				
Rural	•	•	•–.05	•–.2
Urban (Lansing, MI)	•	.03–1.2	.03–2	.05–2
Urban (Chicago)	.005–.03	.03–.3	.1–3	.4–22
Dow Chemical (Michigan)	1–120	7–280	70–3,200	490–20,000
Dust				
Dow Chemical Laboratory	1–4	9–35	140–1,200	650–7,500
Midland, MI	.03–.04	.2–.4	2–4	20–30
Detroit, MI	•–.03	•–.3	.3–4	.1–4
St. Louis, MO	.3	2	34	210
Chicago, IL	.04	•–.3	.6–3	3–8
Wastewater Treatment Sludge				
Milorganite (Milwaukee)	.31	2	30	180
Incinerators				
Dow Powerhouse	38	2	4	24
Dow Rotary Incin. Stack	•	1–5	4–100	9–950
Dow Tar Burner	•	1–20	27–160	190–440
Nashville Incinerator	7.7	14	28	30
European Incinerators	2–20	30–200	60–130	40–120
Mufflers				
Diesel Truck Muffler	.023	.020	.100	.26
Auto Muffler	•–.008	•	.003–.01	.02–.07
Other sources				
Home Fireplace Soot	•–.4	.2–3	.7–16	.9–25
Home electrostatic Prec.	•	.004–.008	.009	.02–.05
Charcoal Broiled Steak	•	•	•	.03

•Not detected

Source: R. Bumb, et al., "Trace Chemistries of Fire," *Science* 210: (October 24, 1980).

TABLE VI-5. Chlorinated Dioxins in the Environment.

lack of correlation between the rate of production of dioxins and the presence of chlorine in the waste stream seems to preclude a simple solution of the problem by reducing the chlorine content of the input waste.

In reviewing the possible impacts of dioxin and furan emissions from resource recovery plants, it is important to take into account the fact that these compounds have finite lifetimes, and decay into much less harmful forms within periods of days to, at most, several months. This fact has been overlooked in most treatments of this topic. Some scientists argue that the toxic loading of the atmosphere from the operation of a high temperature incineration facility is well below the estimated hazardous level.[23] One key premise of this analysis is that the photochemical decomposition of 2,3,7,8 - TCDD has a half-life (the time required for the degradation of half of the molecules in a sample) of hours in the air and on leaves and grasses, and less than a year in soil. To estimate the overall environmental burden, one must then estimate the amount of TCDD produced during a time period comparable to the pertinent half-life and not integrate over all times. For example, if the appropriate half life is one year in soil, to estimate the accumulation of TCDD in the soil from a nearby resource recovery facility, one should only take into account the amount of TCDD settling onto the soil from the plant's fallout over the period of a year, and not for 5 or 10 years. Most of the deposition from previous years will have decomposed into presumably less harmful components, as a result of chemical and biological processes.

It is of interest to examine the amounts of dioxins and furans produced in the incineration process. For each million tons of municipal solid waste burned, approximately 63,000 tons of fly ash is produced. Electrostatic precipitators can successfully collect bewteen 95 and 99% of the fly ash, with the remaining 1 to 5% escaping into the atmosphere with the flue gas. With high efficiency fabric filters, more than 99% of the fly ash can be trapped and removed. This fly ash would contain between 100 to 3000 parts per billion of adsorbed dioxins.[24] Operating at 3000 TPD of refuse incineration, it is projected that the Brooklyn Navy Yard facility will emit approximately one twentieth of a pound of dioxins per year. These emissions are estimated to lead to a certain ground level concentration that depends on distance from the facility but, as shown in Fig. VI-12 these levels are well below those currently used by various sources in assessing what is considered to be a safe exposure level.

As an example of such an analysis, the Netherlands government has adopted as an acceptable level of intake of TCDD 1 nanogram per kilogram of body weight per day.[25] This translates into an acceptable ambient concentration of roughly 350 x 10^{-6} micrograms per cubic meter. Using a safety factor of 250 in arriving at a standard, the Netherland standard is then approximately 1.4 x 10^{-6} micrograms per cubic meter. Calculations by Fred C. Hart Associates indicate that the impact of the Brooklyn Navy Yard facility would be 2.13 x 10^{-9}, a number 10,000 smaller than the standard, which itself is 250 times the calculated acceptable level.[26]

GENERAL ASSESSMENT OF EMISSIONS FROM INCINERATORS

In December 1984 a group of scientists met under the auspices of the New York Academy of Sciences to discuss the emissions from resource recovery facilities.[27] General agreement was expressed that the emissions of sulfur oxides, metals, chlorides and particulates, could be controlled if appropriate existing technologies are employed. Sulfur dioxide emissions from the incineration of municipal wastes are relatively insignificant when compared to those from coal-fired plants. Mercury and other volatile metals vaporize at the temperatures of modern incinerators and end up in the gaseous discharge stream. The chlorine present in the waste stream is converted in large measure to hydrogen chloride.

This general agreement among the participants concerning the ability to monitor and control the emissions of sulfur oxides, metals, chlorides and particulates stands in sharp contrast to the controversy that exists on the amounts and effects of the more complex organic compounds--in particular, the polychlorinated dibenzo-p- dioxins and polychlorinated dibenzo-furans.

One or more of the following processes are thought to be involved in the production of dioxins: the release of dioxins present in the input waste, the synthesis of dioxins from direct precursors (i.e., the modification of structurally similar compounds), or the de novo synthesis of dioxins from basic organic materials (i.e., extensive rearrangement of much simpler organic compounds).

The first mechanism does not seem to provide the sole source of dioxins since data indicate that the amount of dioxin emitted exceeds the dioxin in the input stream. Although there is evidence to support formation through precursors and de novo synthesis, there is no conclusive evidence regarding the relative contribution of each of these processes.

The panelists stressed the risk/benefit considerations of resource recovery facilities. Normally a new process is assumed to be acceptable when it is demonstrated that overall benfits accrue from the process and that the process poses the least risk in comparison with all alternatives. Because of the extreme complexity of the solid waste disposal problem, as well as the lack of vital data, the panelists indicated that they were not in a position to make unequivocal statements regarding risks and benefits with respect to dioxins/furans at this time.

To proceed with the appropriate analyses in the future, more information is required concerning exposure mechanisms, the size of the exposed population, the appropriateness of extrapolation to low doses, and the extrapolation of laboratory data from test animals to humans.

There are numerous ways in which gaseous pollutants such as dioxins and furans can enter the human body. Inhalation is an obvious process, but there are other routes such as ingestion of contaminated food, and skin contact. A complete analysis of the impact of furans and dioxins therefore must take into account climatic conditions, the nature of the buildings (height, ventilation, dusting/cleaning practices, etc.) in which the average citizen lives and works. The extraordinary complexity of a full scale analysis is evident, although it is clear that some rough estimates could be made on the basis of somewhat improved data.

In analyzing the population that would be exposed to effluents from a resource recovery plant, one would have to take into account the siting of the plant, wind flow patterns, stack heights, rainfall and other meterologic conditions. Any meaningful assessment must take the variation of these parameters into account.

In almost any attempt to determine the effects of trace amounts of toxic chemicals on humans there is the problem of knowing how to scale what is learned from intense doses of chemicals delivered to test animals for a short period of time to the more realistic problem of the impact of smaller doses to humans over a prolonged period of time. Finally, as noted above, there also is the question of how to scale from animals to humans. There is the possibility that, on a per volume or weight basis, humans may be either less sensitive or more sensitive to the effects of chemicals such as dioxins and furans.

Moreover, the panelists involved in the New York Academy of Sciences conference pointed out that all analyses to date have confined their attention to the worst-case situation for cancer generation. This approach has clear defects.

In summary, the above conference, and a similar series of symposia held at the State University of New York at Stony Brook, have reached the conclusion that of the many issues of potential concern associated with the operation of modern resource recovery facilities, most seem to be solvable with existing technology. The remaining uncertainties having to do with the production of dioxins and furans may soon be resolved following the outcome of current studies. Proceedings of the January, 1986 Stony Brook symposium are included in Apendix III.

VEHICLE EMISSIONS IN RESOURCE RECOVERY FACILITIES

Vehicular traffic around a resource recovery facility consists primarily of the incoming loaded trucks, the outgoing empty trucks, and a small volume of traffic associated with transporting recovered materials to dealers, and ash residue to nearby landfills.

The internal traffic at a resource facility requires very little fuel per ton of garbage compared with the fuel required per ton of garbage for the operation of a typical sanitary landfill. The difference, of course, is the extensive vehicle operation required for the distribution and covering of garbage within a landfill.

ODORS AND VECTORS AND SURFACE BLOWN LITTER

Resource recovery facilities cause essentially no detectable increase in the odor level in the region surrounding the facility. Because the interior of the plant is kept at a pressure lower than that of the outside environment, no air from the garbage pit escapes to the outside. Moreover, the outside air that enters the building and the fumes from the garbage tipping floor are drawn into the furnace to facilitate combustion and thus emerge as part of flue gas which is odorless.

Since the garbage is unloaded from the transporting trucks inside a closed building there is no problem of surface blown litter at a properly operated resource recovery facility.

WATER POLLUTION AT RESOURCE RECOVERY FACILITIES

Resource recovery plants in general use water only to condition the ash residue to minimize the problem of dusting. In the Martin process, for example, just enough water is used to condition the ash and almost all of it evaporates in the ash discharger assembly. Moreover, many plants are designed so that cooling, wash-down and boiler blow-down water is directed to the ash discharger. There is little or no waste water effluent from modern resource recovery facilities, and therefore there is no significant environmental impact on either surface or groundwater supplies from waste water.

OFFSET OF EMISSIONS FROM ALTERNATE ENERGY SOURCES

In the current designs of most resource recovery facilities, the furnace walls are lined with pipes which carry water. In normal plant operation, the water is converted to steam at a temperature of approximately 750 degrees Fahrenheit and a typical pressure of 600 psi. Under such conditions steam can readily be used to drive turbines to create electricity in the same way as in large coal oil fired power generation plants in use around the world. This component of the operation of modern resource recovery facilities draws upon proven technology, although minor innovations have been made in the placement of the water pipes and in other aspects of the operation. A production of between 400 to 500 Kwh of electricity can be assured from the incineration of a ton of typical municipal waste. On this basis a 1200 ton per day disposal facility can operate a 29 MW turbine.[28] Such a turbine produces enough electricity to power more than 20,000 typical homes.

In assessing the environmental impacts of resource recovery facilities, it is appropriate to note the positive contribution made by such facilities by reducing the amount of electricity that would have to be generated by some other means.

In particular, consider our case of a 1200 ton-per-day resource recovery facility that generates 29 MW of electricity. If 29 MW of electricity were generated by an oil-fired power plant, the emissions of that plant can be estimated, Table VI-6.[a] In determining the overall impact of a resource recovery plant, these emissions should be subtracted since they can be viewed as having been avoided through the operation of the plant. Presumably the electricity generated by the resource recovery facility replaces an equivalent amount of electricity which would have been produced through other means.

ASH RECYCLING

Since the mid 1870s incineration of refuse has been in routine use for garbage disposal in Europe. Ash from the incineration process has been utilized both as fill material and as aggregate in the construction of roads. With the increasing number of resource recovery facilities in the United States and the increasing complexity of the material being incinerated, the question of how the residual ash produced by the incineration process should be disposed of is emerging as a critical issue.

Approximately 20 to 25 percent of the original solid waste mass remains as ash after incineration, and the ash has the approximate chemical analysis shown in Fig. VI-12. Although this reduction in mass is extremely valuable, there is still a need to provide an ultimate disposal for a significant fraction of the waste stream, and this need is currently met primarily through the use of landfills. Furthermore, to the extent that ash contains trace amounts of PCBs, PVCs, metals, dioxins and furans, and other compounds that are known to be potentially toxic, care must be taken in choosing how to dispose of the ash.

There are several promising uses of residue from incineration plants. Some examples include the construction of embankments, landfill cover, graded material in road pavements, and aggregate for cement and masonry manufacture for construction purposes or for artificial fishing reefs.

In considering the use of ash residue for fabricating construction material, the structural rigidity and permanence must be examined. Preliminary studies in this area have pointed out certain difficulties. Differential expansion of the residual aluminum and glass products in the ash relative to the alkaline materials in the concrete blocks reduces the structural strength below acceptable levels for use as concrete cement. However, other research has demonstrated

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[a] In preparation.

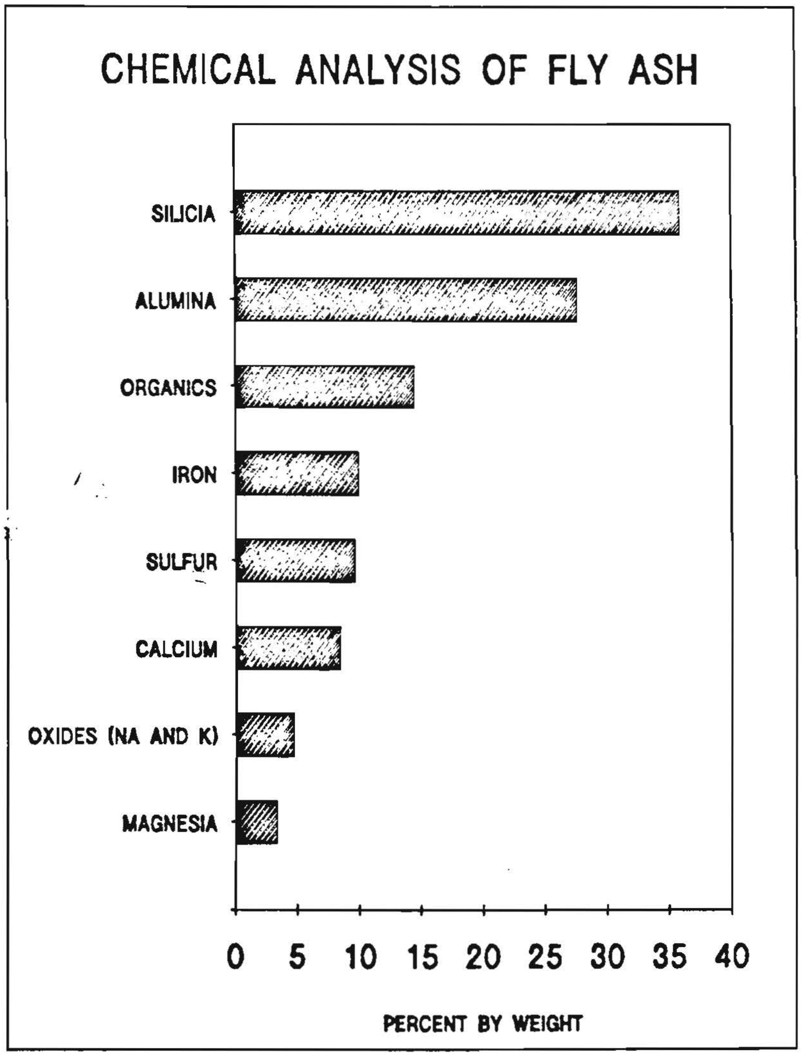

Fig. VI-12 . Chemical analysis of fly ash.

that ash from coal burning plants can be used to make concrete blocks of adequate strength for use in making artificial reefs.[29] This work is being extended to ash from municipal incineration plants to determine what chemical stabilization may be required to bring concrete blocks made using fly ash to construction grade strength (see additional discussion in Chapter V).

Ash from resource recovery plants contains varying quantities of ferrous and aluminum components. The ferrous metals can be separated from the ash stream by the use of magnets. Recovery of aluminum and ferrous scrap from the ash stream is not very profitable and, indeed, many of the original attempts to recover these materials have been suspended. Problems encountered include the variable quality of the recovered products, and the need for extensive additional processing to insure quality and meet product specifications.

Fig. VI-13 illustrates an example of an operating system that currently segregates aluminum and ferrous material from the ash stream. Residue is first moved from the ash dischargers onto a conveyor and then onto a vibrating screen to separate out oversized items. The residue travels to another screen that separates it into two components: material less than and greater than 2 inches in diameter. The particles greater than 2 inches are sent through an electro- magnetic drum separator to lift out the ferrous material. The particles less than 2 inches are sent through a wet screen separator for ash removal and to an impact mill that crushes the material to enhance the recovery of non-ferrous material in the next stage of separation.

Next the two streams are sent to a heavy media separation stage where the heavy nonferrous material is separated from the total nonferrous stream through a process involving floatation. At the end of this stage, it is straightforward to segregate the various constituents: (1) the large oversized objects for placement in landfills; (2) ferrous items greater than 2 inches in size; (3) ferrous items less than 2 inches in size; (4) large aluminum pieces and aluminum flakes; (5) and graded residues of other makeup.[30]

OTHER RESOURCE RECOVERY TECHNOLOGIES

There have been other approaches to solid waste disposal based on the resource recovery concept. They have never been as popular as mass incineration and, indeed, most have failed; nevertheless, it is important for the reader to be aware of the existence of alternate processes. Such alternatives fall either into the category of chemical or biological processes. An example of each of these is reviewed below. Pyrolisis is a disposal method based on destructive chemical distillation. Composting is a method based on the biological decomposition of solid waste by microorganisms.

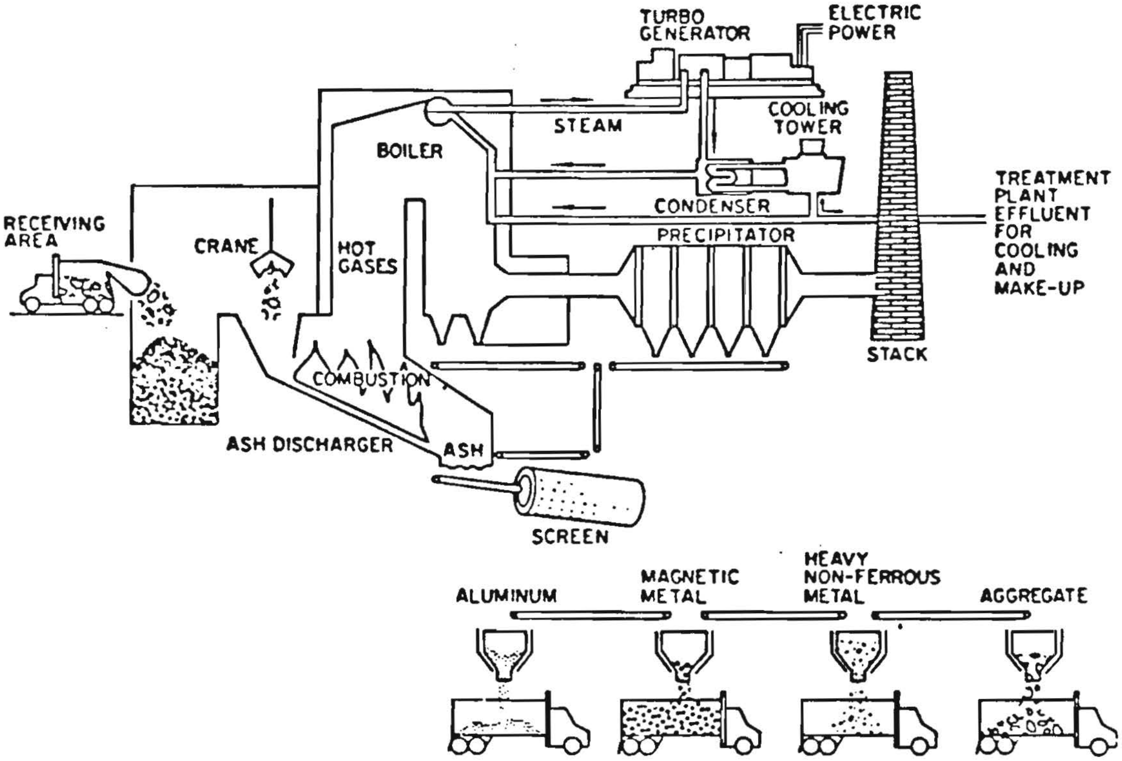

Fig. VI -13. Schematic of resource recovery facility ash separation technique .

Pyrolysis

Unlike incineration whereby heat is generated through the combustion of refuse, pyrolisis is a solid waste disposal scheme in which heat is supplied in the absence of air to cause the release of gases which may provide energy. An example of a pyrolitic reaction leading to the conversion of the primary constituent of paper products is given by the reduction of cellulose:

$$C_6H_{10}O_5 \dashrightarrow CH_4 + 2CO + 3H_2O + 3C$$

In the presence of heat, but not oxygen, the molecule of cellulose changes into a molecule of methane (CH4), two carbon monoxide molecules (CO), three water molecules and 3 carbon atoms. The methane and carbon monoxide are gases which can be recovered and burned. The carbon residue remains as a furnace residue which, depending upon other wastes treated in the pyrolitic chamber, contains various metals, oxides and minerals as well.

For a variety of reasons the pyrolitic process has not proven commercially viable. In the past 10 years 4 pyrolisis plants operated in the United States. At present, no pyrolytic plants are operating for the disposal of municipal solid waste.

Composting

A discussion of solid waste disposal and resource recovery would not be complete without reference to composting. In composting, conditions are created to facilitate the breakdown of organic matter through anerobic and aerobic bacterial action.

If one excludes metal objects, leather, rubber and plastics, most solid wastes consists of organic material. If this organic material is acted upon by bacteria in a controlled manner, the end product is a dark brown or black substance called humus.

Clearly, composting requires the separation of the waste stream into organic and inorganic components. The organic material is then placed in either an open field or in a mechanical system where bacterial activity can proceed. Initially, the material is heated to 130^{0}F (55^{0}C) or more, by the bacterial breakdown of the most easily decomposed compounds. Numerous types of bacteria participate in the decomposition process; different ones are triggered into action as the temperature changes. Moreover, the different types of bacteria preferentially attack different kinds of organic matter in the solid waste in different ways.

In open land composting, the organic material is spread into ground furrows and turned once or twice per week for a period of roughly five weeks. The resulting humus is removed, ground and marketed. In this kind of composting approximately 2.5 acres of land is required to process 50 tons per day. An additional 1.0 acre of land is required for every additional 50 tons per day capacity. Highly mechanized composting operations improve the efficiency in the use of land, but require at least half the space of the open field operations.[31]

To facilitate the composting process, solid waste should be ground into pieces no larger than 3 inches in diameter; the compost should be turned on a regular basis; air with sufficient oxygen content should be regularly introduced into the compost; the moisture level should be kept in the 50-60% range; and the temperature should remain in the 130-140°F (50 - 60°C) range. To control pathogens in the waste stream the temperature should be elevated to the 140-158°F (60-70°C) range for a period of at least 24 hours. As indicated above, composting is possible utilizing anerobic and aerobic bateria, but because the anerobic process produces significant odors, this technique is rarely employed.[32]

There are several important environmental considerations that must be taken into account in composting. One concern is that in the mechanical shredding operation which is required in the preparation of solid waste for composting, it is nearly impossible to prevent some metal from entering the material to be composted. Metal present in the humus can lead to all of the problems associated with heavy metal toxicity.[33]

Since the aerobic composting process requires the solid organic wastes to be exposed to air for an extended period of time, there is the additional problem associated with surface blown litter leaving the composting area. Moroever, great care must be taken to minimize odors released in the composting process.

While it is evident that the composting process represents one means for recovering resources from solid waste, it clearly is not suitable at the present time for use in large metropolitan areas where the land requirements, and other environmental issues make the process prohibitively expensive. The authors are not aware of any major municipal composting facilities now in operation.

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TABLE VI-A.

Energy and Materials Recovery Facilities[1]

Location	Process	Products & Uses	Capacity* (tons per day)	Capital Costs ($ millions)	Status
ALABAMA					
Huntsville (Redstone Arsenal)	Mass burning in modular incinerator	Steam for heating & process	50	3.2	Shutdown 2/85 due to conveyor problems
Tuscaloosa	Mass burning in modular incinerator	Steam for process & heating by B.F. Goodrich Co.	D-300 T-300	8.5	Operational since 2/84
ALASKA					
Sitka	Mass burning of MSW and sewage sludge in modular combustion Unit	Steam for heating use at Sheldon Jackson College	25	4.2	Operational since 5/85
ARKANSAS					
Batesville	Mass burning in modular incinerator	Steam	D-50 T-55	1.2	Operational since 5/81
North Little Rock	Mass burning in modular incinerator	Steam for use by Koppers Co. (wood treating)	D-100 T-100	1.45	Operational ince 9/77
Osceola	Mass burning in modular incinerator	Steam for heating & process at Crompton Osceola Co. (Textile mfg.)	D-50 T-48	1.2	Operational since 1/80
CALIFORNIA					
City of Commerce	Mass burning in water-wall incinerator	Electricity for sale to Southern California Edison	300	35.0	Under construction since 3/85; startup expected in 3/87
Fremont	Mass burning in modular incinerator	Electricity for sale to Pacific Gas & Electric	480	35.0	Air quality permit in public comment period; construction expected in early 1986 with startup in late 1988; negotiating service agreement
Susanville	Mass burning of municipal waste and wood	Electricity sold to PG&E; hot water for	96	4.1	Construction completed; commercial

LOCATION	PROCESS	USES	CAPACITY	COSTS	STATUS
	chips; electricity generation; hot water production	college's district heating system			operation in 2/85
San Diego	Mass burn water wall incinerator	Electricity	2,250	227	Applying for licensing with California Energy Commission. Site has been selected and approved
Ukiah	Mass burning in modular incinerator	Electricity for sale to Pacific Gas & Electric Co.	100	4.8	Bonds issued; energy purchase agreement signed; permit applications underway; construction expected to begin in 10/85 with operation in 2/87
CONNECTICUT					
Mid Connecticut	RDF	Steam	2,000	146	Operational in 1988
New Haven		Electricity	450	24	Construction to begin 4/86; startup expected 8/88
Wallingford		Steam and Electricity	420	25	Startup scheduled for Winter 1987
Windham	Mass burning in modular incinerator	Steam; Electricity	D-108 T-125	7.0	Operational since Nov. 1981; steam was used by Kendall Co.; Kendall plant closed in Summer 1983; turbine generators now producing electricity
DELAWARE					
Wilmington	Shredding, air classification, magnetic separation, froth flotation, other mechanical separation; aerobic digestion	RDF, ferrous & nonferrous metals; glass, humus	1,000 tpd municipal solid waste co-processed with 350 tpd of 20% solids digested sewage sludge	72.3	Solid waste processing in full operation since 3/84
FLORIDA					
Broward County (Southern Fac) (Northern Fac)	Mass burning in water wall furnace for generation of electricity	Electricity for sale to Florida Power & Light	Southern Facility -2250; Northern Facility -2200	350.0 (total for both facilities	Construction expected to begin in early 1986 with operations in 1989

LOCATION	PROCESS	USES	CAPACITY	COSTS	STATUS
Dade County (Dade County Solid Waste Resource Recovery Plant)	Hydrasposaltm (wet pulping), magnetic and other mechanical	Electricity for sale to utility, ferrous metals, aluminum & ferrous metals	D-3000 T-3000	165	Operational since 1/82
Hillsborough County	Mass burning	Electricity for sale to Tampa Electric Co.	1200	80.1	Under construction since 1/85; startup expected in 7/87
Lakeland	Shredding, magnetic separation, air classification, burning RDF with coal	Steam to produce electricity for use by City of Lakeland and Orlando Utility Commission, ferrous metals	D-300 T-200	5 (for waste processing plant)	Operational, processing all of Lakeland's MSW (approx. 150 tpd)
Mayport Naval Station	Mass burning	Steam for use by base and ships	D-2 TPH T-120 tons per week (5 days)	2.3	Operational
Orange County (Walt Disney World)	Slagging pyrolysis incineration (Andco-Torrax)	High temp., hot water for heating and cooling at Walt Disney World	100	15	Plant is shut down; owner is attempting to find interested party for further research & development of process
Panama City	Mass burning in rotary combustor	Steam and electricity	510	38	Under construction; operation expected 5/87
Pinellas County	Mass burning, mechanical separation of metals after burning	Electricity for use by Fla. Power Corp., ferrous & nonferrous metals	D-2000 T-1842	80	Fully operational since 5/83; expansion to 2764 tpd now underway, with construction completion scheduled for late 1986
Pompano Beach	Shredding, magnetic and other mechanical separation, anaerobic digestion of light fraction with sewage sludge	Methane gas, carbon dioxide	50-100	3.65	Operational (demonstration plant)
Tampa	Mass burning	Electricity to be sold to Tampa Electric Co.	1000	59.9 (1981 dollars)	Operations began 9/85
GEORGIA					
Savannah	Mass burning with modified water wall system	Steam and electricity for industrial use	500	35	Construction began 4/85 with operation expected in 4/87
HAWAII					

LOCATION	PROCESS	USES	CAPACITY	COSTS	STATUS
Honolulu	Firing of RDF for generation of steam or electricity	Steam or electricity	1800	145	General obligaation bonds to be sold 8/85
IDAHO					
Burley	Mass burning in modular incinerator	Steam for J.R. Simplot Co. (potato processing)	D-50 T-50	1.5	Operational since 1/82
ILLINOIS					
Chicago (Northwest Waste-to-Energy Facility)	Mass burning in water wall incinerators	Steam for process use on-site and by Brach Candy Co.	D-1600 T-1250	23	Operational
Chicago (Southwest Supplementary Fuel Processing Facility)	Shredding, air classification magnetic separation	RDF for use by utility; ferrous metals	1000	19	Published RFP in 2/84 for private sector to lease and operate
IOWA					
Ames	Baling waste paper, shredding, magnetic separation, air classification, screening, other mechanical separation	RDF for use by utility, baled paper, ferrous metals	D-200 T-180	6.3	Operational since 9/75
KENTUCKY					
Campbellsville	Mass burning in modular combustion units	Steam for process use by Union Underwear Co.	100	4 (appx.)	Project on hold for additional study
Ft. Knox	Mass burning in modular incinerator	Steam for heating & air conditioning at hospital	40	1.9	Construction completed, but modifications needed before full-scale operations can begin
LOUISIANA					
New Orleans	Shredding, air classification, magnetic and other mechanical separation	Ferrous metals	D-770 T-650	9.1	Shredding/landfilling and ferrous recovery operational
MAINE					
Auburn	Mass burning in modular incinerator	Steam for heat and process at Pioneer Plastics	D-200 T-170	3.98	Operational since 4/81
MARYLAND					

LOCATION	PROCESS	USES	CAPACITY	COSTS	STATUS
Baltimore (Southwest Resource Recovery Facility)	Mass burning in water wall furnace, electricity generation, ferrous recovery from ash	Electricity for sale to Baltimore Gas & Electric Co; ferrous metals; negotiations completed for steam sale to district heating system	2250	170	Operational since 5/85
Baltimore County	Shredding, magnetic and other mechanical separation	RDF, ferrous metals, glass nonferrous metals	D-1200 T-850	11.0	Operational; recovering ferrous metals and glass, producing utility grade low ash, secondary-shredded RDF for use in Baltimore Gas and Electric Co. cyclone boiler
Harford County	Mass burning in modular combustion units	Steam for space heating & process use by U.S. Army at Aberdeen Proving Ground	300	14	Bonds expected to be issued in late 1985; construction to begin in late 1985 with operation expected by 6/87
MASSACHUSETTS					
Haverhill & Lawrence	Shredding, magnetic separation, trommel screening at recovery facility in Haverhill; burning RDF for cogeneration of steam and electricity in Lawrence	Steam and electricity for industrial use; surplus electricity sold to utility	1300	99.5	Started commercial operation in 9/84
Millbury (Central MA Resource Recovery	Mass burning in water wall boilers, electricity generation	Electricity for sale to local utility	1500	150	Waste disposal contracts signed; permitting in progess; construction began in 7/85 with startup 12/87
North Andover	Mass burning in water wall furnace, electricity generation	Electricity for sale to utility	D-1500 T-1500	196	Commercial operation expected by late 1985
Pittsfield	Mass burning in modular incinerator	Steam for process & heating by Crane & Co.	D-240 T-240	10.8	Operational since 3/81
Rochester	Shredding, magnetic sep-	Electricity for sale to	1500	160	Bonds sold 12/84; construc-

LOCATION	PROCESS	USES	CAPACITY	COSTS	STATUS
	aration, burning PRF in semi-suspension stoker-grate boiler, nonferrous recovery from ash, generation of electricity	Commonwealth Electric; ferrous and nonferrous metals			tion expected to begin in late 1985, contingent upon obtaining air quality permit, with operation in 36 months
Saugus	Mass burning in water wall furnaces, magnetic separation	Electricity for sale to utility; ferrous metals	D-1500 T-1200	50	Operational; conversion to electric power generation completed 9/85
MICHIGAN					
Detroit	Flail milling, trommel screening, secondary shredding, burning RDF in on-site dedicated boilers, electricity generation in 65 Mw turbogenerator	Steam for Detroit Edison's central heating system; electricity for sale to Detroit Edison; ferrous metals	3300	200	Negotiating with Combustion Eng- prior to contract signing; all permits in hand; remarketing of bonds in process
MINNESOTA					
Collegeville	Mass burning in modular incinerator	Steam for heating, electricity generation & other uses by university	D-58 T-43	2.4	Operational since 11/81
Duluth	RDF process rebuilt; includes primary disk screen, shredding, air knife, sizing disk screen, fluidized bed incneration of RDF and sludge	RDF, ferrous metals, steam for heating and cooling of plant and to run process equipment	400 tons MSW/ shift; 340 of 20% solids sewage sludge	19	Operational
Newport	Production of refuse-derived fuel; burning to produce electricity; separation of ferrous metals and aluminum	Electricity, ferrous metals, aluminum	1000	20.75	Construction began in 7/85, operation expected by 7/87
Red Wing	Mass burning in modular incinerator	Steam for S.B. Foot Tanning Co.	72	2.5	Operational since 9/82
MISSISSIPPI					
Pascagoula	Mass burning in modular combustion unit	Steam for process use by Morton Thiokol	150	6.0	Operational as of 1/85

LOCATION	PROCESS	USES	CAPACITY	COSTS	STATUS
MISSOURI					
Ft. Leonard Wood	Mass burning in modular incinerator	Steam for cooking and heating in barracks complex	D-75 T-30	3.3 (approx.)	Operational
St. Louis	Mass burning, electricity generation	Steam for downtown district heating & cooling electricity for sale to Union Electric Co.	900	30-40	District heating and cooling purchased by Thermal Resources and Bi-State; final final stage of constract negotiations for waste plant; start-up expected in Fall 1987
MONTANA					
Livingston	Mass burning in modular incinerator	Steam for heating at Burlington Northern Railroad repair shops	D-75 T-70	2.6	Operational since 5/82
NEVADA					
Reno	Processing to remove glass & metals, producing RDF; producing carbon char (K-Fuel) by pyrolysis; burning in fluidized bed combustor; electricity generation	Electricity for sale to utility, glass, ferrous metals, and aluminum recovered	250 (Phase I) 1000 (Phase II)	50	Phase I operating; developing final process; arranging financing; in permit process; Phase II construction expected to begin in early 1986
NEW HAMPSHIRE					
Claremont (NH/VT Solid Waste Project)	Mass burning in water wall boiler	Electricity for sale to Central Vt. Public Service Co.	200	17.9	Construction underway; operation expected in 5/87
Durham (Lamprey Regional Solid Waste Cooperative)	Mass burning in modular incinerator	Steam for heating & hot water at Univ. of N.H.	D-108 T-100	3.3	Operational since 9/80
Groveton	Mass burning in modular incinerator	Steam for industrial use	24	n/a	Operational
Manchester	Mass burning in modular incinerator	Electricity for sale to Public Service of New Hampshire	450	20.0	Approximately twelve adjacent communities have agreed to participate in project; construction

LOCATION	PROCESS	USES	CAPACITY	COSTS	STATUS
					expected in early 1986 with startup in Spring 1988
Portsmouth	Mass burning in modular incinerator	Steam for heating at Pease AFB	D-200 T-200	6.25	Operational since 7/82
NEW JERSEY					
Bergen County	Mass burning in water wall furnace for generation of electricity	Electricity for sale to Public Service Electric & Gas	3000	253	Financing complete; construction to begin mid-late 1985 with operations in 1988
Essex County	Mass burning for electricity generation	Electricity for sale to utility	2250	200	Negotiating contracts with BFI; construction scheduled for Fall 1985 with start-up in summer 1988; will include intermediate processing facility on-site for source separated materials
Ft. Dix	Mass burning of presorted solid waste in modular incinerator	Steam for heating on base	D-80 T-60	6	Contract awarded to joint venture firm: American Bridge (Division of U.S. Steel) and Clear Air; Under construction since 7/85; operation expected in 7/86
Warren County	Mass burn water wall incinerator	Electricity	400	40.3	Construction to begin 5/86 startup expected 5/88
NEW YORK					
Albany	Processing plant; shredding, magnetic separation plant: burning PRF in stoker-grate boiler; ash processing center; ferrous, non-ferrous & aggregate recovery from boiler ash	Processed refuse fuel (PRF), steam for heating and cooling state offices, ferrous & nonferrous metals, boiler aggregate	D-750 tons per shift T-750 per shift	28.2 (11.6 processing plant; 15 steam plant; 1.6 ash processing center)	Operational
Brooklyn (Navy Yard) NYC	Mass burn	Steam and electricity; ferrous metal	3000	290	Operation expected in 1989
Cuba (Cattaraugus	Mass burning in modular	Steam for process at	D-112 T-120	5.5	Operational since 2/83

LOCATION	PROCESS	USES	CAPACITY	COSTS	STATUS
County Refuse-to-Energy Facility)	incinerator	Cuba Cheese Co.			
Dutchess County	Mass burning in O'Connor rotary combustor for generation of steam and electricity; ferrous metals recovery	Steam for sale to IBM Corp., electricity to utility, ferrous metals	400	30	Project financed in 12/84; under construction since 12/84; operation expected in early 1987
Glen Cove	Mass burning in stoker-fired furnace with centrifuges sewage sludge	Electricity for sewage treatment plant and incinerator; excess to Long Island Lighting Co.	250	34 (22 for mass burning unit; 12 for sewage plant)	Operational since 8/83
Hempstead	Mass burning; electricity generation	Electricity for sale to utility	2250	250	Negotiations underway between Town & American REF-FUEL preparing EIS; financing expected by end of 1985; construction expected in early 1986, with opearation in 33 months
Islip (MacArthur Energy Recovery Facility)	Mass burning	Electricity for sale to Long Island Lighting Co.; ferrous recovery from ash	D-518	39.5	Bond sale in 9/85; expected startup in late 1987
Monroe County	Shredding, air classification froth flotation, magnetic and other separation	RDF for use by utility as supplemental boiler fuel, ferrous metals, glass	D-2000 T-400	62.2	Facility closed 7/27/84; currently preparing RFP for alternative use
New York (Betts Ave. Incinerator)	Mass burning in refractory furnace	Steam for heating and processes in-plant and adjacent City garages	1000	5-waste heat boiler (1965) 24-modifications (1980)	Closed for design review and possible renovation
Niagara Falls	Shredding, magnetic separation, burning shredded refuse	Steam for use by chemical plant; electricity sold to power company grid; ferrous metals	D-2000 T-1700	100 +	Operational
Oneida County	Mass burning in modular combustion units	Steam for heating, hot water & other use by Griffis Air Force Base; electricity	200	13.5	Operational since 1/85; testing conducted in 3/85; turbine being added to

LOCATION	PROCESS	USES	CAPACITY	COSTS	STATUS
		from excess steam			generate electricity from summer excess steam
Oswego County	Mass burning in modular combustion units, electricity generation	Steam for use by Armstrong World Enterprises; electricity for sale to Niagara Mohawk	200	14.5	Under construction; startup expected in 10/85
Oyster Bay	Mass burning, electricity generation	Electricity for Long Island Lighting Co.	1650	113	Contract negotiations under way; construction expected to begin in 1986 with operation in 1989
Washington County	Mass burning, production of electricity	Electricity for sale to utility	240	48	Energy purchase agreement signed; bonds sold; construction pending environmental litigation and N.Y. State construction permits
Westchester County (Peekskill)	Mass burning in water wall furnace, electrical generation, ferrous metal recovery from ash	Electricity for Consolidated Edison Co., ferrous metals	2250 (Permitted capacity 1980)	179	Began startup 2/84; commercial operation 10/84
NORTH CAROLINA					
New Hanover County	Mass burning in water wall boilers, cogeneration of steam and electricity	Steam for use by W.R. Grace Co. (agrochemical mfr.); electricity for sale to Carolina Power & Light	200	13 (approx.)	Operational
NORTH DAKOTA					
Williston	Mass burning; cogeneration of steam & electricity	Steam for process use by Hardy Salt; electricity for sale to utility	100	5	Awaiting final energy contracts; groundbreaking expected in 1986
OHIO					
Akron	Shredding, magnetic separation, burning RDF in semi-suspension stoker-grate boiler	Steam for urban and industrial heating and cooling, ferrous metals, hot water for residential and commercial heating	D-1000 T-900	80	Temporarily closed while repairing damage from explosion in 12/84; natural gas being used to provide steam to customers

LOCATION	PROCESS	USES	CAPACITY	COSTS	STATUS
Columbus	Shredding, magnetic separation, burning of shredded refuse with supplemental coal in semi-suspension stoker-grate boiler to produce steam and generate electricity	Electricity for city customers	D-2000 T-1500	175	All units operational; making modifications to boilers & support systems
Gahanna	Magnetic separation, disk & trommel screening, shredding, densification of RDF, composting	organi-FUEL 100^{tm} (d-RDF) for gasification in oil or gas boilers and use as supplemental fuel; organi-GRO^{tm} compost aluminum, glass, paper, ferrous metals, other recyclable materials	D-1000 T-400	10	Operational since 11/81; plant also has buyback center for recyclable materials
Montgomery County	Renovation of an existing incinerator	Steam	300	8.6 (for rehab)	Renovation to be completed 5/87
OKLAHOMA					
Miami	Mass burning in modular incinerator	Steam for industrial use by B.F. Goodrich Co.	D-108 T-72	3.14	Operational since 11/82
Oklahoma City	Phase I-shredding, ferrous & nonferrous metals separation; thermal reduction (burning in rotary drum furnace) and electricity generation Phase II-anerobic digestion of organic msw & sewage	Electricity & methane gas for sale to Okla. Gas & Electric Co.; ferrous & nonferrous metals	5600 tons per week (Phases I & II)	29	Phase I startup testing completed; continuous operation expected to begin in mid-1985; awaiting decision on anerobic digestion vs. thermal reduction for Phase II
Tulsa	Mass burning, generation of steam and electricity	Steam for sale to Sun Refining; electricity for sale to Public Service Co. of Okla.	750	51.5	Groundbreaking in 5/84; startup expected in 1/86
OREGON					
Marion County	Mass burning in water wall furnaces	Electricity for local utility	550	47.5	Under construction; startup expected in

LOCATION	PROCESS	USES	CAPACITY	COSTS	STATUS
					Spring 1986
PENNSYLVANIA					
Delaware County	Mass burning in modular incinerator	Steam for use by Fair Acres Geriatrics Inst	50	2.9	Groundbreaking in 12/84; construction on hold pending zoning decision
Erie	Shredding, mechanical separation, air classification, burning RDF, electricity generation	RDF for use as fuel to produce electricity for local utility steam, ferrous metals, glass	600	30	In design and permitting stage; startup expected in 3/87
Harrisburg	Mass burning of MSW and sewage sludge in water wall furnace, bulky waste shredding	Steam for utility-owned district heating system and for city-owned sludge drying system, excess steam to Bethelem Steel, ferrous metals	D-720 T-700	8.3	Operational since 1973; sludge drying facility in test; overhauling plant to reestablish process reliability and increase capacity to design; installin cogeneration, to be on line 5/86
RHODE ISLAND					
Quonset Industrial Park	Mass burning in water wall furnace	Steam and electricity	1500	100	Project financed; construction to
begin			in		Spring
SOUTH CAROLINA					
Johnsonville (Wellman Energy Plant)	Mass burning of industrial waste in modular incinerator	Steam for process use by Wellman Industries	D-50 T-50	2.5	Operational since 1181
TENNESSEE					
Dyersburg	Mass burning in modular incinerator	Steam for process & heat at Colonial Rubber Works	D-100 T-82	2	Operational since 9/80
Gallatin	Mass burning in water wall rotary combustor for cogeneration of steam & electricity; PREBURN™ materials recovery system	Steam for industrial processing and electricity for sale to TVA, ferrous metals and aluminum	200	10	Operational since 12/81
Lewisburg	Mass burning in modular incinerator	Steam for industrial use by Heil-Quaker Corp.	D-60 T-35-40	1.75	Operational since 1980
Nashville	Mass burning	Steam and	D-720	24.5	Operational

LOCATION	PROCESS	USES	CAPACITY	COSTS	STATUS
	in water wall incinerator	chilled water for urban heating and cooling; expansion adds electricity for sale to TVA	T-612		since 1974; expansion to be completed in early 1986, increasing design capacity to 1120
TEXAS					
Cleburne	Mass burning in modular combustion unit	Steam or electricity	115	5.5	Under construction, with completion expected in 10/85 1986
Galveston	PREBURN™ materials recovery system	Ferrous metals & aluminum	200	1.1	Under contract; operations expected 12/85
Lubbock	Mass burning in water wall rotary combustor for generation of electricity; PREBURN™ materials recovery system	Electricity for sale to Lubbock Power & Light ferrous metals & aluminum	500	42	Contract awarded operations expected 12/87
Waxahachie	Mass burning in modular incinerator	Steam for industrial use by International Aluminum Extruders	D-50	2.2	Operational since 7/82; selling 60% of steam produced
VERMONT					
Rutland	Mass burning in modular incinerator, electricity generation	Electricity for sale to Central Vermont Public Services Corp.	240	17	Construction began 10/85; completion expected in Spring 1987
VIRGINIA					
Alexandria/ Arlington	Mass burning in water wall incinerator	Electricity for sale to Virginia Power Co.	975	54.1	Construction began 5/85; startup expected 8/87
Galax	Mass burning in rotary combuster for generation of steam	Steam for sale to Hanes Knitwear, Inc.	55	2.1	Under construction since 5/84; startup expected in 9/85
Hampton	Mass Burning in water wall furnace	Steam for use by NASA Langley Research Center	D-200 T-200	10.4	Operational since 9/80
Harrisonburg	Mass burning	Steam for heating & cooling at James Madison Univ.	D-100 T-75	8	Operational since 12/82

LOCATION	PROCESS	USES	CAPACITY	COSTS	STATUS
Newport News (Ft. Eustis)	Mass burning in modular incinerator	Steam for heating, hot water & cooking	D-40 T-30 +	1.7	Operational since 12/80
Norfolk (Norfolk Naval Station)	Mass burning in water wall furnace	Steam for use by facilities at Norfolk Naval Station	360 (two 180 tpd boilers operated alernately)	2.2 (1967)	Operational; temporarily shut down to retube boilers
Petersburg	Phase I- shredding, magnetic and other separation, sale of RDF cubes; Phase II- addition of boiler/turbine to generate electricity; Phase III- ethanol production, 10 million gal/yr; Phase IV- possible location for 50 tpd cellulose/alcohol R&D facility; Phase V- 37.5 million gal/yr cellulose/alcohol production based on enzymatic hydrolysis process	Phase I & II- ferrous and nonferrous metals, glass electricity for sale to utility, steam for in-plant use; Phases III, IV & V- ethanol, CO_2, dried grain supplement (DGS), distiller's dried grain supplement (DDGS)	2000 (peak) 650 initial to 2400 tpd with backup fuel of wood chips and agricultural waste	12 (Phase I) 11 (Phase II) 7 (Phase III) 33 (Phase IV) 136 (Phase V) 200 Total	Preliminary design completed groundbreaking expected in Summer 1985 with startup 9 months later for Phase I
Portsmouth (Norfolk Navy Shipyard)	Mass burning in water wall furnace	Steam for use by facilities at Naval Shipyard	160 (two 80-tpd boilers, operated alternately)	4.5	Operational
Portsmouth (Southeastern Tidewater Energy Project)	Shredding, magnetic and other separation	RDF for burning in new RDF/coal-augmented power plant under construction at Naval Shipyard, providing steam and electricity for Shipyard and ships; ferrous and nonferrous metals	2000	50	Under construction; operations expected in Spring 1987
Richmond	Flail milling, magnetic separation, disc screening, densification of RDF, hand-sorting aluminum	Densified RDF; ferrous metals; aluminum; compost material	250	3.2	Operational

LOCATION	PROCESS	USES	CAPACITY	COSTS	STATUS
Salem	Mass burning in modular incinerator	Steam	100	1.9	Operational since late 1970s
WASHINGTON					
Tacoma	Shredding, air classification magnetic separation	RDF, ferrous metals	500	2.5	RDF plant closed; city is evaluating bids received 3/84 for a new waste-to-energy facility
WISCONSIN					
Madison	Shredding, magnetic separation, trommel screening, secondary shredding	RDF burned with coal at Madison Gas & Electric Co. for electricity generation; RDF burned with coal at Oscar Mayer Foods Corp. for steam production; ferrous metals	D-400 T-250	2.5	Refuse processing & burning at Madison Gas & Electric operational since 1/79; Oscar Mayer installation operational since 6/83
Waukesha	Mass burning in refractory furnace	Steam for local industry and sewage treatment plant	D-175 T-140	Incinerator 1.7 (1971) Heat recovery system 3.9 (1979)	Incinerator operating since 1971; waste heat recovery boiler added in 1979; operating and sending steam to local industry and sewage plant
CANADA					
ONTARIO					
Hamilton	Shredding, magnetic separation, semi-suspension burning in dedicated speader stoker boilers	Electricity for Ontario Hydro, steam for in-plant use, ferrous metal	D-500 T-450	9 + (1972)	Operational since 1972; 4.0 MW turbine generator added and operating since 11/82; $12 million modernization program to be completed by Summer 1986
Toronto	Shredding, air classification secondary shredding, screening, mass burning in modular incinerator with heat recovery, ferrous cleaning; also transfer operation	Ferrous metal, RDF compost; hot water for plant heating	Resource recovery-220; transfer facility-600	15 +	Operational since 3/77

LOCATION	PROCESS	USES	CAPACITY	COSTS	STATUS
PRINCE EDWARD ISLAND					
Parkdale	Mass burning in modular incinerator	Steam for heating/cooling at hospital complex	108	8.2 +	Operational since 2/83
QUEBEC					
Montreal	Mass burning in water wall furnaces customers	Steam used by City offices & facilities and private	D-1200 T-1200	14.7 + (1967)	Operational since 1970; gas cleaning systems redesigned and and rebuilt in 1983; steam sold to 20 customers through 10 miles of underground pipeline
Quebec	Mass burning in water wall furnace	Steam, used for industrial process by paper mill	1000	25 + (1974)	Operational since 1974

*D = Design Capacity; T = Actual throughput (recent average)

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[1] After Waste Age November 1985 and the U.S. Conference of Mayors

Appendices

A. Agenda

B. List of Participants

C. Report entitled "Residues From Resource Recovery Facilities: Current Research" by Rene Surgi of Signal Environmental Systems.

Appendix A

A Forum on
Modern Resource Recovery Strategies for Long Island Town Decision Makers

23 May 1986

Co-sponsored by Stony Brook's Waste Management Institute
and
the Long Island Regional Planning Board

Agenda

0900 Introduction and Welcome. (H.A. Neal, L.E. Koppelman, J.R. Schubel)

0915 An overview of the day's activities and what we intend to achieve. (L.E. Koppelman)

0930 The Course we have embarked upon: Why and how we intend to get here. Intra- and inter-town cooperation and collaboration: nearly everyone benefits, or everyone loses. (L.E. Koppelman)

1000 Characteristics of the modern resource recovery facility (combustion, emissions, ash and aesthetics).

- 15 min. (1) The Modern Resource Recovery Facility--An Overview. (David Sussman, Ogden Martin Corp.)
- 15 min. (2) The Characteristics of Good Cumbustion and How Modern Resource Recovery Facilities Differ From Conventional Incinerators. (T. Licata, Dravo Industries)
- 15 min. (3) Recovery of Energy and Materials. (John Klett, Ogden Martin Corp.)
- 15 min. (4) The By-Products: Residual Ash Management. (Rene Surgi, Signal Corp.)
- 15 min. (5) Air Emissions: An assessment of what can be expected. (C. Kemp. BFI, Inc.)

1130 Other components of a town's comprehensive municipal solid waste management program (source reduction, recycling). (Harold Berger and Evan Liblit, NYSDEC; Tom Fiesinger, NYSERDA: and Rim Giedraitis, Town of Islip)

1215 Lunch

1330 The Role of the New York State Environmental Facilities Corporation. (Diana Hinchcliff, NYS Environmental Facilities Corp.)

1400 Some unresolved questions and ways to address them: A sharing of ideas.

1430 Adjourn

Appendix B

LIST OF PARTICIPANTS

1. Ann Anderson, Region 1, N.Y. State Department of Environmental Conservation
2. Harold Berger, Director, Region 1, N.Y. State Department of Environmental Conservation
3. R. Fagan, Port Authority of New York and New Jersey
4. Stanley Farkas, N.Y. State Department of Environmental Conservation
5. Tom Fiesinger, N.Y. State Research & Development Authority
6. John Follis, Jr., Nassau County
7. T. Gallagher, Director of Water Resources, Town of Brookhaven
8. Rim Giedraitis, Town of Islip
9. Ted Goldfarb, Associate Vice Provost for Curriculum, SUNY at Stony Brook
10. Robert G. Halzmacher, H2M, Consultant to Southampton Town
11. J. Hartman, Town of Huntington
12. James Heil, Commissioner of Sanitation, Town of Hempstead
13. Frank P. Hession, SUNY
14. Diana M. Hinchcliff, Executive Assistant, NY State Environmental Facilities Corporation
15. Judith Hope, Supervisor, East Hampton
16. Clinton C. Kemp, Consultant, American Refuel, Canruf Company, Canada
17. John M. Klett, Ogden Martin Systems
18. Lee Koppelman, Director, L.I. Regional Planning Board
19. Martin Lang, Supervisor, Town of Southampton
20. Robert LaBua, Consultant to Suffolk County
21. Evan Liblit, N.Y. State Department of Environmental Conservation

22. Tony Licata, Vice-President, Dravo Energy Resources Inc.
23. Gary Loesch, H2M, Consultant to Town of Southampton
24. A. Machlin, Region 1, N.Y. State Department of Environmental Conservation
25. Francis J. Mooney, Town Engineer, Town of Smithtown
26. Sophie Morris, N.Y. State Department of Environmental Conservation
27. Gerhardt Muller, Port Authority of New York and New Jersey
28. Frank Murphy, Supervisor, Town of Southold
29. Homer A. Neal, Provost, SUNY at Stony Brook
30. Linda O'Leary, Project Manager, Regional Waste Task Force, Port Authority of New York and New Jersey
31. Paul Ponessa, Town of North Hempstead
32. Ivan Pouseuine, Lockwood, Kessler and Bartlett, Town of Oyster Bay
33. Louis H. Price, Shelter Island
34. George Proios, Senate Executive Director, New York State Legislative Commission on Water Resource Needs of Long Island
35. Kevin Quinn, Town of North Hempstead
36. Sheldon Reaven, Professor, Dept. of Technology and Society, SUNY at Stony Brook
37. Frank Roethel, Associate Professor, Nassau Community College, and Research Professor, Marine Sciences Research Center
38. Pat Roth, Obmudsman (Community Relations Specialist), New York State Department of Health
39. Ann-Marie Scheidt, Director of Public Affairs, SUNY at Stony Brook
40. J.R. Schubel, Dean and Director, Marine Sciences Research Center
41. Jeffrey Simes, Supervisor, Town of Shelter Island

42. Garrett Smith, Special Assistant for Air and Waste Management, U.S. Environmental Protection Agency, Region 2
43. Rene Surgi, Signal Research Center
44. David B. Sussman, Vice President, Environmental Affairs, Ogden Martin Systems, Inc.
45. William Wise, Associate Director, Marine Sciences Research Center
46. Gerrit Wolf, Harriman College, SUNY at Stony Brook
47. Peter Woodhead, Research Professor, Marine Sciences Research Center

Appendix C

RESIDUES FROM RESOURCE RECOVERY FACILITIES CURRENT RESEARCH

Presented by

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for

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The refuse from households enters Signal Environmental Systems (SES) facilities as shown in Figure 1. Two types of ash are produced when municipal solid waste is burned - bottom ash and fly ash. Bottom ash falls into the vibrating feeder and the majority of fly ash collects in the electrostatic precipitator. An important item not shown in Figure 1 is the spray drier. The spray drier to be positioned between the boiler and the electrostatic precipitator, will inject either dry lime or a lime/water slurry to neutralize the acid gases produced during combustion. The ash stream, generated from refuse combustion, consists of about 95% bottom ash and 5% fly ash. This combination, taken collectively, is referred to as composite ash.

Ash can be characterized chemically and physically. The data in Table I provides the composition of both fly ash and bottom ash from coal and municipal solid waste (MSW) combustion. The composite ash, as it is disposed from resource recovery facilities, presents little environmental concern. However, fly ash contains elevated levels of lead (Pb) and cadmium (Cd). Hence, the environmental impact and attenuation of Pb and Cd leaching from fly ash residues is the subject of current SES research.

Much work has been conducted concerning the impact and uses of coal fly ash, which can comprise up to 65% of the total coal ash residues. One of the obvious differences in coal fly ash and MSW fly ash is the morphology. Coal fly ash is composed of spherical particles between 10-70 microns. These spherical particles can be hollow (cenospheres) or contain smaller spherical particles (pleurospheres). Figure 2 is an SEM photograph of coal fly ash. The large pleurosphere in the center of the figure is approximately 25 microns in diameter. By comparison, the MSW fly ash depicted in Figure 3 is composed of solids jagged and irregularly shaped particles having diameters between 50 and 500 microns. The large particle to the left in the figure has a diameter of about 125 microns.

To evaluate environmental impact of fly ash, batch or column leaching experiments can be performed to evaluate leaching of Pb and Cd. Batch experiments are usually empirical in nature, and the results usually overestimate the amount of Cd and Pb leached when compared to column leaching results. The degree of overestimation depends on the nature of the experimental procedures and varies widely. Column experiments provide data on the relative rates of metal leaching and qualitative comparisons of metal attentuation mechanisms. Neither column nor batch experiments permit accurate assessments of the leachate concentrations generated when ash is surface disposed. The available data correlating actual ashfill leachate quality to column leachate quality is scarce. However, the literature that is available suggests that column leaching experiments are a good qualitative predictor of metal leaching. Current studies by Malcolm Piernie (White Plaines, New York), supported in part by SES, are underway to correlate column leachate quality with actual ash monofill leachate quality. In any event, the amount of metal leached is highly dependent on such experimental parameters as the liquid/solid ratio, pH of the eluant, eluant composition, flow rate and residence time of the eluant. However, in sophisticated experiments in which parameters are rigorously maintained and evaluated, results from column leaching experiments provide a means to compare natural or formulated metal immobilization systems and facilitate comparisons of different residues.

The eluant used in these experiments was a synthetic acid rain (pH 3.93) containing the anions and cations at concentrations found in the acid rain falling in the northeastern United States. The pH is lower than the 4.2-4.4 reported by the National Atmospheric Deposition Program (NADP) for this region of the United States in order to compensate for added acidity due to dry deposition of SO_2, NO_x and HCl. Furthermore, the formulated anion and cation concentrations equalled the highest concentrations reported by NADP in order to increase the ionic strength thereby increasing the solubility of metals bound with the fly ash. Such experimental configuration was used to model a worst case scenario.

When 400 grams of MSW fly ash was placed in a column and eluted with 775 mL of synthetic acid rain at a rate of 1.55 ± 0.20 mL/min, the time resolved leaching displayed in Figure 4 was typical. Initially, larger amount of Pb and Cd were leached. This behavior was expected using a high solid/liquid ratio of 0.5. Although the pH buffering capacity of ash residue is high, this behavior was not a function of pH, which remained virtually constant throughout the experiment.

In some applications, addition of excessive base (sufficient to maintain a leachate pH greater than 12.5 in laboratory experiments) can reduce the solubility of metals. However, such applications should be evaluated to insure that the pH is not excessive for the waste type. Figure 5 shows the result of acid rain leaching of fly ash containing sufficient base (CaO) to obtain a leachate pH of 12.5, note that Pb, which is amphoteric, can be solubilized at pH values above about 12.5 in laboratory experiments.

Among the projects SES funds at Allied-Signal Engineered Materials Research Center is the development and formulation of priority immobilizers. Such immobilizers, applied to the ash, attenuate Pb and Cd leaching. One such system has proven particularly successful.

This immobilizer was applied to 200 grams of fly ash and leached with 775 mL of synthetic acid rain. A comparison of the initial leachate quality from immobilized ash to the leachate quality from unimmobilized ash shows a reduction, by two orders of magnitude, of the amount of Cd and Pb leached. Another important detail in Figure 6 is the difference between distilled water and acid rain leaching. It would appear that the anions in acid rain lower the concentrations of Pb and Cd in aliquots collected at longer times and hence reduce the overall Cd and Pb available to the environment. From this data, it is evident that this immobilizer attenuates Pb and Cd leaching during initial exposure to acid rain.

It would be naive to think that all the Pb and Cd in resource recovery residue is available to the environment when the residue is surface disposed. A sequential extraction procedure, developed for soils, has been evaluated and applied to resource recovery ash. Figure 7 contains a flow diagram of this procedure and Table II contains the results of this extraction when applied to MSW fly ash. According to this procedure, only fractions 1 (exchangable metals) and 2 (surface oxides and carbonates) would be available to the environment if fly ash were surface disposed. The results of this experiment indicated that about 50% of the total Cd and 17% of the total Pb in fly ash would be available to the environment if the ash is surface disposed. The results of this experiment indicated that about 50% of the total Cd and 17% of the total Pb in fly ash would be available to the environment if the ash is surface disposed.

Figure 8 contains a photograph of the newly completed automated sampling and leaching apparatus. Each of the 6 columns are 60 cm in length and 12 cm I.D. Each column is provided with autosampling capabilities under the control of a Durant programmable sampler. Three temperatures can be maintained independently over the 360 cm depth to model the effect of temperature on metal solubility and bacterial growth. Additional columns can be added to increase the ash depth.

Future research will concern sophisticated modeling of actual disposal conditions, including continuous ash additions, the interactions of MSW residue and soils, and the use of SAS software and geochemical leaching models to generate computer predictions of leachate quality.

FIGURE 1

**Signal
Environmental
Systems**

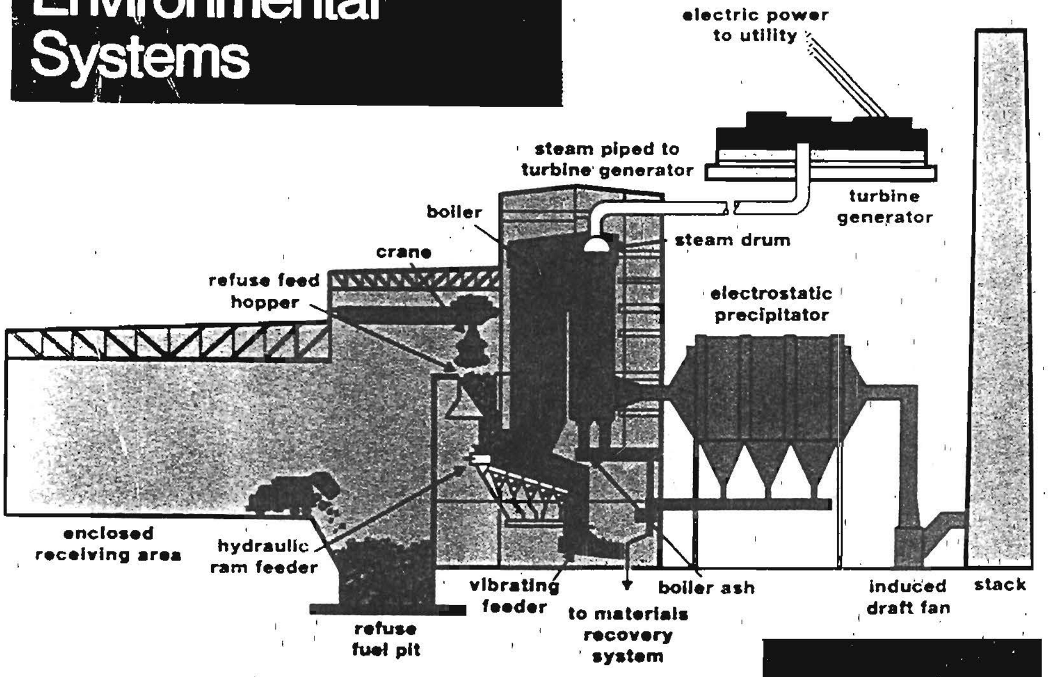


TABLE I

ELEMENTAL CONCENTRATIONS OF METALS IN ASHES

ELEMENT	MSW ASH (MG/KG) FLY ASH	MSW ASH (MG/KG) BOTTOM ASH	COAL ASH (MG/KG) FLY ASH	COAL ASH (MG/KG) BOTTOM ASH
CA	54,500	50,500	45,000	NR
SR	200	250	775	800
BA	800	800	991	1600
CD	470	<100	1.60	0.86
SiO_2	319,000	368,000	483,000	NR
AL	70,000	33,000	92,000	NR
FE	17,500	132,000	35,000	NR
TI	14,600	3,600	19,400	NR
PB	5,200	900	67	7
CR	400	500	136	120

FIGURE 2

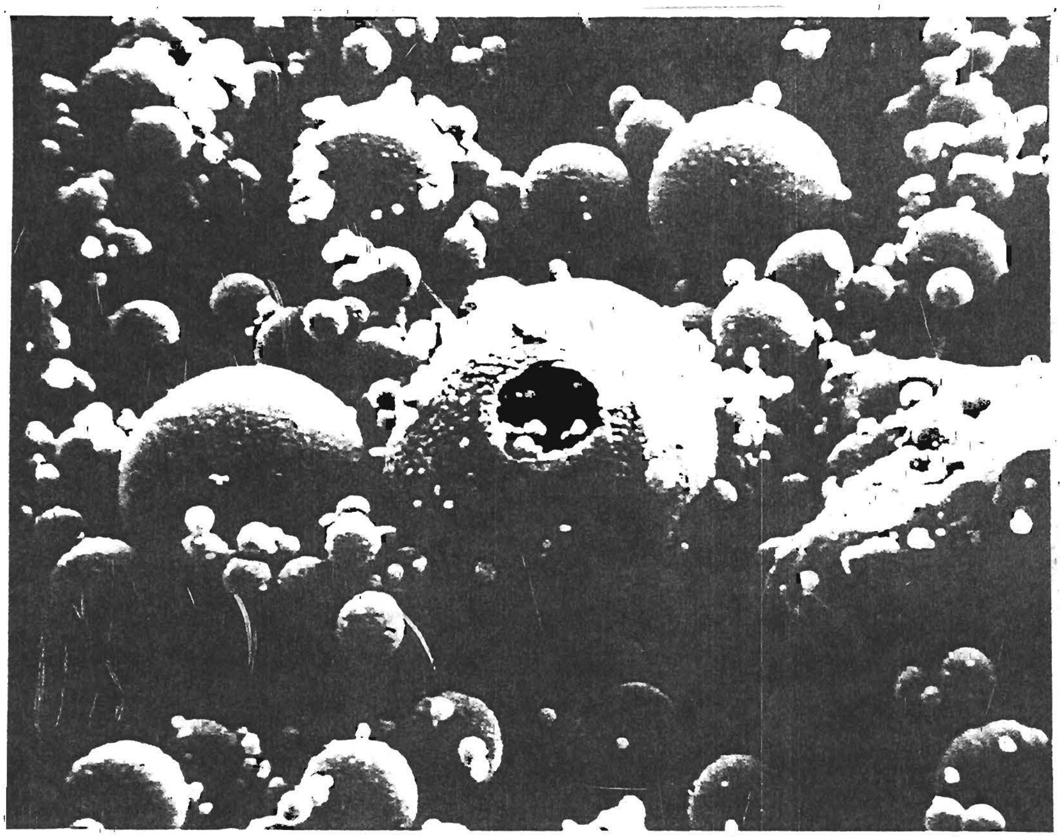


FIGURE 3

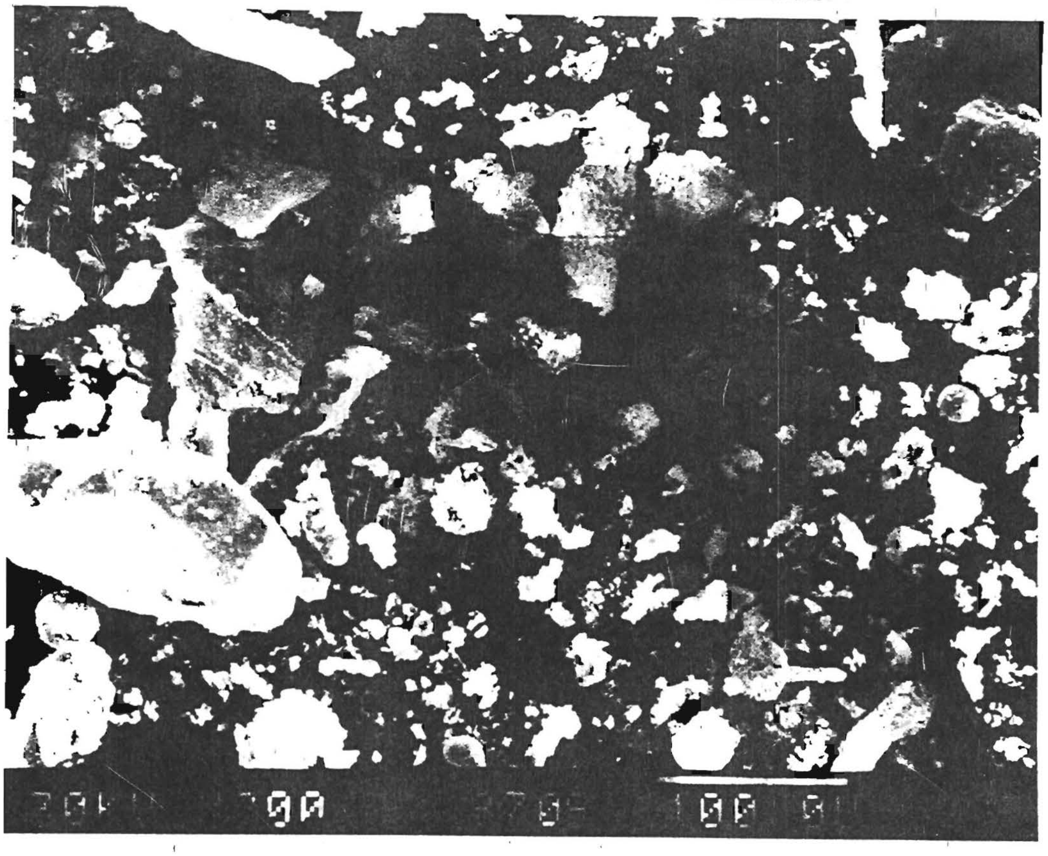


FIGURE 4

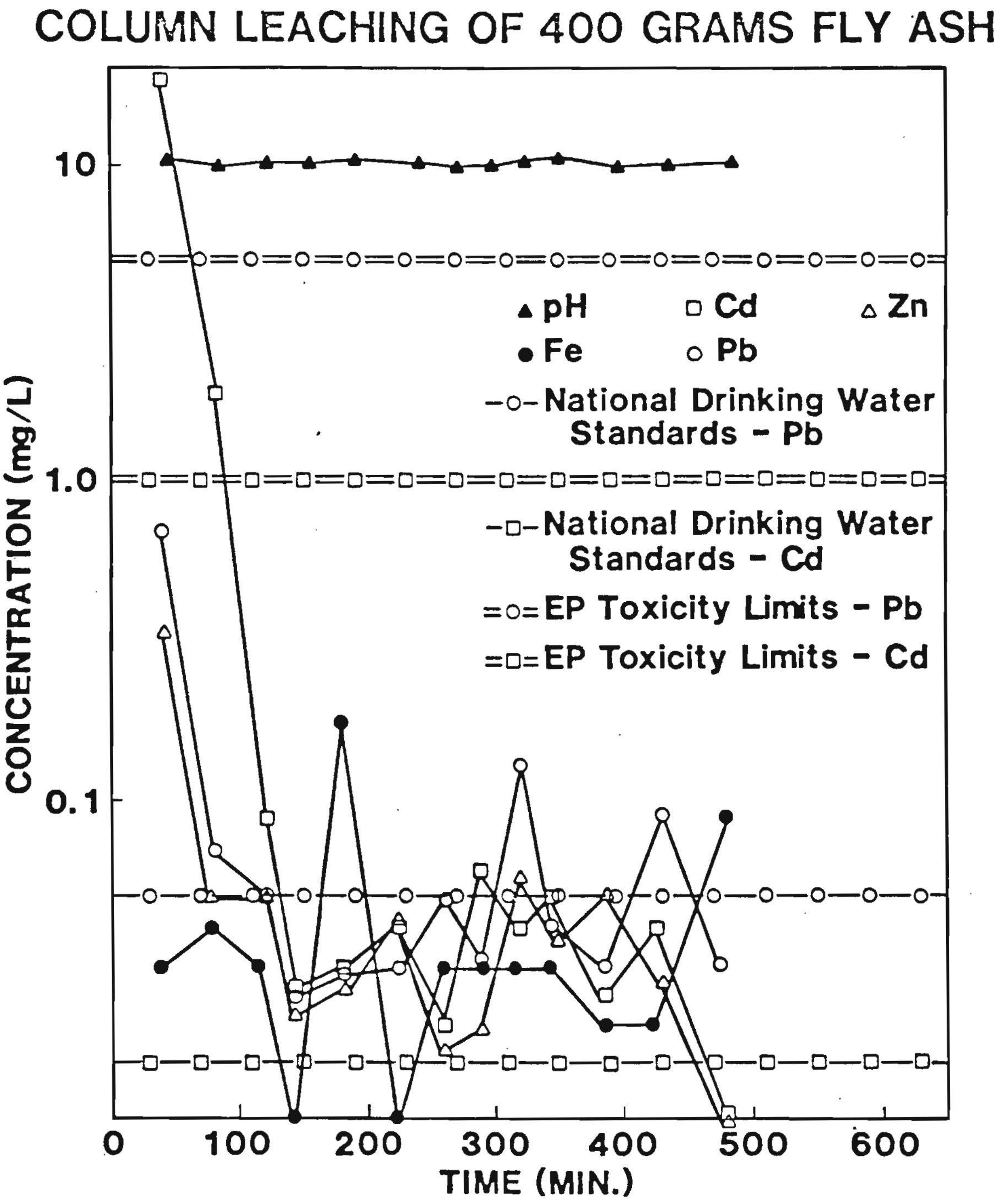
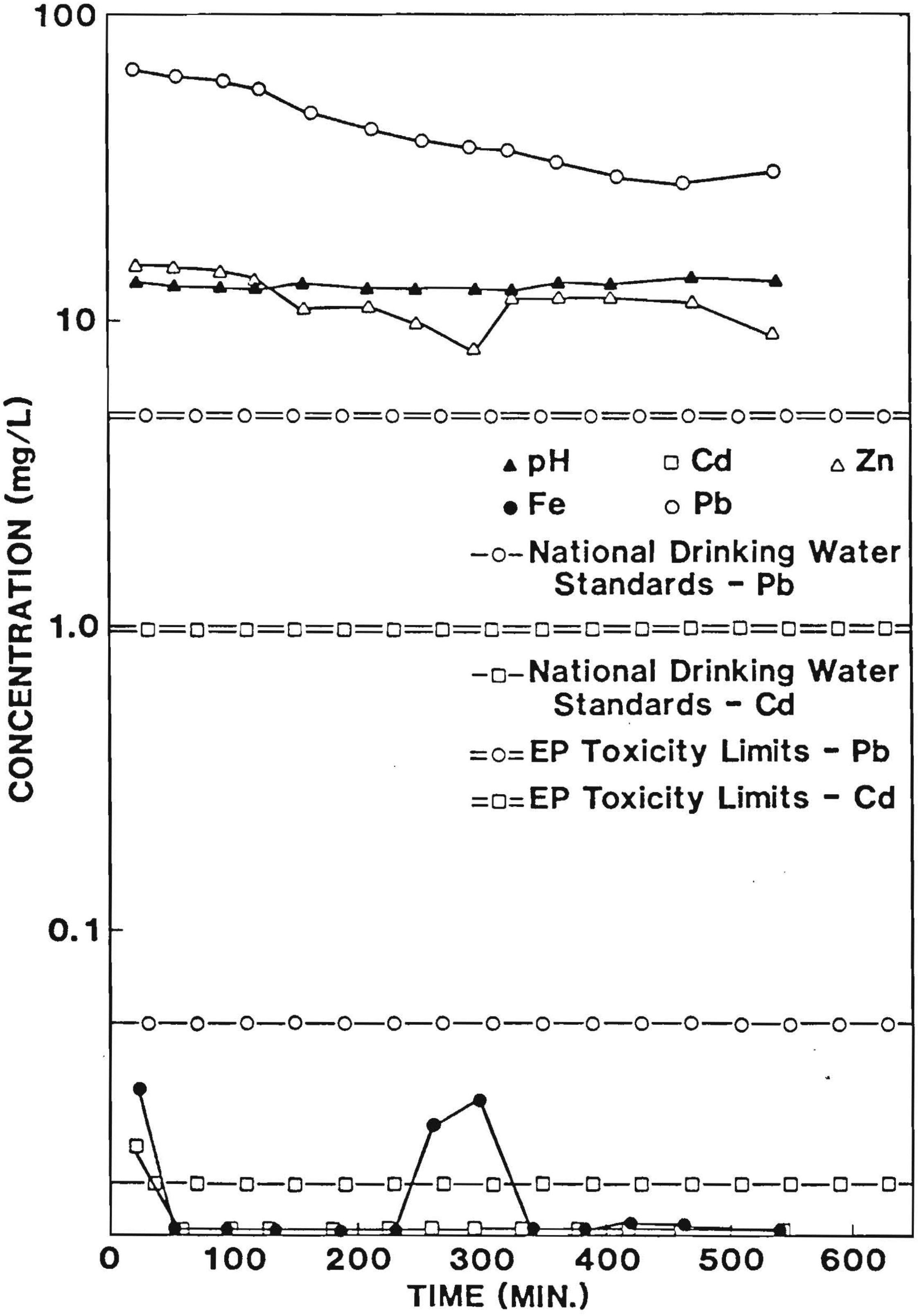

COLUMN LEACHING OF 400 GRAMS FLY ASH
CONCENTRATION (mg/L)
10
1.0
0.1
TIME (MIN.)
0
100
200
300
400
500
600
▲ pH
□ Cd
△ Zn
● Fe
○ Pb
–○– National Drinking Water Standards – Pb
–□– National Drinking Water Standards – Cd
=○= EP Toxicity Limits – Pb
=□= EP Toxicity Limits – Cd

FIGURE 5



200 GRAMS FLY ASH - EXCESSIVE BASE (CaO)

FIGURE 6

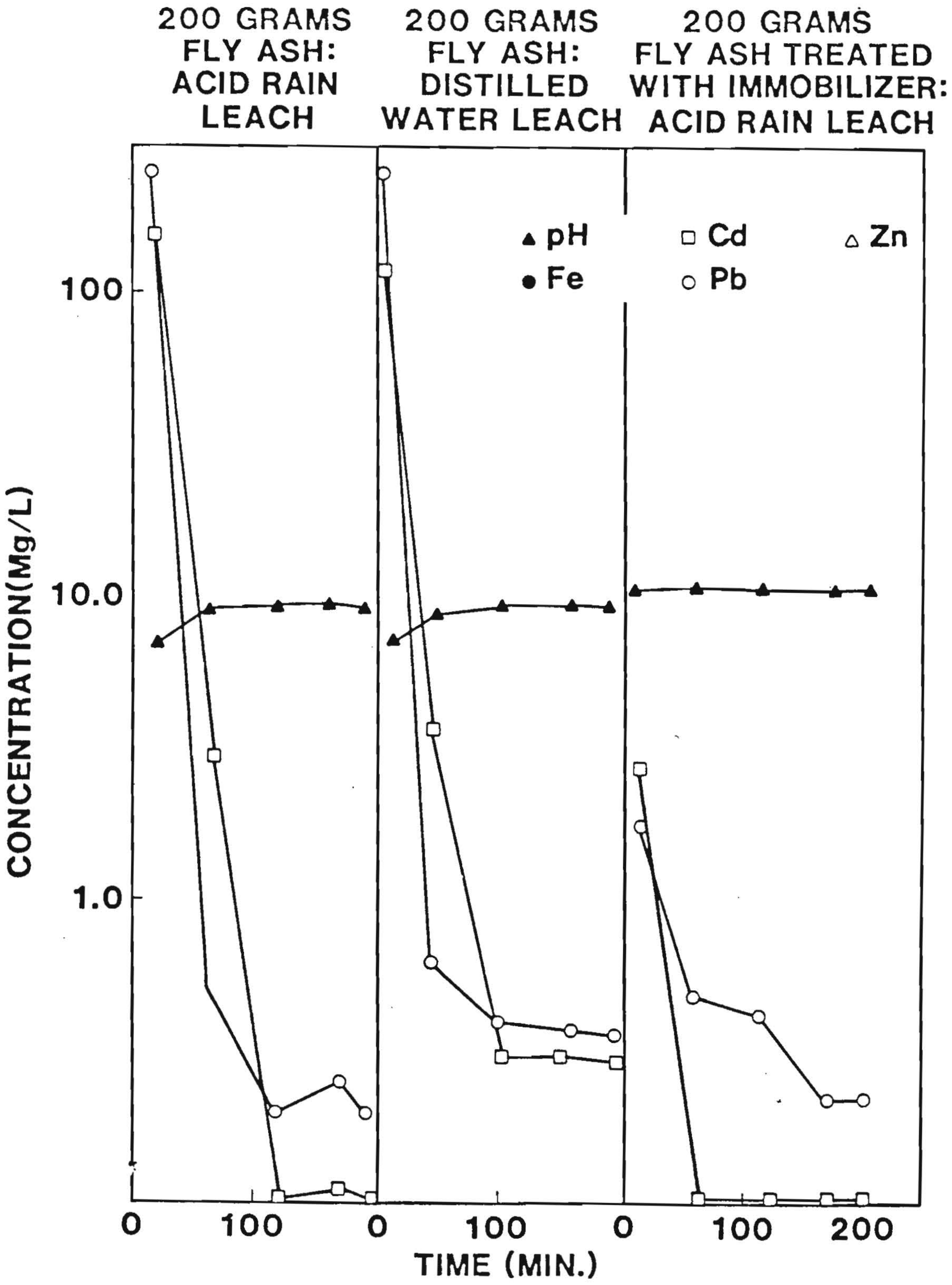

200 GRAMS FLY ASH: ACID RAIN LEACH
200 GRAMS FLY ASH: DISTILLED WATER LEACH
200 GRAMS FLY ASH TREATED WITH IMMOBILIZER: ACID RAIN LEACH
▲ pH
□ Cd
△ Zn
● Fe
○ Pb
100
10.0
1.0
CONCENTRATION(Mg/L)
0
100
0
100
0
100
200
TIME (MIN.)

FIGURE 7

FLOW DIAGRAM SHOWING SEQUENTIAL BATCH EXTRACTION PROCEDURE

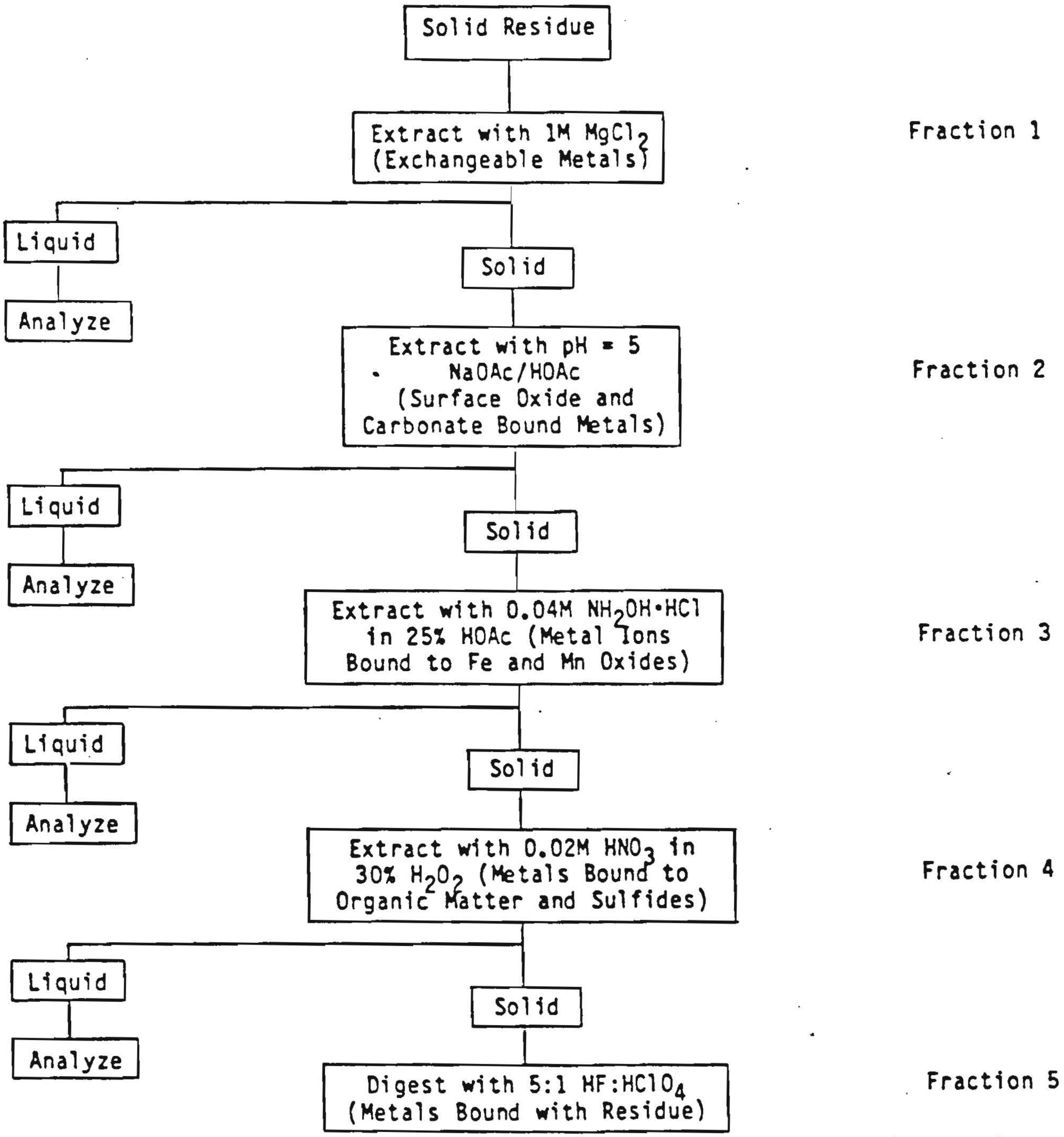


TABLE II

AVAILABILITY OF PB AND CD FROM MSW FLY ASH (<425μm)

	CONCENTRATION LEACHED (UG/G ASH)		
FRACTION	CD	PB	
EXCHANGEABLE METALS	21 (19)	192 (8)	MAXIMUM POTENTIAL RELEASE IF ASH IS SURFACE DISPOSED
SURFACE OXIDES AND CARBONATES	34 (31)	224 (9)	
FE AND MN OXIDE BOUND METALS	40 (37)	1200 (49)	NOT AVAILABLE FOR RELEASE TO THE ENVIRONMENT
METALS BOUND TO ORGANIC MATTER AND SULFIDES	10 (9)	182 (7)	
METALS BOUND WITH RESIDUE	4 (4)	672 (27)	
	109 (100%)	2470 (100%)	

FIGURE 8