AMES
LABORATORY

HEALTH AND ENVIRONMENTAL EFFECTS OF REFUSE DERIVED FUEL (RDF) PRODUCTION AND RDF/COAL CO-FIRING TECHNOLOGIES

HERAP

Health and Environmental
Risk Analysis Program

AMES LABORATORY, U.S. DOE
IOWA STATE UNIVERSITY
AMES, IOWA 50011

OCTOBER 1981

Research supported by the Health and Environmental Risk Analysis Program, Office of Health and Environmental Research, Assistant Secretary for Environment, United States Department of Energy under contract No. W-7405-Eng-82 with the U.S. Department of Energy.

ISU--90005951

DE90 005951

HEALTH AND ENVIRONMENTAL EFFECTS of REFUSE DERIVED FUEL (RDF) PRODUCTION and RDF/COAL CO-FIRING TECHNOLOGIES

J.J. O'Toole, T.E. Wessels, J.F. Lynch, V.A. Fassel,
L.L. Lembke, R.N. Kniseley, G.A. Norton, G.A. Junk,
J.J. Richard, E.L. Dekalb, R.J. Dobosy

Ames Laboratory, DOE
Iowa State University
Ames, Iowa

October, 1981

Research supported by the Health and Environmental Risk Analysis Program, Office of Health and Environmental Research, Assistant Secretary for Environment, United States Department of Energy, Under Contract No. W-7405-ENG-82 with the U.S. Department of Energy

ACKNOWLEDGEMENTS

We wish to thank the following individuuals for their help, both direct and indirect, in assembling information and preparing this document. Engineering Research Institute (ERI), Iowa State University for cooperation on the Ames project and assistance with the sampling program at the Ames powerplant. Phillip J. Walsh of ORNL and Samuel C. Morris of BNL for providing background information and reports on occupational and public health assessments; to Dean Smith and Gary Johnson of Research Triangle Park, EPA for background data on Multi Media Environmental Goals; to Jay Campbell of NCRR in helping project new RDF facilities and Joe Duckett of Schwartz and Connelly for assistance in assessing occupational hazards; and Zak Mansdorf of Midwest Research Institute for assistance in evaluating the pathogenic threat in the workplace.

Particular thanks are expressed to the following persons for providing description and technical data on the operational RDF/coal sites used in this study.

Bob Vetter - City of Madison - Engineering Division
Ted Jagelski - City of Madison - Engineering Division
Pete Casey - Madison Gas & Electric
Joe Vrusca - Wisconsin Department of Natural Resources
Paul Koziar - Wisconsin Department of Natural Resources
Henry Bell - City of Columbus - Division of Electricity

Ed Eberts - City of Columbus - Division of Electricity

Dick Harris - City of Columbus - Division of Sanitation

Bob Miles - Ohio EPA

Duane Snyder - Ohio EPA

Steve Thacker - Ohio EPA

Mr. Czapla - Hooker Chemical Co. - Niagara Falls, New York

Chuck Spodalka - Hooker Chemical Co. - Niagara Falls, New York

George Woodward - Hooker Chemica Co. - Niagara Falls, New York

Bob Armbrust - New York State Department of Environmental Conservation

John Beecher - New York State Department of Environmental Conservation

Sean Irwin - NEWCO Waste Inc. - Niagara Falls, New York

Bob Burton - Rochester Gas & Electric, Rochester, New York

Gordon Keenan - Rochester Gas & Electric, Rochester, New York

Dennis Suglumele - Rochester Gas & Electric - Rochester, New York

Steve Betts - New York State Department of Environmental Conservation

Richard Meyer - Ratheon Service Co. - Rochester, New York

Claude Hiers - City of Lakeland, Florida - Department of Electric and Water Utilities

Karen Anthony - Florida Department of Environmental Regulations

Arnold Chantland - City of Ames

Gary Titus - City of Ames

Don Riggs - City of Ames

Ken Moravetz - City of Ames

Bill Youngquist - Iowa Department of Environmental Quality

Mike Hayward - Iowa Department of Environmental Quality

We would also like to express our appreciation to the following persons for information and assistance for the air modeling analysis.

Mr. Michael Durham, Iowa Department of Environmental Quality

Ohio Environmental Protection Agency

New York State Department of Environmental Control

Wisconsin Department of Natural Resources

Mr. Mark Stevens, Environmental Science and Engineering Corp., Gainesville, Fl

Mr. Larry Hacker, USEPA, Kansas City Region Office

Lakeland Utilities, Lakeland, FL

CONTENTS

Appendix page

LIST OF TABLES

LIST OF FIGURES

1. EXECUTIVE SUMMARY

The potential energy value of municipal solid waste in power generation is yet to be realized. It is estimated that 150 million tons of municipal solid waste (MSW) were generated in 1981. Projections for 1990 estimate 184 million tons will be produced. In 1981, 3 to 4% of the MSW was processed in some form of resource recovery system including energy recovery. Of the four types of MSW disposal activities (resource recovery, source separation, mass incineration without energy recovery and landfilling) only resource recovery's share of disposal activities is projected to increase from the 1981 figure of 3 or 4% to 1990 estimates of 13 to 20% or 25 to 37 million tons/year.

These 1990 estimates were made from a survey of existing and planned resource recovery facilities which included energy recovery by: 1) co-firing refuse-derived fuel with coal or oil, 2) firing a refuse-derived fuel alone, 3) mass incineration in large waterwall boilers and 4) mass incineration in modular combustion units.

This survey showed that by 1990 as high as 13,000 TPD of MSW will be processed for use in new co-firing facilities as well as 13,000 TPD in facilities retrofitted for co-firing. The energy potential of 13,000 TPD of MSW is about 0.03 Quads and convertible to 0.4 GW(e)/yr.

Six facilities, representing the scope of different co-firing techniques with their associated RDF production systems were reviewed in detail for combustion equipment, firing modes, emission control systems, residue handling/disposal, and effluent wastewater treatment. These facilities encompass all currently operational or soon to be operational co-firing plants and associated RDF production sytems. They are located in Ames, Iowa; Rochester, New York; Columbus, Ohio; Madison, Wisconsin; Niagara Falls, New York; and Lakeland, Florida. The latter four sites have been modeled for air dispersion of stack pollutants using the Climatological Dispersion Model (DCMQC).

Occupational health and safety risks for these coal/RDF co-firing plants were evaluated on the basis of fatal and nonfatal accidents and disease arising from the respective fuel cycles, coal and RDF. Data on the coal cycle was obtained from reports of the BEAD program at Brookhaven National Lab. In the case of the RDF fuel cycle, accident data on the municipal solid waste collection system was available from EPA studies. Data on fatal and nonfatal accident rates in the processing of MSW to RDF was not available, so a surrogate industry (SIC2649, BLS) was selected. Occupational risks from the two fuel cycles were tabulated on the basis of their respective energy contributions, 80% coal 20% RDF per GW(e)/yr.

Occupational risks include exposure to pathogenic organisms in the workplace. While there is still a paucity of data on what constitutes an infectious dose of the more common pathogens in the workplace, a review of reports on workers exposed to an array of potential pathogens in different occupations is presented. The degree of risk in this environment is as yet not clear.

Unusual events that are life threatening in the RDF processing industry (e.g., explosions) are also discussed and remedial and safety measures reviewed.

Assessment of health and environmental impacts of these six co-firing operations has led to the following conclusions:

1. Replacement of coal BTUs with RDF BTUs using 1990 projections for co-firing installations may reduce sulfur oxide emissions by as much as 110,000 tons per year compared to total U.S. emissions of 30 million ton. Typical urban ambient sulfate concentrations of 25-50 ug/m^3 could be reduced 0.2-0.3 ug/m^3. Extrapolation of epidemiological data, which indicates 3.5 deaths/10^5 persons per 1 ug/m^3 of sulfate aerosol, suggests the maximal effect of RDF combustion could result in one less death per 10^5 persons in urban areas.
2. Replacement of coal BTUs with RDF using 1990 projections may increase Total Suspended Particulate (TSP) emissions from 4,000 to 48,000 tons per year. This represents less than 0.4% of TSP emissions nationally from all sources. Lack of adequate chemical/physical characterization of this incremental TSP from RDF makes it impossible to assess the overall impact on public health.
3. Estimates of nitrogen oxide emissions for 1990 co-firing projections show a decrease of 2700 to 4800 tons/year. This represents such a small change in the national NO_x emission budget (0-0.01 to 0.02%) that its effect is considered insignificant from a public health standpoint.

Particulate trace element emissions are tabulated from available data on the Ames, Iowa and St. Louis, Missouri RDF combustion facilities, which include both mechanical collectors and electrostatic precipitators. Atmospheric dilutions to maximum receptor sites obtained from the CDMQC model and a crude screening model are used to compare expected ambient levels to TLVs and AMEGs. The highest expected ground concentrations of all toxic trace elements measured are well below AMEG values.

Benzo(a)pyrene is examined on the basis of hypothetical emissions expected from stoker fired coal boilers and subjected to air model dilutions. Conservative estimates show B(a)P contributing less than one-tenth of one percent to urban air levels.

General knowledge about the chemical characterization and quantitative emissions of organic compounds formed and released under different combustion conditions is still very limited, however, a review of the organic compounds identified in fly ash or stack emissions is presented.

Problems associated with ash and wastewater disposal from RDF/coal plants were not seen to differ qualitatively in toxic metals or organic compounds from coal burning plants and their environmental impacts are expected to be similar.

2. INTRODUCTION

MUNICIPAL SOLID WASTE (MSW) DISPOSAL

Factors Affecting Changes in MSW Disposal

Municipal solid waste (MSW) disposal practices in the United States have changed significantly during the past two decades. Among the factors that have contributed to this change are the increasing environmental awareness of the general public, the intensifying competition for land use, the escalation of energy and material resources costs, the emergence of strong residential opposition to the siting of landfills, and the enactment of stringent land disposal and air pollution regulations. Two acts of Congress that significantly affected MSW disposal practices in the past decade are the Clean Air Act of 1970 and the 1976 Resource Conservation and Recovery Act (RCRA). The Clean Air Act, and similar state regulations, brought about the closing of about 50% of the uncontrolled-air incinerators in the U.S. by the mid-1970's due to the reluctance of the facility owners to add air pollution control equipment. Development of controlled-air incineration, enhancement of emission control devices, and the addition of energy recovery systems replaced many of the closed facilities and created new markets for solid waste incinerators. RCRA, local opposition to landfill sitings, and land use competion were responsibile for the closing of some landfills, operational changes at others, and detailed design and siting requirements for proposed sites.

MSW Quantities and Compositions

Quantities

The quantity of MSW generated in the U.S. cannot be determined exactly. Estimates of the MSW quantity have been noted to be accurate to within 25% (1). In a 1978 EPA publication, the 1975 MSW quantity was estimated as 172.8 million tons (1), whereas the Council on Environmental Quality (CEQ) reported the 1978 MSW quantity as 154 million tons, reflecting a 1% annual growth for the 1970-1978 period (2). In a recent EPA conference report the 1980 MSW quantity was indicated to be in the range of 130-150 million tons (3). For the purpose of this report, the quantity of MSW generated in 1980 was assumed as 150 million tons. Based on a population of 220 million, this quantity reduces to 1364 lbs/person/ year or 3.74 lbs/person/day.

The quantity of MSW generated in 1990 was assumed as approximately 184 million tons. This quantity is based on 1364 lbs/person/year, the U.S. Bureau of Census Series II population projection of 244 million for 1990, and a 1% annual growth rate of MSW generated per capita per year.

Composition

Factors affecting MSW composition include season of the year, geographic location, population characteristics, and degree of urbanization. Table 1 shows the typical MSW composition. It is not possible to assign such a composition to any particular community, since MSW composition can vary considerably among communities and within a community, among seasons. For the purposes of this study, the 1990 MSW compositions were assumed to not vary significantly from the MSW compositions of the 1970's.

TABLE 1

Composition of Municipal Solid Waste (1)

Material	Content (% by weight)
Food wastes	17
Garden trimmings	10
Paper products	40
Plastics, rubber, and leather	6
Textiles	2
Wood	4
Metals	10*
Glass and ceramics	10
Ash, rock, and dirt	1

* 9% ferrous, 1% nonferrous

MSW Disposal Techniques

Four major MSW handling/disposal techniques are utilitzed in the United States. They are: (i) recycling through source separation programs; (ii) resource recovery (materials and/or energy) through mechanical, thermal and/or biological processes; (iii) volume reduction through incineration without energy recovery; and, (iv) landfilling of bulk, shredded, or baled MSW. These techniques are not necessarily mutually exclusive. Resource recovery and volume reduction incineration typically require landfill disposal of residues. Table 2 shows the amount of MSW disposed by these four techniques in 1981 and projections for 1990.

Recycling through source separation programs has been estimated to reduce the MSW mass by 8% or 12.0 million tons in 1980 (4). The four main source separation methods are: commercial paper recycling programs, recycling centers, buyback programs, and curbside collection programs (5).

Through commercial paper recycling programs, high-grade ledger, computer paper, and corrugated boxes are collected from government offices and commercial establishments. Office recycling programs can reduce office solid waste up to 40%.

Recycling centers, which started to emerge after Earth Day 1970, make up a very diverse group of often short lived facilities that collect paper, glass, and metal cans. A recent EPA study reports that there are now more than 2000 recycling centers in the U.S. (6). These centers usually reduce the MSW stream of a community by 2-3%, but occasionally divert up to 30% of the MSW stream (4).

TABLE 2

Present (1981) and Projected (1990) MSW Disposal Practices

	Million Tons Disposed (% of Total)	
Disposal Technique	1981	1990
Source Separation	12.0 (8%)	14.7 (8%)
Resource Recovery	4.2 - 6.2 (2.8% - 4.1%)	24.9 - 37.2 (13.5% - 20.2%)
Volume Reduction Incineration	12.0 (8%)	9.2 (5%)
Landfills	121.8 - 119.8 (81.2% - 79.9%)	135.2 - 122.9 (73.5% - 66.8%)
Totals	150.0 (100%)	184.0 (100%)

Buyback programs involve the buyback of paper and/or aluminum cans by local dealers. Approximately 25% of all aluminum cans are recycled through buyback programs. Substitution of recycled aluminum cans for bauxite reduces the amount of energy necessary for production of new aluminum cans by 95% (4).

Curbside collection programs are more likely to receive greater public participation than other recycling programs because the only requirement of citizens is that they place recyclables at the curbside. A good curbside collection program can divert 10-15% of the MSW stream. Presently there exist about 230 such programs serving 280 communities, whereas in 1970 only 2 such programs were in operation (5).

It is extremely difficult to project growth of recycling through source separation to 1990 due to uncertainty of markets, stability of economic trends, and the short 6-12 month lead time for most source separation programs. For the present study, we assumed that source separation recycling would divert 8% of the 1990 MSW stream, or 14.7 million tons (Table 2). This represents a 2.7 million tons increase from 12.0 million tons of 1981 or about 22% for the 9 year period.

According to a recent EPA survey, resource recovery facilities presently operating, suspended or under construction are listed in Table 3 (5). Operations have been suspended at several facilities. A summary of facilities operating, suspended, or in shakedown, according to technology type, is presented in Table 4 . A total of 38 facilities are presently operating and an additional 12 facilities have suspended operations. Three modular combustion unit (MCU) facilities have suspended operations; the facility at Blytheville, AR is presently undergoing modifications, whereas the unit at Siloam Springs, AR has closed permanently. Genesee Township, MI is seeking a steam market for their unit. Nine RDF facilities have suspended operations. Four of these facilities (in Chicago, IL; Duluth, MN; Akron, OH; and Lane County, OR) are closed for assessment of technical problems and modification of equipment. Three facilities (East Bridgewater, MA; Tacoma, WA; and Milwaukee, WI) are closed due to lack of RDF markets. The Bridgeport, CT facility closed after a partner in the venture filed for bankruptcy. The wet pulping facility at Hempstead, NY was closed because of contractual problems and citizen concern over stack emissions.

The total design capacities of the resource recovery facilities now operating is 18,968 tons per day (TPD) (Table 4). The total design capacity of all the facilities in operation, shakedown, or suspended stage is 28,215 TPD (Table 4). The yearly tonnage of MSW disposed through resource recovery facilities, for a capacity factor of 60%, is listed in Table 2 as a range of 4.2 to 6.2 million tons, representing 2.8% to 4.1% of the total 150 million tons in 1981.

Projections on the contribution to MSW disposal via resource recovery facilities in 1990 is filled with uncertainties. A recent nationwide survey of communities that have investigated or have begun planning a resource recovery facility is summarized in Table 5 (5). In the evaluation of the planning and construction process of a facility, five stages have been identified. Phase 0, is an initial study to determine if local conditions preclude consideration of resource recovery; Phase I, involves a feasibility analysis; Phase II is a

TABLE 3

Listing of Resource Recovery Facilities

State	City or County	Year Started	Design Capacity	Technology Type	Operation Status April 1, 1981	Comments
FL	Lakeland	1981	300 TPD	RDF-Fluff	Shakedown	10% RDF/90% coal
IA	Ames	1975	200 TPD	RDF-Fluff	Operating	10% RDF/90% coal, processing 150 TPD
NY	Monroe County	1979	2000 TPD	RDF-Fluff	Operating/shakedown	Processing 500 TPD currently, 1/2 of RDF produced is landfilled
NY	Niagra Falls	1981	2200 TPD	RDF-Fluff	Shakedown/	RDF primary fuel
OH	Columbus	1981	2000 TPD	RDF-Fluff	Shakedown	80% RDF/20% coal
WI	Madison	1979	400 TPD	RDF-Fluff	Operating	10% RDF/90% coal
CT	Bridgeport	1980	1800 TPD	RDF-Powdered	Suspended	RDF intended as supplemental fuel for off-site investor owned steam/electric generating station, suspended due to bankruptcy of partner
IL	Chicago	1977	1000 TPD	RDF-Fluff	Suspended	RDF intended as supplemental fuel for off-site steam/electric generating station
LA	New Orleans	1978	750 TPD	RDF-Fluff	Operating	RDF presently landfilled, facility designed for materials recovery, presently seeking RDF market
MD	Baltimore County	1976	1200 TPD	RDF-Fluff or pellets	Operating	Most RDF is landfilled, some used for test burning in off-site steam/electric generating stations. Presently seeking RDF market
MA	East Bridgewater	1977	360 TPD	RDF-Fluff	Suspended	RDF (ECO-Fuel II) originally for industrial boilers, closed due to lack of RDF market, attempting to market briquettes for home fuel
MN	Duluth	1980	1400 TPD	RDF-Fluff co-disposal	Suspended	Fluidized bed incineration of RDF and sludge, suspended for modification
NY	Albany	1980	750 TPD	RDF-Fluff	Shakedown	RDF to be burned in dedicated boiler for steam generation

Table 3 . (continued)

State	City or County	Year Started	Design Capacity	Technology Type	Operation Status April 1, 1981	Comments
NY	Hempstead	1978	2000 TPD	RDF-wet pulping	Suspended	Primary fuel for on-site steam/electric generation, closed due to contratual dispute and citizens concern over stack emissions
OH	Akron	1980	1000 TPD	RDF	Suspended	Under modification, dedicated boiler, steam for heating and cooling
OR	Lane County	1979	500 TPD	RDF-Fluff	Suspended	Under modification, RDF market not determined
WA	Tacoma	1979	500 TPD	RDF-Fluff	Suspended	Suspended due to lack of RDF market, densification of RDF being investigated
WI	Milwaukee	1979	500 TPD	RDF-Fluff	Suspended	Suspended due to slugging problems in utility boiler when used as supplemental fuel, seeking other RDF markets, considering dedicated boiler
DL	Wilmington	1982	1000 TPD	RDF-Fluff co-disposal	Construction	Burning in dedicated boiler for steam generation
FL	Dade County	1981	3750 TPD	RDF-wet gulping	Construction	RDF to be burned in dedicated boiler for steam/electric generation
MI	Detroit	1984	3000 TPD	RDF-Fluff	Construction	RDF to be burned in dedicated boilers for steam and/or electric generation
VA	Portsmouth	1986	2000 TPD	RDF-Fluff	Construction	RDF to be burned on-site as primary fuel for steam/electric generation, expected mix is 97% RDF and 3% coal
IL	Chicago (NW)	1971	1600 TPD	Mass burn	Operating	
MA	Braintree	1971	384 TPD	Mass burn	Operating	
MA	Saugus	1975	1500 TPD	Mass burn	Operating	
NY	New York (Betts Ave.)	1965	1200 TPD	Mass burn	Operating	
NY	Oceanside	1974	750 TPD	Mass burn	Operating	Processing 500 TPD currently

Table 3 . (continued)

State	City or County	Year Started	Design Capacity	Technology Type	Operation Status April 1, 1981	Comments
PA	Harrisburg	1972	720 TPD	Mass burn	Operating	
TN	Nashville	1974	530 TPD	Mass burn	Operating	
VA	Hampton	1980	200 TPD	Mass burn	Operating	
VA	Norfolk	1967	366 TPD	Mass burn	Operating	
VA	Portsmouth	1976	160 TPD	Mass burn	Operating	
WI	Waukesha	1979	175 TPD	Mass burn	Operating	
FL	Pinellas County	1983	2000 TPD	Mass burn	Construction	
MA	North Andover	1985	1500 TPD	Mass burn	Construction	
NY	Clen Cove	1982	225 TPD	Mass burn	Construction	
NY	Westchester County	1984	1500 TPD	Mass burn	Construction	
TN	Gallatin	1981	200 TPD	Mass burn	Construction	
VT	Burlington	1983	120 TPD	Mass burn	Construction	
AR	Blytheville	1981	70 TPD	MCU	Suspended	
AR	North Little Rock	1977	100 TPD	MCU	Operating	
AR	Osceola	1980	50 TPD	MCU	Operating	
AR	Siloam Springs	1975	17 TPD	MCU	Closed	
FL	Jacksonville	1980	72 TPD	MCU	Operating	
FL	Mayport	1980	50 TPD	MCU	Operating	
ME	Auburn	1981	100 TPD	MCU	Operating	
MA	Pittsfield	1981	240 TPD	MCU	Operating	
MI	Genesee Township	1980	100 TPD	MCU	Suspended	
NH	Durham	1980	108 TPD	MCU	Operating	

Table 3 . (continued)

State	City or County	Year Started	Design Capacity	Technology Type	Operation Status April 1, 1981	Comments
NH	Groveton	1975	24 TPD	MCU	Operating	
TN	Crossville	1977	60 TPD	MCU	Operating	
TN	Dyersburg	1980	100 TPD	MCU	Operating	
TN	Lewisburg	1980	60 TPD	MCU	Operating	
VA	Newport News	1981	40 TPD	MCU	Operating	
VA	Salem	1978	100 TPD	MCU	Operating	
WI	Grafton	1970	24 TPD	MCU	Operating	
AL	Prudhoe Bay	1981	100 TPD	MCU	Construction	
AR	Batesville	1981	50 TPD	MCU	Construction	
CT	Windham	1981	108 TPD	MCU	Construction	
ID	Heyburn	1981	50 TPD	MCU	Construction	
KY	Fort Knox	1982	40 TPD	MCU	Construction	
MN	Collegeville	1981	64 TPD	MCU	Construction	
MN	Redwing	1982	72 TPD	MCU	Construction	
MO	Ft. Leonard Wood	1982	82 TPD	MCU	Construction	
NH	Portsmouth	1982	200 TPD	MCU	Construction	
TX	Gatesville	1981	5 TPD	MCU	Construction	
TX	Palestine	1981	20 TPD	MCU	Construction	
FL	Key West	1980	80 TPD	Composting	Construction	
PA	Altoona	1963	25 TPD	Composting	Operating	
RI	Providence	1981	250 TPD	Composting	Operating	
FL	Dade County		400 TPD	Composting	Shakedown	
FL	Pompano Beach	1978	100 TPD	Anaerobic		
FL	Orange County	1982	100 TPD	Pyrolysis	Operating	

procurement planning stage, including development of markets, sites, waste supply, preferred procurement and financing approaches; Phase III, procurement stage including contracting for waste supply, markets, construction, and operation; and Phase IV, the actual construction phase.

Certainty factors have been applied to the summary statistics for each phase, as listed in Table 5 . If all communities presently involved in the planning, construction, or operation of a resource recovery facility indeed have an operating facility by 1990, there will be 245 facilities with design capacities totalling 170,516 TPD. If the certainty factors shown in Table 5 are applied, there will be 155 facilities totalling 113,543 TPD design capacity. By applying an operating factor of 60% a range of MSW tonnage disposed through resource recovery was calculated as 24.9 to 37.2 million tons, representing 13.5% to 20.2% of the total 184.0 million tons (Table 2).

The amount of MSW disposed through incineration, for the purpose of volume reduction , without energy recovery, was estimated to be 17.3 million tons in 1975 and projected to be 10.0 million tons in 1990 (1).

For the purpose of this report, the amount of volume reduction incineration was assumed as 12.0 million tons for 1981 and 9.2 million tons for 1990, representing 8 and 5% of the total MSW, respectively (Table 2).

As shown in Table 2 nearly 80% of MSW was landfilled in 1981, whereas it is expected that about 70% of MSW will be landfilled in 1990.

TABLE 4

Present Resource Recovery Facilities

Technology Type	Operating Shakedown, or Suspended	Operating or Shakedown	Suspended
Anaerobic Digestion	100 * (1) **	100 (1)	---
Composting	355 (3)	355 (3)	---
Mass Incineration	7,585 (11)	7,585 (11)	---
Modular Combustion Units	1,315 (17)	1,128 (14)	187 (3)
Refuse Derived Fuels	18,860 (18)	9,800 (9)	9,060 (9)
	28,215 TPD (50)	18,968 (38)	9,247 TPD (12)

* Design Capacity, TPD
** # of Sites

TABLE 5

Summary of EPA Survey of Communities Involved in Planning, Constructing, or Operating Resource Recovery Facilities (5)

Technology Type	0 (Study of Conditions) 10%	I (Feasibility Analysis) 33%	II (Procurement Planning) 75%	III (Procurement) 95%	IV (Construction) 95%	Total (0-IV)	Shakedown Operating Suspended	Total	
Anaerobic							100	100 -	100
Digestion							(1)	(1)	
Composting					400	400	355	755 -	755
					380	380			
			(4)		(1)	(1)	(3)	(4)	(4)
Fluidized									
Bed			150			150		150 -	112
			112			112			
Combustion			(1)			(1)		(1)	(1)
Mass	4,050	22,075	25,800	12,350	5,545	69,820	7,585	78,104 -	51,698
	405	7,358	19,350	11,735	5,268	44,113			
Incineration	(4)	(23)	(25)	(9)	(6)	(67)	(11)	(77)	(52)
Modular									
Combustion	1,960	8,115	3,350	3,760	791	17,976	1,315	19,374 -	11,051
	196	2,705	2,512	3,572	751	9,736			
Units	(11)	(20)	(13)	(10)	(11)	(65)	(17)	(81)	(55)
Pyrolysis	100			100		200		200 -	105
	10			95		105			
	(1)			(1)		(2)		(2)	(1)
Refuse									
Derived	1,000	9,330	6,600	5,400	9,750	32,098	18,860	49,640 -	40,332
	100	3,100	4,950	4,050	9,262	21,472			
Fuels	(1)	(13)	(6)	(5)	(4)	(29)	(18)	(45)	(31)
Undecided	4,685	7,600	8,500			20,875		20,875 -	9,390
	469	2,533	6,375			9,390			
	(13)	(11)	(6)			(30)		(30)	(10)
Total						141,501	28,215	169,198 -	113,543
						85,308			
						(195)	(50)	(245)	(155)
						(105)			

Scope of This Study

This study is designed to be the first of a series of Health and Environmental Effects Documents focused on Municipal Solid Waste (MSW) to energy technologies. Although future reports will include such technologies as mass incineration, modular combustion units (MCU's), anaerobic digestion, and pyrolysis, the present study was limited to the co-firing of refuse derived fuels (RDF) and coal. Facilities designed to use RDF as either a primary or a secondary fuel were included. RDF co-firing technology was selected for the initial document because of its present popularity and projected future growth, and the limited, but expanding, data base on environmental emission and waste stream characteristics.

Table 6 shows the percentages, based on design capacity, of the present and planned resource recovery facilities for the major technology types. The refuse-derived fuels technology presently has the greatest design capacity (one-half to two-thirds of the total). According to the projections used in this report, in 1990 the RDF technology will contribute about one-third to the total design capacity of resource recovery facilities, whereas mass incineration will contribute about 50%. Not all RDF facillities produce fuels for co-firing with coal. Table 7 lists the types; fluff, powdered, and fiber (wet pulped) of RDF facilities presently in shakedown, operation, suspended, or under construction. RDF is generally co-fired with coal or burned alone in dedicated boilers. Co-firing may take place in old boilers modified for RDF burning, which are generally not subject to New

Source Performance Standards, (NSPS), or in relatively new boilers, subject to NSPS which may have been either designed to burn RDF or modified to burn RDF. Other types of RDF facilities include co-disposal in dedicated boilers, and fluidized bed furnaces.

On the basis of the mixture of existing RDF facilities, it was assumed that of the RDF facilities being planned, 25% will be co-fired in retrofitted old boilers, 25% will be co-fired in new boilers, and 50% will be burned in dedicated boilers. Also, 25% of the facilities being planned, but of an undecided type, were assumed to be RDF facilities. As such, these facilities were portioned as the planned RDF type facilities (Table 7). The total 1990 design capacities in tons per day (TPD) for RDF types are also shown in Table 7 . It was assumed that by 1990 the design capacities of old, co-fired boilers will be 9,400 to 12,800 TPD. The design capacities of new, co-fired boilers were assumed to be 10,000 to 13,400 TPD.

TABLE 6

Summary of Present and Planned Resource Recovery Facility Types

Technology Type	Shakedown or Operating 1981	Shakedown, Operating, or Suspended 1981	Planned Operational 1990
Mass Incineration	40%	29%	45-46%
Modular Combustion Units	6%	5%	10-11%
Refuse Derived Fuels	52%	67%	36-30%
Other	2%	1%	1- 1%
Undecided	0%	0%	8-12%

TABLE 7

Summary of Present and Planned RDF Facility Types

	Shakedown or Operating 1981	Shakedown, Operating, or Suspended 1981	Construction	Planning Phases RDF Type	Planning Phases Undecided Type	Total 1990
Fluff Co-fired Old boilers	2,600* (3)** 26%***	4,100 (5) 23%	---	2,930-5,587 (2-6) 25%	587-1,305 (1-2) 25%	7,617-10,992 (8-13) 18%-20%
Fluff Co-fired New boilers	4,500 (3) 46%	4,500 (3) 26%	2,000 (1) 21%	2,930-5,587 (2-6) 25%	587-1,305 (1-2) 25%	10,017-13,392 (7-12) 23%-24%
Powdered Co-fired Old boilers	---	1,800 (1) 10%				1,800 (1) 4%-3%
Fluff Dedicated New boilers	750 (1) 8%	1,750 (2) 10%	3,000 (1) 31%	5,861-11,174 (5-13) 50%	1,174-2,610 (1-4) 50%	11,785-18,534 (9-20) 28%-33%
Fiber (wet pulped) Dedicated New boilers	---	2,000 (1) 11%	3,750 (1) 38%	---	---	5,750 (2) 13%-10%
Fluff Dedicated New boilers Co-disposal	---	---	1,000 (1) 10%	---	---	1,000 (1) 2%-2%
Fluff Fluidized bed furnace Co-disposal	---	1,400 (1) 8%	---	---	---	1,400 (1) 3%-2%
Fluff No market	1,950 (2) 20%	2,950 (4) 17%	---	---	---	2,950 (4) 7%-5%
Powdered No market	---	360 (1) 2%	---	---	---	360 (1) 1%-1%
Total	9,800 (9) 1000%	18,860 (18) 100%	9,750 (4) 100%	11,722-22,348 (9-25) 100%	2,348-5,219 (3-8) 100%	42,680-56,177 (34-55) 100%

* Design capacity, TPD
** # of sites
*** % of the column total

RDF/COAL CO-FIRING TECHNOLOGY

Historical

The first large scale co-firing activity was conducted at the Union Electric Meremac Station powerplant in St. Louis in 1974 and 1975 (50). The feasibility of co-firing on a large scale was demonstrated and the first data was obtained on stack emissions from both RDF/coal co-firing and firing coal alone. The fluff RDF was fired in a 125 MW pulverized coal utility boiler without a dump grate. A significant increase in ash flow resulted if a dump grate was not installed when RDF was fired in a suspension fired boiler.

In 1974, EPA supported a smaller scale test on a small, traveling-grate municipal boiler at Columbus, OH to gather boiler tube corrosion and environmental emissions data (8). Then, in 1975, an RDF-fluff processing plant was built in Ames, IA. RDF was test fired in two small traveling grate units. EPA and ERDA supported a study to gather environmental emissions and boiler operational data when firing up to 50% RDF in these units (9). These tests were followed when EPA and ERDA supported tests on the 35 MW suspension fired unit #7 at Ames in 1976, 1977 and 1978, focusing on the effect of boiler operation variables and the impacts of RDF on boiler efficiencies and emissions. The installation of a dump grate in 1978 made co-firing feasible on a fulltime basis (10), and further refinment of firing techniques made it possible to meet particulate emission standards while co-firing with RDF. In 1980, 19,000 tons of RDF were fired in unit #7 at Ames.

Three other significant efforts at co-firing in larger suspension fired utility boilers have occurred since Ames' success. EPA supported the city of Chicago in building a 1000 TPD MSW to RDF processing plant for co-firing of its RDF in the Commonwealth Edison suspension fired boilers adjacent to the processing facility. Serious equipment problems in the RDF processing plant forced plant shutdown, and the city of Chicago has so far not chosen to invest the substantial additional capital necessary to make the plant operative.

Wisconsin Electric Power in 1978 and 1979 conducted extensive tests and evaluation of RDF produced at the American Can Co.'s processing facility in Milwaukee. RDF was fired in 2 large utility boilers (310 MW each) in which some boiler slagging and electrostatic precipitator (ESP) efficiency problems were experienced. The utility has chosen not to continue use of RDF.

The third large-scale co-firing experience has occured at the Madison, Wisconsin G & E 50 MW suspension fired unit in which a dump grate was installed. In 1980 a second 50 MW unit was modified for co-firing coal plus RDF. The facility has been in operation since 1979, with last year's consumption of RDF at 10,200 tons.

The EPA has supported a study designed to test-fire a densified or pelletized RDF in a traveling grate small institutional boiler at Hagerstown, MD (11). Some environmental emissions data were collected in a relatively brief test. A second set of tests were conducted on a larger traveling grate unit at Erie, PA using a similar densified RDF, but test results have not been released by EPA.

A powdered RDF called ECO-Fuel II which was produced and marketed by Combustion Equipment Associates (CEA), was successfully fired with oil in an industrial boiler in Bridgeport, CN (5). However, CEA has experienced financial problems and no longer produces the ECO-Fuel II.

SIX RDF/COAL CO-FIRING SITES

Fuels

Coal

Table 8 shows typical ranges of ash content, C, H, O, Cl, heating value and moisture for RDF and coal. These ranges indicate that the ash contents of coal and RDF are similar and more particularly, high ash coal (12 to 15%) approaches the ash content of many RDF's. The carbon content of RDF is about one-half or less that of coal. Sulfur content of RDF as seen in the table varies from 0.1 to 0.4 percent. Coal has a heating content of about twice that of most RDF and about one-half the moisture. A comparison of ash and BTU contents of RDF and coal used at the six co-firing sites, summarized in this study, is shown in Table 19 .

Refuse Derived Fuels (RDF)

An overall comparison of the six systems indicates there are four levels of MSW processing being utilized at these six plants. The simplest is Columbus, which uses only primary shredding and ferrous metals removal. Second in complexity are Hooker and Lakeland which use only primary shredding, ferrous metals removal, and air classification. At Lakeland, air classification is optional but a disc screen is also

TABLE 8

Range of RDF and Coal Composition in Percentage

	Urban (a) Refuse	RDF (b) Ames - 78 Data	RDF (c) Columbus (expected)	Coal (d) Combined Range	Coal (d) Eastern & Mid Cont.	Coal (d) Western
Ash	5-25	10-18	13-36	4.1-25	6-25	4.1-20
Carbon		25-34	17-37	58-80	63-80	58-74
Hydrogen		3.6-5.0	2-5	3.8-6.0	4-6	3.8-5.8
Sulfur	0.1-0.3	.2-.46	0.07-0.15	.34-6.4	.55-6.4	.34-1.9
Oxygen		27 (avg.)	15-29	2.5-22	2.5-18	8.8-22
Chloride	0.3-1.5	.22-.75	0.06-0.10	0.01-0.8	0.01-0.8	0.01-0.13
Heating Value (BTU/lb)	2000-5000	4954-6297	2300-7600	10084-14362	11374-14362	10084-12901
Moisture	15-30	19-28	5-50	0.5-37	0.5-18	4.1-37

(a) Reference (46)

(b) Reference (10)

(c) Columbus, OH design specifications

(d) Reference (46)

TABLE 9

Fuel Composition at Co-firing Sites

	RDF				COAL			
	BTU/lb	% Ash	%S	Source	BTU/lb	% Ash	% S	Source
Ames	5600	13	0.32	Residential Commercial Lt. Industry	10,200	7.94	2.8	Wyoming*
Columbus	4400	18.4	0.11	Residential Commercial	12,800	7.26	0.97	Kentucky
Hooker	5500	8 design	NA	Residential Commercial	12,800	9	0.77	Pennsylvania or W. Virginia
Lakeland	4700	16	0.1	Residential Commercial	11,500	12	2.5-3	Kentucky
Madison	5500	15	NA	Residential Only	11-1200	10	2.5-3	W. Kentucky or S. Illinois
Rochester	5000	17	NA	Residential Commercial Lt. Industry	12,500	10	2.3	W. Virginia

* Coal burned during 1978 emission studies

used. Third are Madison and Ames which employ primary and secondary shredders. The RDF is air classified and sand and grit are removed. Ferrous metals are also removed. Last is Rochester, which uses, in addition to the Madison-Ames level, secondary air classification, third stage pre-combustion shredding, and extensive processing of heavy residues for recovery of glass, non-ferrous metals and heavy combustibles. A more specific comparison of processing steps at each site shows the following:

1. Two of the six systems sell RDF produced by city or city/county-owned processing systems to private utility power plants located away from the processing sites. The other four processing facilities are each located at their respective power plant sites and owned by the same administrative entities. A minor exception at these four sites is that Columbus operates three of its five shredders at scattered city-wide transfer stations, and has done so for some time.
2. Primary shredding is used at each of the six sites, but secondary shredding is used only at three sites--Ames, Rochester and Madison.
3. Single stage or primary air classification is performed at four of the six sites. Lakeland has installed a simple air classifier but intends to produce and co-fire RDF without using the air classifier. Rochester is the only site to use secondary air classification. This is performed before a third stage of shredding also called pre-combustion shredding.

4. Ferrous separation is performed at each site, non-ferrous separation is accomplished at only one site--Rochester. Ames found it impractical and and not cost-effective.
5. Sand and grit removal is specifically addressed at three sites with disc or vibrating screens. A trommel is used at Madison to remove much of this fraction. Hooker and Columbus do not include this processing step.
6. Three of the facilities use live-bottom RDF storage at the processing/power plant location. Rochester has live-bottom storage at the Russell Station power plant which is separate from the processing plant, and Madison Gas and Electric has a small amount of storage at the power plant also.
7. At two of the processing sites RDF is trucked to separate power plants, Columbus trucks from off-site shredders as well as on-site shredders, and all sites except Columbus transport RDF from storage to boiler using transport air as the boiler feeding mechanism. Columbus uses separate small RDF storage hoppers at each boiler.

Combustion/Energy Conversion

Facilities Locations

Rochester Gas and Electric and Monroe County, NY RDF Processing and Co-firing

Monroe County, including the city of Rochester, NY, and Rochester Gas and Electric are cooperating in an RDF processing and co-firing venture. Monroe County has built a processing plant in the City of

Rochester and Rochester Gas and Electric has constructed a RDF handling facility at their Russell power plant in the northwest part of the city very near the shore of Lake Ontario. The processing plant is in a commercial land use area, and the power plant is located near more residential areas.

The processing plant receives residential and commercial MSW from Rochester and a number of other surrounding communities in Monroe County.

Columbus Refuse and Coal Fired Municipal Electric Plant

This co-firing facility is located in the south central portion of the Columbus, OH metropolitan area approximately 8 km SSE of downtown Columbus. The immediately surrounding area is a combination of industrial and rural land uses and the plant is approximately 1 km west of the Scioto River. The majority of the population of Columbus is located both north and northwest of the facility. The RDF processing facillities consist of three shredder/transfer stations located around the city and two shredders located on the plant site. The plant processes residential MSW from the entire Columbus metropolitan area.

City of Lakeland, FL , Department of Electricity and Water Utilities

The City of Lakeland is cooperating with the Orlando Utility Commission in building a RDF processing and co-firing facility near the City of Lakeland. The plant is located 6 KM north of the city in a rural land use area adjacent to 2000-acre Lake Parker.

The plant currently receives MSW from the City of Lakeland anticipates eventually serving the surrounding county also.

City of Madison, Madison G & E

The City of Madison has operated a shredding and resource recovery facility in various stages of development for ten years. They upgraded their MSW processing plant in 1978 and began producing RDF for sale to Madison Gas & Electric beginning in 1979. The city's plant is located three miles from downtown Madison and RDF is trucked to the power plant. MG&E power plant is located betwen Lakes Mendota and Monona in downtown Madison just a few blocks from the state capitol building.

The city uses only MSW collected from Madison residential sources by city sanitation crews and from the nearby communities of Maple Bluff and Monona.

Niagara Falls, New York , Hooker Chemical

Hooker Chemical contracts with local private waste haulers for MSW to process into RDF for burning in Hooker's new refuse-to-energy plant. Current contracts provide MSW collected by NEWCO Waste, Inc. They collect residential and commercial wastes from the surrounding communities. The Hooker plant includes an RDF production facility and is located in the industrial land use section of the City of Niagara Falls between Niagara Falls and Tonawanda and just north of the Niagara River.

City of Ames

The City of Ames has built an MSW to RDF processing facility adjacent to the city's municipal power plant in downtown Ames. Light industrial, commercial and residential land uses all exist within one-half mile of the plant.

The Ames processing plant uses residential, commercial and light industrial wastes from Ames as well as surrounding communities.

Power Plant Combustion Systems

The power plants surveyed in this study included two base loaded conventional suspension fired municipal utilities (Ames and Lakeland) one base loaded suspension fired private utility (Rochester G&E), one suspension fired private utility used for peaking power (Madison G&E), one base loaded municipal utility used also as a primary MSW disposal system (Columbus), and one private industry using MSW as a primary fuel to produce both electricity and steam for use in chemical manufacturing (Hooker Chemical). Of the six plants, Ames Unit #7, Madison and Rochester have retrofitted old suspension fire pulverized coal units to burn 10 to 20 percent RDF on a BTU heat input basis; Lakeland and Ames Unit #8 have new suspension fired units built to co-fire RDF with coal or oil at 10% and 20% of heat input, respectively, and Columbus and Hooker are using new traveling grate units designed for firing high percentages of RDF. Columbus fires 80% RDF and Hooker can fire 0 to 100% RDF, but routinely fires 100%.

The Ames Unit #8, even though a conventional suspension fired pulverized coal design, has a boiler 30' higher than is normally necessary for pulverized coal burning only. This design feature is an attempt to reduce particulate loadings as flue gas leaves the boiler into the air pollution control equipment.

Hooker's Foster-Wheeler traveling grate boilers are identical to those used in the wood products industry for burning wood bark and can be used to burn 100% RDF with an air pollution control emission option to burn 100% coal for 15% of the time on a yearly average basis.

Boiler sizes vary from 35 to 84 MW for retrofitted suspension fired units at Ames, Madison and Rochester, to 75 and 364 MW for new suspension fired units at Ames and Lakeland, respectively, MW traveling grate units at Columbus and Hooker.

Firing mechanisms for RDF are some form of suspension firing in all cases. The units at Ames, Madison, Lakeland and Rochester all use pneumatic transport air as a carrier to fire RDF through separate RDF firing nozzles. At most facilities where RDF is co-fired with coal in a pulverized coal boiler, the RDF firing nozzles are being placed below the coal nozzles. Ames experimented with firing port location in 1978 and discovered that placing RDF ports below coal ports significantly decreased particulate loads in the flue gas leaving the boiler yet maintaining complete burning of the RDF.

RDF firing rates for the pulverized coal units vary from 4.5 to 14 tons per hour (TPH) for the smaller units at Ames, Madison and Rochester to 26 TPH for the larger Lakeland unit. The traveling grate units fire at 20 TPH RDF for Columbus and 37.5 TPH for Hooker. Coal rates vary from 15 to 38 TPH for the smaller pulverized coal units, to 130 TPH at Lakeland. Columbus will fire 2 TPH coal per boiler when they begin operation in late 1982. Currently Hooker is firing no coal except when MSW is not available for processing. Table 10 summaries this information.

TABLE 10

RDF/Coal Co-firing Power Plant Descriptions

						Coal		RDF	
Site Name	Plant Type	Boiler Type	Unit #	Date Operated on RDF	MW Rating	Feed Rate TPH	%Total BTU Input	Feed Rate TPH	%Total BTU Input
Ames* Municipal Utility	Base Loaded Municipal Utility	Combustion Engineering Suspension fired coal Unit retrofitted w/ dump grate & RDF nozzless	7	1976	35	15	80	6	20
		New B&W Suspension fired coal unit with RDF nozzles and dump grate & extra boiler height to reduce RDF ash carryover	8	Jan. 1982	73	38	80	14	20
Columbus Division of Electricity	Waste Disposal electric product.	New B&W traveling grate units to burn RDF/coal ratio 80%/20% to 0/100	1-6	Late 1982	6@15**	2	20	20	80
Hooker Chemical	Elec & Steam Product.	Foster-Wheeler boilers designed to burn wood bark. 0-100% RDF or coal is suspension fired over traveling grate.	1&2	1981	54**	0	0	37.5	100
Lakeland McIntosh	Base loaded Municipal Utility	New suspension-fired B&W unit fired with coal/RDF or oil/RDF. Has dump grate.	3	Jan. 1982	364	130	90	26	10
Madison Gas & Electric	Peaking plant Private utility	B&W suspension fired coal units retrofitted with nozzles & dump grates for RDF/coal.		June 1979	2@50**	17	85	6.5	15
Rochester Gas and Electric	Base Loaded Private Utility	Tangentially suspension fired Combustion Engineering Coal units are being retroffited with dump grates and RDF nozzles	1	Fall 1981	48	18.9	90	4.4	10-15
			2	"	70	24.5	90	5.75	10-15
			3	Aug.81	66	23.5	90	5.5	10-15
			4	Fall'81	84	27.2	90	6.5	10-15

---

[*] Ames also has two traveling grate units (8 x 12 MW) which were tested on RDF in 1976-77. Currently they are used as standby units.

[**] MW rating and boiler feed rates are for each boiler.

Air Emissions Control Systems

All six facilities employ electrostatic precipitators (ESP) on each boiler for control of suspended particulates from the stack. Columbus also uses high efficiency mechanical collection devices prior to each ESP. Lakeland uses a flue-gas desulfurization scrubbing device prior to routing the stack gas through the ESP.

Five of the six MSW to RDF processing plants use bag-house collection for air pollution control to reduce dust produced during MSW processing. This serves to reduce not only dust emissions to the ambient air but also dust levels inside the processing buildings. Columbus uses only primary shredding, which does not require dust control.

Residue Handling and Disposal Systems

Four of the six plants produce some sluice pond wastewater in their ash disposal process (Table 11). Madison and Hooker dispose of ash without sluicing. At Columbus and Ames, bottom and flyash are sluiced to settling basins. The overflow at Columbus goes to a nearby wastewater treatment plant (WWTP). At Ames sluice water seeps out of the settling basin and could reach a nearby watercourse but the city will have completed a system for recylcing sluice water for use with new Unit #8 in early 1982. Rochester sluices only bottom ash and discharge water to a WWTP. Lakeland treats sluice water in their own wastewater treatment system at the power plant.

Both flyash and bottom ash (wet or dry) are disposed of at landfill sites for Madison, Hooker, Columbus and Rochester. Ames leaves the ash

TABLE 11

Ash Disposal at RDF/Coal Co-firing Facilities

	Ames	Columbus	Madison	HOOKER	LAKELAND	ROCHESTER
Ash Disposal Site	All ash sluiced to clay lined settling basin behind powerplant	Franklin Co. SLF S.E. Corner of intersection of I 270 & I 71	Bottom & Fly ash disposed of dry at ICKE Const. private L.F.	All ash landfilled at NEWCO waste site 1/4 mile from plant	All ash & F & D sludge are fixed in IU Conversion sys. ash fixing process & filled on pp property as low grade cement	Wet bottom ash & dry fly ash is hauled to the Huff Refuse Demolition site at Ogden, east of Rochester
Permitting Agency	IDEQ	OHEPA	WDNR	NYSDEC	Fla. DER comprehensive powerplant permit	NYSDEC
Remaining Life	N/A	2 yrs.	6 mos.	20 yrs.		N/A
Site Construction & groundwater level	Site is lined with local clay, overflow drains to the Skunk River	Site is clay lined & has leachate collection system. Ash is mixed with 10,000 cy/day of MSW. GWT is within 20' of surface w/o pumping	Site is almost full, located in old sand pit and marsh. No retarding lining groundwater is at base of site	Natural clay base on site, less than 5' to groundwater some leachate gets into storm drains	Fixed sludge in filled in low areas, groundwater is near surface but leaching data indicates fill material has low leaching potential	Site is old sand pit. No precautions taken to protect groundwater which is close to surface
Receiving Stream	Skunk River	Scioto is near landfill	Large lake in the area	Niagara River	Artificial marsh	
Sluice Water	Seeps to ground water or evaporates	ph adjusted and sent to nearby STP which discharges to Scioto River	No sluice water	No sluice water		Bottom ash settling pond discharges to the Van Lane WNTP which discharges to the Genesee River
Processing Plant Residual Disposal Site	Ames City SLF	Franklin Co. SLF	Dane Co. Vevona SLF	NEWCO Waste Inc. 1/4 mi. from Hooker	County SLF	Tantalo SLF-Seneca Falls, NY

in the existing settling basin and Lakeland combines FGD scrubber sludge and powerplant ash in an ash fixing system. The resulting "fixed" sludge is landfilled adjacent to the power plant.

The ash landfill sites for Madison and Rochester are construction/ demolition waste sites that offer no separation between waste and the groundwater table. These are both used on a yearly contract basis. The Madison ash site will only be in use until the end of 1981.

Processing plant residual is disposed of at city or county sanitary landfills in all six cases.

3. HEALTH AND ENVIRONMENTAL CONSIDERATIONS

LABOR REQUIREMENTS FOR RDF TECHNOLOGY

Labor information was collected from the six co-firing sites as reported in Table 12 .

TABLE 12

Labor Requirements for RDF Preparation and RDF/Coal Co-firing

	number of employees	
Site	RDF Preparation	RDF preparation and Power plant operation
Ames, IA	16.5	46.5
Madison, WI	13.0	120.0
Rochester, NY	132.0	NA *
Niagara Falls, NY	NA	110.0
Columbus, OH	NA	102.0
Lakeland, FL	NA	43.0

* NA = Information not available.

Labor Requirements for RDF Preparation

Work-power requirement for RDF preparation are summarized in Table 13 . The number of work-hours per day were calculated from the values listed in Table 12 according to the operating schemes of the specific sites. Heating values of the fuel produced, expressed in million BTUs per day, were calculated as 75% of the raw MSW BTU content (@ 4500 BTU/lb). Work-hours per million BTUs were calculated as the quotient of the work-hours per day and million BTUs per day.

These facilities differ according to the degree of processing involved with the RDF preparation, as discussed previously. The processing scheme at Rochester, NY is more involved than either the Ames, IA or the Madison, WI facilities, but the economies of scale of the large through-put operation at Rochester, NY results in work-hour requirements within the range of the Ames, IA and Madison, WI sites.

TABLE 13

RDF Preparation Labor Requirements

Process	Site	MSW (TPD)	Labor-hr/day	MM BTU/day	Labor-hr/MM BTU's
RDF Preparation	Ames	107 *	110	722	0.1524
		200 **	110	1,350	0.0815
	Madison	200	104	1,350	0.0770
		500	104	3,240	0.0321
	Rochester	2000	1,056	13,500	0.0782
				12,000	.0882

* = Actual operating through-put.
** = Design through-put.
*** = Based on the design specifications for the Rochester plant (66% of MSW mass is RDF @ 5000 BTU/lb.).

Labor Requirements for RDF Combustion

An analysis of work-hour requirements for the 5 RDF/coal co-firing plants for which data were made available shows that in spite of the differences in RDF processing in the two most common types of plants there does not seem to be large differences in work-hour requirements per million BTUs of heat input.

Retrofitted power plants like the Ames (200 TPD) and Madison (500 TPD) facilities, both of which have small RDF processing facilities when compared to the facilities at Columbus, OH (3000 TPD) and Hooker, Niagara Falls, NY (2200 TPD), show similar work hour requirements (Table 14) ranging from 0.0322 to 0.0538 HR/MM BTU heat input. This similarity may be explained as follows: First, the two retrofitted plants, Ames and Madison, burn a very small overall percentage of RDF (from 1.6 to 9.6%) in an older municipal utility plant with a low capacity factor. Such an arrangement is very labor intensive when compared to a new large scale utility boiler, such as the one at Lakeland, having a high capacity factor (Ames CF=20%, Madison CF=25%, Lakeland CF=65%). Second, plants designed primarily for waste disposal using a high-percent RDF, with multiple boiler designs and large RDF processing plants also pay a significant price in work-hour costs. To assure that MSW can always be processed and electricity or steam be produced without resorting to expensive alternate disposal methods or fuels, requires redundant, maintenance-intensive designs with relatively large operational and maintenance crews. Thus certain high capacity factor plants appear to have work-hours/MM BTU requirements as high as retrofitted plants with low capacity factors.

TABLE 14

Combined RDF Preparation and Power Plant Operation Labor Requirements

	PROCESSING	POWER	FUEL MIX % RDF					
SITE	PLT. TPD DESIGN	PLANT MW	WHEN COFIRING	% OF YR BTU INPUT	MANHRS/WK AVG.	MM BTU/WK YRLY AVG.	HR/MM BTU	COMMENTS
Ames	200 107 (a)	115	20	9.6(f)	1860	44.4E+3(f)	0.0419	115 MW rating includes new 65 MW coal/RDF unit not operating last year. BTU based on 1980 use of 35 MW coal/RDF unit. Also have 8 & 12 MW standby traveling grate units.
Madison	500 200(b)	200	15	1.6(f)	4800	96.7E+3(f)	0.0496	Madison is a peaking plt. w/100 MW coal/RDF and 100 MW of gas & oil. 9 boilers, 7 turbines.
Lakeland	300	564	10	2.4(g)	1720	54.12E+4(g)	0.00318	1-364 MW coal/RDF/oil and 2-100 MW oil units.
Hooker	2200	54(d)	100	85	4400	81.675E+3(e)	0.0538	Can burn 100% RDF to 100% coal in 2 traveling grate units to produce electricity or steam.
	1000(c)		100		4400	37.125E+3	0.1185	
Columbus	2000(h)	90	80	80	4080	84.375E+3(e)	0.0484	Designed for 80% RDF/20% coal in 6 traveling grate units with 3, 30 MW turbines.
	3000				4080	126.600E+3	0.0322	

(a) Actual averaged over the number of days operated in 1976 through 1978.
(b) RDF produced depends on available market. This 200 TPD reflects average demand over the days operated in 1980.
(c) Actual MSW processed during August 1981.
(d) An equal amount of steam capacity is available for use in chemical manufacturing.
(e) Projected, based on design MSW input x 0.75 to give BTU in RDF/day times 5 days/wk, 52 wk/yr.
(f) Based on BTU's used in 1980; includes coal, RDF, oil and gas.
(g) Based on 4920 hrs of 364 MW coal only; 2080 in coal/10% RDF and 200 MW oil only @ 35% capacity factor projected for 1982.
(h) 2000 TPD currently available; plant will be operational 1983. 3000 TPD maximum capacity.

The work hour and BTU input numbers for the Columbus, Lakeland, and Hooker facilities are projections, and the assumption was made that operations will be successful enough to achieve design predicted capacities. The projected figures for Columbus and Hooker do not approach those of the Lakeland facility (.0032 HR/MM BTU) which has a new large-scale single boiler design and a small RDF plant; a more labor efficient combination. This much lower HR/MM BTU requirement at Lakeland is impressive when it is noted that it includes flue gas desulfurization and a sludge fixing method of ash and scrubber sludge disposal with no wastewater discharge. This facility also has the capability to expand to two, eight-hour RDF processing shifts, and thus double the MSW processing and RDF co-firing capacity without significantly increasing work-hour requirements.

OCCUPATIONAL HAZARDS

The occupational health hazards in the fuel supply and energy conversion processes for co-firing RDF and coal include considerations of the injury and mortality rates arising from both RDF and coal supply systems. For the present study we assumed that the developing co-combustion technologies will probably approach an 80% coal, 20% RDF fuel ratio on an energy basis.

Coal, being the major fuel, will bring with it occupational health threats in proportion to its energy contribution. The coal cycle, including mining, cleaning, processing, transport, conversion and disposal has come under analysis in the health assessment program currently underway at Brookhaven National Laboratory by the Biomedical and Environmental Assessment Division (BEAD). The occupational health impacts of the coal cycle have been analyzed and reviewed in recent documents prepared by Samuel C. Morris and other team members at BEAD (12-14).

In projecting occupational health hazards from coal mining, which is the major contributor to mortality and morbidity of the coal cycle, Morris et al.(12) have considered important changes and trends in the mining industry which have become evident in recent years. Major factors influencing fatality and injury incidences are the Coal Mine Health and Safety Act of 1969 (CMHSA) and the downward trends in underground mine productivity. Although a steady decrease in fatality rates per work-hour in both underground and surface mining is apparent since CMHSA, no long-term improvement for the incidence of non-fatal disabling accidents underground is yet evident. The factors which influence this statistic have been discussed by Morris et al (12). Those investigators examined negative change in underground mining productivity in the last 15 years in the light of national coal target goals and the total influence lower productivity will have on gross mortality and morbidity figures. According to Morris et al (12), the decrease in productivity may be a transient phenomenon and the decreasing rates of mortality in deep and surface mines, as well as the decreasing rates of surface mine injuries will lead to much lower risk by the end of the century.

The diseases directly influenced by the deep mine environment, coal workers pneumoconiosis (simple and complicated) and chronic bronchitis, are projected to decrease with the lowering of mine dust levels under

CMSHA's influence. These projections are based principally on the recent work of Rockette (15). The dramatic reduction in anticipated death rate with lower mine dust levels is countered by the consideration that chronic respiratory disease exerts its morbidity influence during the entire worker's life, not just the working years. Excess Standard Mortality Ratios on stomach cancer, lung cancer, asthma, and tuberculosis among miners contribute to the final estimate of disease incidence.

The occupational health hazards shown in Table 15 for both coal and RDF fuels is based on the health effects data from coal as prepared by Morris (13), and the health hazards from RDF as perceived by the Ames Laboratory team.

Columns 1 and 2 of Table 15 display the coal mining and processing hazards on the basis of GW(e)/yr (13), an energy value equivalent to 3.4 MM tons of bituminous coal rated at 2.4 x 10^{+7} BTU/ton. The coal transport accident rates in columns 1 and 2 are based on 3.4 MM tons transported by each mode. Columns 3 and 4 represent, in the case of coal transport, the accident rate of the combined modes of truck, rail and barge at the mixture assumed by Morris et al. (12). The coal related accidents of columns 3 and 4 are multiplied by 0.80 to estimate coal's contribution to a 80/20 coal/RDF gigawatt year accident rate.

"Power Plant Accident" rates in Table 15 are not seen to differ significantly if refuse derived fuel (RDF) replaces 20% of the coal in the typical operational experience at Ames, Iowa, and Madison, Wisconsin. Basically, operations within the power plant, including number of personnel, do not change. The additional personnel required

TABLE 15

Occupational Health Effects - Coal/RDF Combustion Per GW(e)/yr

	Each Fuel Activity (a)		Deep/Surface (c) Coal Mix		Coal/RDF (d) 80/20	
	Deaths	Non Fatal (b)	Deaths	Non Fatal	Deaths	Non Fatal
Coal Mining						
Underground						
Accidents	1.7	170	0.73	73	0.58	58
Disease	0-0.2	0.1-5.0	0.09	.04-2	0.07	.03-1.6
Surface						
Accidents	.12	18.0	0.07	10	0.06	8
Coal Cleaning Accidents	0.06	3-5	0.06	3-5	.05	2-4
Coal Transport			0.223	3.44 (e)	0.178	2.75
Rail Accidents	0.014	1.1				
Barge	0.46	1.6				
Truck	1.2	20.				
Power Plant Accidents	0.13	5	0.13	5	0.13	5
Mun. Solid Waste						
Collection		1058 (f)				212 (i)
Transport	9.5	156 (g)			1.9	31
RDF Processing Accidents		91-252 (h)				18-50
Total			1.3	95-99	2.97	128-372

(a) Deaths and injuries are reported on the basis of 1 GW (e)/yr for each activity shown on the first column

(b) Injury incidence is "lost workday" cases consistent with Bureau of Labor Statistics data

(c) The fuel source is a mixture of 43% deep and 57% surface mined coal after Morris (13)

(d) The fuel source is a mix of 80% deep/surface coal and 20% refuse derived fuel (RDF)

(e) This death and injury incindence represents the average of 53% rail, 22% barge, and 11% truck (13)

(f) Derived from a data base prepared under EPAs Office of Solid Waste; Report SW-169.2 (1979) (17)

(g) Based on Madison, WI data of 4.96 miles per ton MSW and 9.06 x E+6 ton MSW per GW (e)/yr; then using National Safety Council 1979 data + 3.5 injuries per E+6 vehicle miles.

(h) Based on the surrogate industry "converted paper products", SIC2649 using BLS lost work days injuries for 1979 and the range of man hrs/MW energy equivalent experienced at operating RDF/coal sites

(i) See text

to prepare RDF fuel is assigned in Table 15 to the category "RDF Processing Accidents".

In Table 15, the accident rate in column 2 under "MSW collection" was obtained from an EPA report (16). The information in this report resulted from an extensive survey involving solid waste organizations who reported detailed descriptions of accidents, time lost, cost incurred, equipment and employee exposure and other operational data. The data base included details on over 12,000 injuries in a total exposure period exceeding 40 million person hours.

This EPA survey indicated that the risk of employee injury in solid waste collection was severe and exceeded the highest incidence for accidents in the BLS standard industrial code. The "Lost Workday Accident Rate" was reported as 23 per 200,000 work hours. The report, however, provided no data on the incidence of fatal accidents experienced by these workers. The accident incidence rate, published by the EPA, was used in Table 15 to estimate the expected injury rate for the collection of municipal solid waste (MSW) in amounts yielding refuse-derived fuel (RDF) equal to $8.16 \times 10^{+13}$ BTU thermal, the equivalent of 1 GW(e)/yr. The data for manpower requirements in the collection of muncipal solid waste was provided by the City of Madison, Wisconsin, the only coal/RDF co-firing site where these data were readily available. Similar data are not presently available from other cities, hence a range of work-power values per ton of MSW collected cannot be provided.

The non-fatal accident rate in column 2 for MSW collection was estimated as follows:

1. The "lost workday accident" rate for solid waste collection was 23/200,000 work hours (17).
2. The Madison, Wisconsin data for MSW collection was 1.0147 work hrs/ton collected.
3. The fuel value of MSW was equivalent to 9 MM BTU/ton ± 20%.
4. 1 GW(e)yr was equivalent to $8.16 \times 10^{+13}$ BTUs thermal.

Given these premises,

1. Then 1 GW(e)/yr requires ($8.16 \times 10^{+13}$ BTU)/$9 \times 10^{+6}$ BTU/ton) = 9.067MM tons MSW.
2. But 1.0147 work hrs per ton collected x 9.067MM tons = 9.2 MM work hrs/GW(e)/yr.
3. Thus, the incidence of "Lost Workday Accidents" per GW(e)/yr = 23 x 9.2 MM work hrs/0.2 MM work hrs = 1058.

The injury rate assignment for MSW collection may in fact be inappropriately credited to co-combustion technology because solid waste is collected whether it goes to a combustion site or a landfill. An alternative rate may be based on estimates of the transportation risk for delivery of the MSW fuel source as follows.

The Madison, Wisconsin data indicate transportation mileage of 4.96 miles/ton MSW. The total mileage for 9. MM tons MSW (1 GW(e)/yr equivalent) is 9. MM tons x 4.96 miles/ton = 45 MM miles. National Safety Council data (18) for 1979 indicate a commercial trucking accident rate of 0.21 deaths and 3.5 injuries per 10 million vehicle miles. Thus, the accident rate for transport of 1 GW(e)/yr MSW would be 9.5 fatalities and 156 injuries. This incidence rate is shown in columns 1 and 2 of Table 15 . Columns 5 and 6 represent only 20% of this rate since RDF contributes only 1/5 of the fuel input to 1 GW(e)/yr co-combustion. It is evident that although RDF contributes only 20% of the energy in co-firing, transportation of this portion of the fuel can account for almost two thirds of the occupational fatalaties and non-fatal accidents.

Since no data were available on RDF processing, the accident incidence rates in Table 15 were based on a surrogate industry, namely, "converted paper products", (SIC 2649). The "lost work day" injury incidence for this industry in the BLS report for 1979 (19) was 7.0 cases per 0.2 MM work hours. The RDF processing accident rate in column 2 was estimated by first calculating the work-hours per GW(e) ($8.16 \times 10^{+13}$ BTU) using the range of work-hours/MM BTU in Table 13 as follows:

(Madison) ($8.16 \times 10^{+13}$ BTU) x $0.0321/10^{+6}$ BTU = $2.62 \times 10^{+6}$ work-hours

(Rochester) ($8.16 \times 10^{+13}$ BTU) x $0.0882/10^{+6}$ BTU = $7.20 \times 10^{+6}$ work-hours

(Madison) Accidents/GW(e)/yr = ($7/0.2 \times 10^{+6}$ hrs) x ($2.62 \times 10^{+6}$ work-hours) = 91

(Rochester) Accidents/GW(e)/yr = ($7/0.2 \times 10^{+6}$ hours) x ($7.20 \times 10^{+6}$ work-hours) = 252.

The selected surrogate industry did not take into account unusual events that have occurred in the solid waste processing facilities, such as dust explosions. Approximately 100 of these explosions have been reported and the majority of these have occured at shredding-landfill operations (20,21). Ninety-five of these explosions have been documented by Zalosh (21), and Three of these 95 explosions resulted in injuries, none of which were fatal. In addition, Ahlberg and Boyko (22) have described three major and one minor explosion that occurred at the Ontario Center for Resource Recovery. No personal injuries resulted from these explosions.

Although the major concern over explosions has been centered on shredders, the only recorded death resulted from an explosion at the East Bridgewater, Mass., resource recovery plant in a cyclone which de-entrained the RDF (12). The cause remains unknown.

Most explosions in waste processing plants have been associated with flammable liquids or vapors within the shredder, or with dust formed during size reduction operations. Dust explosions have long been a problem in the milling and handling of grain. In the period from 1958 thru 1977, 54 explosions occurred in feed mills resulting in 22 deaths and 209 personal injuries (23). Similar concerns regarding explosions are related to facilities for preparing pulverized coal as a boiler fuel. Considerable technology currently exists for the control of shredder explosions or minimizing their effect. An ASTM Committee (E38.07; Health and Safety Aspects of Resource Recovery) is currently compiling explosion protection guidelines (20,21,24). These will include:

1. measures for upstream removal of flammable and explosive materials;
2. proper venting of shredders;
3. explosion detection and suppression systems;
4. isolation of personnel by use of barricades or blast mats.

Current technology appears to be capable of maintaining the personal risks associated with explosions at a level consistent with other industries.

Exposure to Pathogens

The health risks resulting from microbiological aerosols in municipal solid waste recovery facilities have been difficult to evaluate since few studies have attempted to demonstrate human health effects. There appears to be no significant epidemiological evidence to suggest that microbiological aerosols such as found in municipal solid waste (MSW) handling facilities pose a human health hazard. As a guide to potential health risks, studies at (i) wastewater treatment facilities, (ii) composting facilities, (iii) agricultural facilities and (iv) industrial facilities are of relevance. Pertinent studies at these facilities are reviewed below.

Although activated sludge and trickling filter plants (25) have been found to emit potentially hazardous microbiological aerosols containing *Escherichia coli*, *Aerobacter aerogenes*, coliforms, *Klebsiella*, *Proteus*, *Staphylococcus aureus*, *hemolytic streptococcus*, mycobacterium, coliphage and animal viruses, no correlation between specific organism levels and the incidence of disease has been determined. Clark et al (26), in a seroepidemiological study on 200 sewage treatment and maintenance workers in three metropolitan areas, failed to demonstrate any increased risk of infection due to parasites, bacteria, or viruses.

Olver (27) reported that Aspergillus fumigatus was readily isolated from compost piles (100 to 6.1 x 10^{+7} colony forming units per gram dry weight) and in air around the composting site, Clark et al (28) evaluated the results of clinical and serological findings of 173 workers at a sewage sludge composting facility. Of the 173 employees, one worker developed an ear infection caused by Aspergillus niger, and changes were also observed on the employee's chest X-ray. Lundholm and Rylander (29) have reported that four of 11 workers developed clinical symptoms of nausea, headache, and diarrhea at a compost plant processing both MSW and sludge. These authors suspected that the high levels of gram-negative bacteria (25,000 to 500,000 CFU/m^3) or endotoxins were responsible for the symptoms.

Dutkiewicz (31,32) reported results of a thorough study on agricultural facilities. Concentrations as high as 1.3 x 10^{+6} were found in grain handling areas; the predominant airborne microorganism was the gram negative bacteria Erwinia herbicola. Dutkiewicz examined the results of immunologic tests on 336 workers at grain plants, 550 rural inhabitants and 314 patients with different respiratory diseases. The results indicated that agricultural workers exposed to high levels of dust-borne bacteria showed a positive immunological response to the bacteria. Dutkiewicz concluded that the bacterial allergy was identified with asthma and that in an agricultural environment, bacterial agents may be responsible for allergic diseases. Lacey et al (30) reported that farmer's lung disease was caused by the repeated exposure to high levels of spores of thermophilic actinomycetes.

Salvaggio et al (33) reported that the sera of sugar cane workers showed a high percentage of precipitating antibodies to thermophilic actinomycetes growing in bagasse. These actinomycetes may cause the acute disease, bagassosis. Kleyn et al (34) described mushroom workers' lung disease which is similar to farmers' lung disease. Haglind et al (35) investigated the prevalence of byssinosis and chronic bronchitis in Swedish cotton mills. Of the 248 employees interviewed, 19% reported symptoms of light byssinosis. Haglind et al found a positive correlation between the incidence of byssinosis, the number of airborne viable gram-negative bacteria, and the dust level in the mills.

Results of a NIOSH (National Institute of Occupational Safety and Health) supported study at MSW recovery facilities was recently reported by Fletcher et al (36) as follows: S. aureus and K. pneumoniae were recovered as high as 10^3 to 10^4 CFU/m^3. Other organisms recovered were: Mycobacterium not tuberculosis, Nocardia spp., Streptomyces spp., Salmonella spp., Aspergillus fumigatus, and A. flavus. In the draft summary report of this NIOSH study, Mansdorf et al (37) reported on illnesses at five MSW handling facilities: (i) several cases of skin rashes occurred at facility B, with the number of employees varying between 20 and 60; the cause of the skin rashes was not stated, (ii) at facility C, one worker out of 61 reported an infection; the cause was not reported, (iii) at facility D, one worker out of 11 reported respiratory difficulty, (iv) at facility E, the number of employees varied between 75 and 96 employees; no illnesses were reported, and (v) at facility F there were no illnesses reported among 85 employees. Data were not available for facility A.

Levels of airborne microorganisms within municipal solid waste handling facilities vary dramatically as the preliminary reports by various investigators (38-39) and the work by the Ames Laboratory (40, 41) have shown. The levels of airborne organisms varied from 10^{+2} to 10^{+7} CFU/m^3. These levels were generally two to three orders of magnitude higher than those recovered at other locations, such as enclosed shopping malls and parks.

The level of airborne microorganisms has been found to vary considerably among locations inside MSW facilities. Duckett's report (42) indicated dramatic differences in counts between different sampling sites in the NCRR facility. Inside the processing area of the Ames MSWRS (43), the statistical mean of the log transform of counts of total aerobic bacteria and fungi collected with the Anderson impactor was $7.5 \times 10^{+4} \pm 2.6 \times 10^{+5}$ CFU/m^3. Levels of total aerobic bacteria and fungi collected with the impactor in the control room of the Atlas storage bin were similar to the levels found inside the processing area. Counts recovered from the air of the tipping floor and entryway were approximately one order of magnitude lower. Since air samples were collected before and after the installation of dust control equipment over the processing circuit, the effectiveness of the dust control equipment could be measured. The reduction in levels of total aerobes collected with the impactor inside the processing area of the Ames MSWRS was 82%. Levels of fungi, and of total and fecal coliforms collected were reduced 81, 48 and 63% respectively.

The level of airborne microorganisms varied with the status of facility operation. After the installation of dust control equipment and when the processing circuit was not operating in the Ames facility (43), total aerobes obtained with all glass impingers averaged 1.5 x 10^{+4} ± 5.2 x 10^{+4}. When the processing circuit was operating, impinger counts averaged 1.4 x 10^{+5} ± 6.6 x 10^{+5} CFU/m^3. Similarly, Duckett reported orders of magnitude differences in counts when the NCRR facility was processing solid waste and when it was not.

Counts of microorganisms indicated a seasonal periodicity. The highest levels of microorganisms were recovered from July through September and the lowest levels of microorganisms were recovered from January through March of each year.

In the Ames MSWR study (43), airborne fungi identified and counted during the period from July, 1978 through August, 1979 showed that Aspergillus spp. were the most prevalent fungi, with A. fumigatus and A. flavus occurring at a frequency of 100% and at levels between 10^{+3} and 10^{+4} CFU/m^3 A. fumigatus was the predominant species with A. flavus, A. nidulans or A. niger the other most predominant species. Species of Penicillium occurred frequently but at lower levels, 10^{+3} CFU/m^3. Opportunistic phycomycetes such as Absidia sp. and Mucor sp. were recovered at a lower frequency.

At the Ames MSW facility, microbiological types exhibited a high degree of variability between test runs. Of aerobic bacteria, 50-80% of the bacteria present were Bacillus spp., with Corynebacterium spp., Micrococcus spp., Staphylococcus spp., and Pediococcus spp. ranging from one to four percent.

In any air quality study, particle sizing information is important to determine potential respiratory tract penetration. Particle penetration (44) varies between individuals and with activity but generally lung penetration increases with a decrease in particle size down to 0.5 microns. The sizing distribution of viable particulates inside the processing area of the Ames MSWRS (43) was determined with the Anderson impactor. Forty four percent of the particles were collected on stages with a 50% effective cut-off diameter of less than 4.7 microns. Fungi were infrequently recovered on particles less than 2.1 microns but bacteria such as Staphylococcus aureus were regularly recovered on particles as small as 0.65 to 1.1 microns.

Assessment of the human health risks associated with microbiological aerosols at municipal solid waste processing facilities is difficult because of incalculable variables associated with human resistance and exposure routes, and the many unknowns relating to viability of the pathogens present. It is apparent that interpretation of microbiological air quality data must be done carefully. No microorganism or group of microorganisms have received acceptance as the indicator organisms for microbiological air pollution. No processing techniques for air samples of microorganisms have received acceptance as standard methods. Recently, ASTM subcommittee E38.07 voted to accept a "standard practice for sampling airborne microorganisms in and around municipal solid waste facilities". The standard procedures included in the ASTM practice were reviewed or developed at the Ames Laboratory. The precision of the sampling methodolgy for the practice was determined at the Ames Laboratory (41).

Interstudy comparisons are also complicated by other factors which must be considered in a health risk assessment, virulence of the microorganism and host susceptibility (45). Because a viable pathogenic organism is recovered from the air does not necessarily indicate the organism is capable of producing an infection or disease. The susceptibility of the host is also an important parameter in determining whether an infection will result from inhalation or ingestion of one or more microorganisms.

The results of the Ames study provide order-of-magnitude estimates of the numbers and types of bacteria and fungi that are disseminated in aerosols in a MSWRS in all seasons and during all stages of facility operations. Efforts to estimate inhalation doses of viable particulates remain to be made and compared to other studies. At this stage, only very general conclusions can be drawn, as follows: (i) during processing of MSW, particulates are generated which contain genera and species of microorganisms capable of upper and lower respiratory tract deposition; (ii) opportunistic bacteria and fungi are present in the air of a MSWRS; (iii) airborne microbiological types may vary because of the composition of MSW, processing activity at the facility, meteorological conditions, geographic location, and air sampling devices and sample processing techniques used. Furthermore, the following recommendations are warranted: (i) there is a need for continued surveillance of the health status of personnel in MSW handling facilities and a need for maintaining accurate medical records, (ii) the use of good hygienic practices should be encouraged (iii) the dust collection equipment should be kept in optimal working conditions and (iv) potential workers should be carefully examined for a history of health problems likely to be exacerbated by such workplace conditions.

PUBLIC AND ENVIRONMENTAL HAZARDS

Limitations of Available Data

Environmental emission studies of co-firing operations have been conducted and data published for only three different sites. Unfortunately, a combination of different operating conditions, and sampling and analytical problems has resulted in disappointingly small amount of useable data and an even smaller amount that has been verified at more than one site. For example, the data are not of sufficient quantity and quality to constitute a statistically valid data base. The need for such a statistically valid data base is even more apparent when the variations in types of boiler, their co-firing conditions, and the nature of the RDF fuel are considered.

Following is a brief site by site analysis of significant factors that may have affected data quality.

Maryland Correctional Institution

Densified RDF was co-fired in a relatively small, institutional stoker-fired boiler. This unit was operated at 30% of rated capacity, which brought boiler efficiencies down from a normal 75 to 80% range to 50% range. This is not a standard operating range and resulted in atypical ash compositions and mass flows (percentage of bottom ash vs. fly ash). Also, this unit did not have an ESP. Mechanical collectors exhibit different emission rates than ESPs.

City of Ames

Testing was conducted at Ames on units 5 & 6 (stoker fired units) and on unit #7 (suspension fired) after the installation of a dump grate. Changes in operation and firing techniques since the sampling on unit #7 was completed in 1978 leads to the conclusion that the data collected from this unit may not be representative of what is now a typical operating mode at the Ames processing & power plant. TSP measurements which were run after the 1978 tests on which trace element data was reported, showed a significant decrease in stack emissions while burning 18% RDF at 100% load. This change is possibly attributable to the moving of the RDF firing nozzles to below the coal firing nozzles. Further, a decrease in the lead content of fly ash from 1200 ppm to 600 ppm from 1978 to 1980 indicates that either improved operation of the RDF processing facility or changes in refuse (e.g., the new Iowa container deposit law) may have significantly affected the lead content of RDF.

Trace element analytical data provided on unit #7 stack particulate was taken from particulate filters only and did not include the pre-filter cyclone catch which was too small for analysis. This cyclone catch is known to be of a larger particle size. Because certain trace metals tend to be enriched on the smaller particles, the results probably overestimate the emission rates for certain volatile (Cd, Pb, Cr, Ar, etc.) trace metals.

St. Louis Union Electric

Some sampling locations chosen in the St. Louis study were less than optimum and violated standard EPA stack sampling criteria for obtaining representative stack samples of emissions. In addition, the trace element analyses data on stack samples was taken during coal/RDF firing at 110% or more of boiler load. The particulate emissions rates at these higher boiler loads were proportionately much higher than at 80% load amd decreased ESP performance is largely responsible for these increases. As a result, trace element data taken at these higher boiler loads may not be representative of day-to-day operation.

Emissions from RDF/Coal Co-firing Facilities

Halogen Emissions

The principle halides seen in stack emission tests are chlorides and fluorides. The latter arises principally from minerals and salts in the coal ash which can vary over two orders of magnitude among different coals (46). RDF does not contribute significantly to fluoride emissions when compared to coal alone as seen in Table 16. Chlorides occur in coal over a range of 0 to 0.5% (46) with typical values ranging from 0.02 to 0.15% by wt. (47); about one tenth to one one hundreths the sulfur content.

Compared to coal, RDF has a chloride content about an order of magnitude greater (47). Much of the ten-fold increase in emissions of chloride seen when RDF is burned (Table 16), results from vinyl chloride or similar plastics in the MSW.

Stack emissions tests at the Ames facility show most of the chlorine emitted as hydrochloric acid when RDF is burned. The fate of this HCL, ie. its reactions in the plume and the atmosphere is not known. Compared to the sulfate acid anion, which results from sulfur oxide emissions, HCL emissions from RDF/coal is about two orders of magnitude less per unit of energy (47) (Table 16).

Criteria Pollutants

Criteria pollutant emissions data are listed in Table 16 for tests conducted at the Ames, IA facility during 1976, 1977, 1978, and 1981. Also, some data are listed for test at Columbus, Oh, Wright Patterson AFB, and St. Louis, MO facilities.

The co-firing facilities projected to operate in 1990 were categorized as: (1) those designed for co-firing or operating according to the current NSPS (New Source Performance Standards); and (2) facilities modified for co-firing and complying with standards less stringent than NSPS. The total capacity of facilities designed to meet NSPS were estimated to range from 10,017 to 13,392 TPD in 1990. Also, the total design capacity of facilities retrofitted to co-fire RDF and coal would range from 9,417 to 12,792 TPD in 1990.

The criteria pollutant emissions from co-firing facilities designed to meet NSPS were assumed not to vary significantly from emissions of comparable facilities designed and operated as coal only plants.

The changes in emissions of criteria pollutants from RDF/coal facilities retrofitted for co-firing when compared to coal only firing are listed in Table 17 for the Ames, IA and St. Louis, MO facilities.

TABLE 16

Criteria Pollutant Emissions from RDF/Coal Co-firing (8,9,10,48,50)

Boiler	10^9 J/Hr Heat Input	% Load	Coal/RDF	Date	Units	SO_x as SO_2	NO_x as NO_2	TSP	Cl	F
Ames	334	80%	100/0	1978	g/SCM	6.83	0.89	0.21		
#7					g/s	265	34.6	8.0		
					g/mJ	2.93	0.381	0.09	0.0046	
#7		80%	80/20	1978	g/SCM	4.82	0.85	0.40		
					g/s	183	32.4	15.31		
					g/mJ	1.93	0.340	0.16	0.0403	
#7		80%	100/0	1981	g/SCM				0.0057	0.013
					g/s				0.28	0.63
					g/mJ				0.003	0.006
#7		80%	80/20	1981	g/SCM				0.11	0.014
					g/s				6.2	0.78
					g/mJ				0.050	0.006
#6		80%	100/0	1976	g/SCM	3.06	0.43	1.02		
					g/s	61	8.2	20		
					g/mJ	1.47	0.206	0.49	0.006	
#6			50/50	1976	g/SCM	1.52	0.31	1.78		
					g/s	33	6.6	38		
					g/mJ	0.79	0.162	0.93	0.088	
#5		80%	100/0	1977	g/SCM	3.82	0.33	1.58		
					g/s	61	5.2	25		
					g/mJ	1.96	0.167	0.80	0.013	
#5			50/50	1977	g/SCM	2.82	0.256	1.95		
					g/s	46	4.3	33		
					g/mJ	1.48	0.134	1.02	0.097	
Columbus	High s.		100/0		g/SCM	6.1	0.42		0.023	
Ohio	coal		80/20		g/SCM	3.1	0.36		0.059	
stoker-fired										
Wright			100/0		g/SCM	1.1	0.44			
Patterson					g/s	9.8	4.5			
AFB	densified									
stoker-fired	RDF		2:1 vol.		g/SCM	0.46	0.32			
					g/s	4.9	3.0			
St. Louis		90%	100/0		g/MJ	1.2	0.22	0.07		0.0015
					g/s					0.42
		110%	92/8		g/MJ	1.2	0.18	0.135		0.0025
					g/s					0.89

These data were derived from criteria pollutant emissions reported in Table 16 . Numerous factors influence the change in emissions when co-firing RDF and coal. The percent of RDF, type of coal, and type and efficiency of emission control device are among the most important factors.

Sulfur oxide emissions are reduced when co-firing RDF and coal due to the low sulfur content of RDF (usually less than 0.50% S) when compared to even low sulfur coal (16). The reductions of sulfur oxide emissions are greatest when high sulfur coal is displaced by RDF. Sulfur emission reductions of up to 46% were measured when co-firing 50% RDF with a mixture of Iowa and Wyoming coal (sulfur content 1.73%) when compared to Iowa/Wyoming coal alone (sulfur content 3.06%).

Nitrogen oxide emissions are, to a large degree, dependent upon the amount of excess air and temperature in the boiler. The data in Table 17 indicate a decrease of up to 20% in nitrogen oxide emissions when co-firing RDF and coal, as compared to coal only.

Total suspended particulate (TSP) emissions are dependent upon type of fuel, percent ash content of the fuel and type and efficiency of the emission control device. Table 17 shows that the largest absolute increase in TSP emissions were measured for the stoker fired units at Ames, which are equipped with low efficiency mechanical collectors. The suspension fired boilers at Ames and St. Louis are equipped with ESPs and as such have greater collection efficiency than the mechanical cyclone collectors. The absolute increase in TSP emissions from the suspension-fired boilers at Ames and St. Louis are considerably less than the increase at stoker-fired boilers (0.05 to 0.065 g/MJ for suspension-fired compared to 0.22 to 0.44 g/MJ for stoker-fired).

TABLE 17

Critieria Pollutant Emission Changes (RDF/Coal - Coal only)

SO_x (as SO_2)

			Emissions Change		Fuel		
		% RDF	g/MJ	%	(Coal/RDF) Sulfur	Coal Sulfur	% Change Sulfur
Stoker Fired	Ames #5	50%	-0.48	-24%	1.86%	3.46%	-45%
	Ames #6	50%	-0.68	-46%	1.73%	3.06%	-43%
Suspension Fired	Ames #7	20%	-1.00	-34%	2.30%	2.79%	-18%
	St. Louis	8%	0.0	0%	1.30%	1.45%	-10%

NO_x (as NO_2)

			Emissions Change		Fuel		
		% RDF	g/MJ	%	(Coal/RDF) Nitrogen	Coal Nitrogen	% Change Nitrogen
Stoker Fired	Ames #5	50%	-0.033	-20%	NA *	NA	NA
	AMES #6	50%	-0.044	-21%	NA	NA	NA
Suspension Fired	Ames #7	20%	-0.041	-11%	0.83%	1.00%	-17%
	St. Louis	8%	-0.04	-18%	1.43%	1.55%	-8%

Total Suspended Particulate

			Emissions Change		Fuel		
		% RDF	g/MJ	%	(Coal/RDF) Ash	Coal Ash	% Change Ash
Stoker Fired	Ames #5	50%	+0.22	+28%	13.29%	11.62%	+14%
	Ames #6	50%	+0.444	+90%	13.44%	11.73%	+15%
Suspension Fired	Ames #7	20%	+0.05	+55%	10.41%	9.74%	+7%
	St. Louis	8%	+0.065	+93%	8.20%	6.83%	+20%

* - Not Available.

The relative increase of TSP emissions for both the stoker fired and the suspension fired tests reported in Table 16 and and 17 shows nearly a two-fold increase when RDF replaces 10% to 50% of the coal.

For projecting the emissions in 1990 from coal fired boilers retrofitted for RDF co-firing with coal, the following assupmtions were made:

1. Projected design capacities to range from 9,400 to 12,800 TPD.
2. A 60% capacity factor to yield 2.06 to 2.80 million tons per year.
3. A 75% conversion of the incoming BTUs (@ 4500 BTUs/lb) to RDF fuel yeild $1.4 \times 10^{+7}$ to $1.89 \times 10^{+7}$ million BTUs (MM BTUs).
4. A coal/RDF mixture of 80% coal/ 20% RDF yield a total number of BTUs ranging from $7.0 \times 10^{+7}$ to $9.45 \times 10^{+7}$ million BTUs (0.9-1.2 GW(e)/yr).
5. A decremental range of 0.0 to -2.33 lbs/MM BTUs of sulfur oxide emissions change (as listed in Table 17) to yield a sulfur oxide emission decrease of 0.0 to 110,092 tons by 1990.
6. A range of NO_x emission changes as listed in Table 17, to yield a decrease of NO^x emission by 2,695 to 4,820 tons per year.
7. A TSP emission increase by 4,060 to 48,384 per year.

Criteria Pollutant Health Considerations

The national health impact of air emissions arising from RDF/Coal co-combustion facilties is related to the change that this technology produces in the criteria pollutant budget. In the case of sulfur dioxide, the mortality figures are based on sulfate as the surrogate compound. As indicated above, employing refuse-derived fuel as an energy source has a potential for reducing sulfur dioxide emissions in the range of 0 to 100,000 tons per year. When compared to the 30,000,000 metric tons per year resulting from all emission sources, this is less than 0.4%. The effect of this 0.4% on the range of 25 to 50 micrograms of sulfate per cubic meter found in 32 urban sites is to reduce it from roughly 0.2 to 0.3 micrograms per cubic meter.

The mortality rate from sulfate aerosol as interpreted by both Wilson and Hamilton (7,49) from the original data of Lave and Seskin is roughly 3.5 deaths per 10^5 persons per microgram of sulfate. A straight extrapolation of 0.2 to 0.3 micrograms sulfate per cubic meter decrease due to RDF firing would reduce the mortality figure in the area of one death per 10^5 persons.

In the case of total suspended particulates (TSP), the change due to RDF firing with coal is expected to increase in the range of 4,000 to 48,000 tons per year by 1990. This represents less than 0.4% of TSP emissions nationally from all sources. The characteristics such as particle size, levels of toxic organic matter and trace element content influence the degree of health hazard. These are considerations which cannot be evaluated in the absence of adequate data, hence it is not possible to characterize the health impacts of the small fraction likely to contribute to national ambient levels.

In the case of nitrogen oxides, the change in emission budgets resulting from RDF/Coal firing ranges from a decrease of 2700 to 4820 tons/year. This decrease represents a range of 0.01% to 0.02% change in the national nitrogen oxide emission budget and is, for all purposes, insignificant. In summary, then, the technology of RDF/Coal combustion in the future indicates an immeasurable effect of criteria pollutants when compared to epidemiological data currently available.

Trace Element Emissions

The emission of potentially toxic trace elements from the co-combustion of coal and RDF depends on the concentration of these elements in the fuel mixture, the nature of the combustion process, the characteristics of the boilers fuel feed, and the particulate collectors employed in emission control.

In the case of the refuse derived fuel employed in this process, Table 18 indicates the enrichment relative to coal of certain of these elements. Lead, zinc, chromium and copper are approximately 30 times more concentrated in RDF than in coal, while antimony, manganese, molybdenum and tin are two to three times as concentrated. On the other hand, certain elements such as arsenic, boron, beryllium, cobalt, nickel and vanadium are found in lower concentrations in RDF than in coal.

Factors which influence the stack emissions of toxic trace elements are related to the percent of the total ash which reaches the stack, the particle size of the stack ash and the efficiency of the collection device. In addition to these general factors, each trace element has physical-chemical characteristics which influences its route of passage to bottom ash, fly ash and stack.

The upper limit or "worst case" toxic trace element emissions is evident in the incineration of municipal solid waste. Greenberg et al (16) have indicated in their studies on three incinerators located in

TABLE 18

Concentrations of Elements in Coal and the Combustible Fraction of Urban Refuse (Typical Values in Parentheses)(46)

Major Elements (conc. in pct.)	Urban Refuse	Coal
Aluminum	0.3-1.6 (1.1)	.1-2.0 (.14)
Chlorine	.3-1.5 (0.4)	0-.1 (.01)
Iron	.05-.7 (0.2)	.01-1.0 (0.1)
Sulfur	.1-.3 (0.2)	1.-2.5 (1.2)
Zinc	.04-.8 (0.1)	.001-.10 (.003)
Minor Elements (conc. in ppm)		
Antimony	20-80 (45)	1-1, 800 (20)
Arsenic	LT 3	1-70 (45)
Barium	35-100 (50)	20-1,600 (80)
Beryllium	LT 2	.4-90 (25)
Cadmium	3-70 (15)	.2-5 (0.5)
Chromium	10-175 (30)	.3-400 (1)
Cobalt	2-17 (5)	.3-135 (25)
Copper	30-450 (195)	1-180 (7)
Lead	110-1,300 (230)	1-100 (7)
Manganese	50-480 (85)	20-240 (25)
Mercury	-	.07-.6 (.15)
Nickel	4-50 (15)	3-900 (65)
Silver	.1-16 (2)	.01-8 (0.2)
Vanadium	5-70 (15)	2-80 (20)

the Washington, DC area what the range of emission rates are for toxic elements such as lead, cadmium, zinc, copper, and others. They indicate in their report that the ground concentrations in the vicinity of these incinerators can reach levels which can be considered hazardous to human health. Part of their explanation for the high level of emissions is the unusually high stack gas temperatures which maintain many of these elements in a volatilized form and favor the emissions by way of the stack to that of precipitation as bottom ash or collection in fly ash.

Table 19 shows data obtained for the suspension fired boiler at the Ames powerplant. From these data it is evident that there is a marked increase in the percent of bottom ash when the RDF/coal mixture is fired, and at the same time, a slight decrease in the percent of fly ash. It is apparent, however, that the percentage decrease in fly ash is not sufficient to overcome the effect of total ash increase with the RDF/Coal mixture. The ultimate important consideration is the absolute increase in stack ash which almost doubles when coal/RDF is burned under the same boiler load.

Although the data are limited, an estimate was made in Table 19 of the ash distribution if the fuel were 100% RDF. If this were the case, it is evident that stack ash loadings would increase five or six times over that of coal alone. This is an important consideration in retrofitting coal fired plants for RDF combustion in as much as the existing collectors, whether they are cyclones or ESPs, will be likely overloaded with simply moderate percentages of RDF. It should be emphasized that on a BTU basis, the contribution of ash by RDF is more than twice that of coal.

TABLE 19

Ash Distribution of Ames Unit #7 (kg/HR)

	Coal*** only A	%	80% Coal/20% RDF*** B	%	Estimate of Ash if 100% RDF* C	%
Bottom Ash	64.4	6.5	218	14.6	832.4	23.7
Fly Ash**	889.7	90.5	1220	82.0	2540	73.2
Stack Ash	27.2	2.8	50.7	3.4	144.7	4.1
Total	983.3	100	1488.7	100	3517	100
Ash Input in Fuel	1206.1		1605.3		3337	

* C=.(B-.8A)/.20
** ESP collector
*** Reference (10)

Changes in the particle size distributions of the fly ash when it reaches the ESP or cyclone collector is another very important consideration. In the case of cyclone collectors, as reported by Radian, (46) the collection efficiency for particle sizes of ten microns is 85%, but less than 20% for particle sizes of one micron, and less than 5% for particles smaller than 0.5 microns.

While the efficiency of electrostatic precipitators is much better than cyclones, they also have a dropoff in the small size range. In one report where coal was the fuel, a bi-phasic change in collector efficiency was noted (46). Above two microns an excess of 99% collection efficiency was observed. Below two microns down to 0.4 microns, the efficiency of collection dropped from 98 to 90%. It then increased between 0.4 microns to 0.1 micron, where it reached 97% efficiency. At sizes lower than 0.1 micron down to 0.01 micron, the efficiency once again dropped from 97 to 90%.

The particulate sizes of stack dust when RDF fuel was added to coal were measured at the St. Louis Meremac powerplant (50). No effect on the particulate size range distribution when compared to coal only firing could be discerned statistically; however, changes with excess boiler loads did occur. At this time no evidence, other than the St. Louis data are available.

Studies at the St. Louis operation included efforts to evaluate electrostatic precipitator performance. Characteristics which influence ESP efficiency such as the resistivity of particulate and the maximum ESP operating input voltage were monitored. While some changes were noted, no conclusive trends in ESP performance could be seen in comparing coal versus RDF/coal mixtures. It was observed, however, that collection efficiencies for small particle sizes between 0.01 and 0.1 micron seemed to be more efficient for coal than for the RDF mixtures.

At equivalent energy inputs, the RDF/coal mixtures produced an increase in the effluent gas flow rate over that of coal alone. One of the principle parameters limiting ESP performance is its design flow rate. Therefore, it is evident that this consideration is important in installing ESP for RDF/coal combusiton, and also for retrofitting existing coal boilers.

As summarized by Radian (47), the role of particle size in emissions of potentially toxic trace elements becomes more important in light of observations which indicate that: (i) a much higher percentage of volatile trace elements are found on small particles; and (ii) surface enrichment of volatile trace element occurs because of their tendency to condense on stack particles. The larger surface area of small particles increases the probability of enrichment per unit weight. In their studies on particulate emissions from incinerators, Greenburg et al (16) estimated that 75% of the volatiles trace element mass occurred on particles less than two microns in diameter, well within the respirable range.

At the St. Louis plant under coal/RDF firing, analysis of the particulate load in the ESP outlet duct with the Anderson sampler showed that certain volatile trace elements were distributed largely in the final filter stage, which captures particle sizes less than 0.3 microns. This filter stage accounted for only 1 to 3% of the particulate mass, but as much as 45% of the total particulate cadmium. Other elements found enriched at this stage were lead at 13% and copper at 70%. Lead, however, seems to be more evenly distributed on the various Anderson stages. The ESP collector efficiency for particles in the 0.4 micron range under RDF/coal combustion was seen to range from 25 to 70%, depending on boiler load. The average ESP collection efficiency for total particulate varied from 90 to 98%.

The evidence demonstrates that many volatile trace elements are concentrated in small particulates which have become highly enriched, and that, to a significant degree, these small particles may escape the collection device. This is especially true of cyclones which have very low efficiencies for small particles compared to electrostatic precipitators. Thus a relatively high percentage of the volatile trace elements in the fuel may escape emission controls.

Sampling and analytical procedures directed to mass balance studies provide one means of accounting for elemental losses, or at least directing attention to points in the combustion process where these elements may escape. The only reported studies of this nature carried out at coal/RDF combustion conditions were those done at the St. Louis operation. Unfortunately, the data are incomplete and the mass balance results are poor.

Data on a number of key trace elements derived from the St. Louis study (50) are shown in Table 20 . Elemental flows in grams per hour are compared when coal and coal/RDF mixtures are burned. Except for the fact that fly ash accounts for a larger percentage of total ash than bottom ash, it is difficult to see any consistent pattern within or between elements. This is probably due to the very poor recovery observed in most cases.

TABLE 20

Trace Element Emissions Corrected for Recovery and Projected to 100% RDF*

	Stack Emissions with 92/8 Coal-RDF Mixture			
	g/hr 92/8	Mass Balance Recovery %	g/hr 100% Recovery of 92/8	g/hr 100% Recovery 100% RDF
Pb	196	60	327	3525
Zn	300	49	612	5467
Cr	58.6	48	122	1022
V	56	59	95	110
Se	12.9	51	26	48
Cu	45.6	23	200	2581
Cd	8.8	27	32.6	241

* based on data from St. Louis report (50)

In Table 20 the percentage of trace elements in fuel which are released with the stack particulate ranges from 1 to 20%. In the case of the more toxic elements, cadmium, chromium and lead, when fired under coal/RDF conditions, the stack particulate emissions are recorded as only 3, 1, and 4% respectively. However, the low recovery on mass balance suggests that these numbers might be considerably higher.

The ratio of fly ash (g/hr) to stack ash (g/hr) during coal firing is about the same when the RDF/coal mixture is fired, except in the case of cadmium. This change in the fly ash to stack particulate ratio from coal to RDF/coal firing is accompanied by a marked drop in the percent of total recovery of cadmium. As the table shows, with coal combustion alone recovery is 80%, whereas coal/RDF recovery is only 24%. It might be suspected that part of the low recovery is the failure to measure all of the cadmium emitted in the stack. This is suggested in the previously discussed Anderson sampler data taken during tests at the St. Louis plant which shows that almost one half of the cadmium appeared on the final filter in the less than 0.3 micron particle range. The low ESP collection efficiency of roughly 50% for particle sizes in the range of 0.1 to 0.3 microns reinforces this conclusion (50).

Using the data in Table 20 for cadmium, we attempt to rationalize corrections for the low mass balance recovery in the following manner. First, in the stack to fly ash particulate ratio, RDF/coal firing is adjusted to that found in firing coal alone. Adjusting the coal/RDF ratio of 4.8 to 2.7 adds an additional 3.8 grams per hour to the stack particulate under Coal/RDF firing. This raises the total recovery for Coal/RDF cadmium from 24 to 27%. Next, the 27% recovery factor is adjusted to 100% recovery by multiplying the bottom ash, fly ash and stack particulate g/hr values by 100/27. This results in a stack particulate of 32.6 grams per hour output.

Assuming constant ESP performance, we have attempted to estimate emissions of the important toxic trace elements if 100% RDF fuel were to be burned under similar firing conditions. The estimated RDF input in g/hr required to maintain 100% boiler load is multiplied by the trace element concentrations which yields TE input in g/hr. This value for each TE is multiplied by the percent of each TE's input seen to exit as stack particulate; values obtained from coal/RDF firing data. The last column in Table 20 reports this hypothetical value.

Evaluating the toxic trace element emissions in an RDF/coal co-fired boiler under conditions of 100% RDF are important inasmuch as the Hooker plant at Niagara Falls, NY has the option to fire 100% RDF for a major portion of the year.

Health Considerations of Trace Element Emissions from Co-firing

Potential exposure at ground levels to toxic trace elements from stack emissions of these co-firing facilities eventually depends on the total number of sites emitting particulates and the size of the individual plants. In projecting RDF/Coal co-firing technologies, we have made certain assumptions:

1. That the total megawatt output from RDF fuel is limited by the municipal solid waste available.

2. That the average co-firing will result in an 80% coal/20% RDF mixture;
3. That the typical upper limit in size of individual RDF/Coal plants is based on a population-limiting factor, as well as cost effective radii for transporting the limiting fuel supply.
4. The trace element composition of the present municipal solid waste will probably not change although new container deposit legislation can effectively lower lead, zinc and cadmium levels.

The emission factors used in the models herein are based on limited current experience at very few sites. Table 21 summarizes trace element emission data and projects dilution from dispersion modeling, also;

1. It includes trace element emission data in micrograms per cubic meter from those sites studied. The trace element parameter of micrograms per cubic meter is relatively constant within a constant fuel concentration level and can be employed in modeling emissions from plants of different sizes. Emission data from plant studies have been adjusted to account for low recovery during limited mass balance studies and also to correct for low collector efficiency of cyclone and electrostatic precipitators.
2. The climatalogical dispersion model (Appendix A) provides a stack dilution factor used to predict trace element levels at receptor sites showing maximum annual concentrations. Dilution factors are also provided from a more conservative urban screening model.

These model receptor predictions are then compared to urban air levels and to recommended maximum levels using multi media environmental goals (AMEGS) from EPA (72).

TABLE 21

Trace Element Emissions (ug/m^3) from Coal/RDF Combustion Sites

---

Site Collector Coal/RDF	(a,b) Ames (ESP) 100%	80/20	(Cyclone) 100/0	50/50	(c) St. Louis Suspension (ESP) 100/0	92/8	(d) St. Louis 100% Recovery 100% RDF	(e) AMEGs	Dilution to Meet AMEGs	Air Model Dilution "Screen"	CDMQC	(f) Urban Air
Element												
Pb	65	854	3120	14,762	82	343	6169	0.4	$4x10^{-4}$	$2-4x10^{-5}$	$7x10^{-7}$	0.8
Zn	454	1890	5316	18,718	151	517	9421	12	$6.4x10^{-4}$			0.5
Fe			26,700	15,500				12	$5.0x10^{-4}$			1.5
Be					1.2			0.005	$10x10^{-4}$			$3x10^{-4}$
Ba					402	497		1.2	$2.4x10^{-4}$			
CR	21	46	232	572	128	108	1884	0.12	$2.0x10^{-4}$			0.006
V					97	111	56	1.2	$1x10^{-2}$			0.02
Se	9	14	27	31	55	24	24	0.5	$1x10^{-2}$			0.004
Hg	5.0	9.4						0.12	$1x10^{-2}$			
Cu	15	42			32	88	5047	0.2	$2.3x10^{-3}$			0.02
Cd					4.8		271	0.12	$1.3x10^{-2}$			0.01
Ni	31	46						1	$2.0x10^{-2}$			0.01
Mn								12				0.03
As	32	36			33	20		1.2	$2.0x10^{-2}$			0.02
Sb					29	5		1.2	$2.0x10^{-2}$			0.02
B(a)P (g)					0.049-0.128		0.128	0.02	$1x10^{-1}$		$1.3x10^{-6}$	0.3-30.0.

(a) Reference (10)

(b) Reference (9)

(c) Reference (50)

(d) Derivation described in text

(e) AMEGS were formerly "Estimated Permissible Concentrations" (EPA)

(f) Reference (46)

(g) Data are after Hooker (108 MW) dispersion model and BaP emission of 15-40 ug/mm BTU.

The dilution required of each trace element to reach AMEG levels from the observed highest stack emission concentrations is shown in the ninth column of Table 21. Lead, zinc, iron, and chromium require between three and four orders of magnitude dilution, with berillium, barium, and copper somewhat less. Of these high dilution elements, iron is the only one showing reduced emissions when RDF is added to the fuel.

The question as to whether or not stack dilution factors will be sufficient to meet the AMEG dilution required is evident from the air model dilution factors under "screen"(51) and CDMQC (Climatological Dispersion Model). The more conservative screen dilution factor exceeds the required AMEG dilution by an order of magnitude in the case of the largest emission factor shown for each element. The CDMQC dilution factor is an additional order of magnitude greater. As shown in Table 21, the Pb and Zn stack emissions are approximately 30 times greater for the Ames cyclone equipped facility than for the ESP equipped facility. When comparing the Ames ESP to the St. Louis ESP, emissions of these elements are within a factor of three of one another.

When the St. Louis emission data are corrected for recovery and adjusted to 100% RDF combustion (see Table 20), emissions of lead, copper, cadmium, and chromium would require the greatest dilution to match the AMEG ambient air level. The dilution required in the case of chromium approaches the conservative dilution factor seen under the "screen" air model.

It can be seen that anticipated emissions from co-firng power plants which employ electrostatic precipitators are well within the non-hazardous range. On the other hand, power plants employing cyclone or multicyclone mechanical collectors, while they will probably be within safe levels, should be monitored when RDF fuel values indicate unusually high levels of toxic elements, particularly those of lead, zinc, iron, copper and cadmium. To summarize, then, trace element emissions do not appear to exceed AMEG levels and consequently we have not employed biological health models such as TERMOD (52).

Organic Emissions from Coal/RDF Combustion

The emergence of coal and refuse as an alternative fuel has enhanced the need for data on organic emissions from their co-combustion. Tabulation of the available data on the current knowledge of organic emissions is very sparse. Furthermore, the techniques of sampling and analysis lack replication and precision, making a large degree of uncertainty characteristic of this information. The organic compounds reported in literature from 1964 through the summer of 1981 on coal combustion, co-combustion with RDF, and mass incineration have been summarized by Junk (53).

In 1964, Hangebrauck et al. (54) appeared to be the first to have recognized the need for stack emission data for specific organic compounds. Coal, oil and natural gas fuels were investigated. Data from commercial, municipal and open refuse burning were also reported. The PAH emissions included benzo(a)anthracene and benzo(a)pyrene, both recognized carcinogens. Other compounds such as formaldehyde and aliphatic hydrocarbons were also detected.

In 1966, Diehl et al. (55) studied the emission of PAH from coal-fired installations. They concluded that: (i) the PAH concentrations in flue gases from coal combustion can be highly variable and this variation cannot normally be related to identifiable operating parameters; (ii) the larger installations emit as much or more of the PAH as do smaller ones and this emission rate is a function of higher fuel input and larger volumes of flue gas produced per unit time; (iii) the operating variables may have a greater influence on the concentration of PAH in the flue gas than do the size or the design of the coal-burning unit.

In 1974, a study by Herman (56) provided quantitative data for a number of PAH emitted from coal-fired power plants. He also compared several sampling methods for PAH and polychlorinated biphenyls (PCB). In 1975, the organic compounds in stack emissions, on fly ash and on grate ash were analyzed by Cowherd et al. (57). Three PAH, 7,12-dimethylbenzo(a)anthracene, benzo(a)pyrene, and 3-methylcholanthrene, and several PCB isomers were detected and quantitative data were reported. The distribution of PCB isomers was similar to Aroclor 1260 indicating the presence of seven major components (58). The PCB were detected in both the grate and fly ash. The average amount ranged from 0.02 to 0.07 ug/g. No PCB were detected in the coal fuel. Although this investigation (57) included the sampling and analysis of several waste streams, it was limited to the detection of carcinogenic PAH and to the detection and quantitation of PCB.

The studies on the organic emissions from the combustion of coal reveal that: (i) one hundred and nine specific compounds have been identified; (ii) the emphasis on PAH has distorted the distribution of identified compounds; and (iii) quantitative data for specific compounds other than PAH and PCB are almost non-existent.

The synthetic organic waste content of refuse raises the question on the nature of organic emissions when refuse and other similar waste materials are incinerated. Boettner et al. (59) in 1973 reported emissions from the incineration of over a dozen commercial plastics and the natural products, wood and wool. Under conditions of incomplete combustion, a large number of products, including straight-chain saturated, unsaturated, aromatic, polycyclic and heterocyclic hydrocarbons, in addition to hydrogen chloride, sulfur dioxide, cyanides, ammonia and nitrogen oxides were produced. By 1974 much attention was being focused on the environmental fate of PCB (56,60,61). This attention made the report by Hermann (56) especially noteworthy because sampling procedures for both PCB and PAH from stationary sources were evaluated. State of the art sampling and analytical methodologies were reviewed. Those judged to be best were used for the determination of the emission of PCB and PAH from incinerators, from power plants, from trash and tire burning, and from copper wire insulation plants.

The incineration products of some plastics produced several classes of organic compounds, including PAH, aromatic, aliphatic and halogenated compounds(62). Studies of a municipal incinerator showed PAH levels on fly ash to be an order of magnitude higher than in the stack emissions. The amounts present in the stack emissions were another order of magnitude greater than that present in the waste water(63).

Developing concerns over the toxicity of dioxins were heightened when the formation of PCDD and PCDF during the combustion of a formulation of 2,4,5-trichlorophenoxyacetic acid was reported (64,65). The highly toxic 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) was identified. Ahling et al.(64) concluded that PCDD and PCDF could form under certain combustion conditions. In the same year, Olie et al.(66) and Olie and Hutzinger (67) reported the detection of PCDD and PCDF in the fly ash and in the stack gases of municipal incinerators. These reports reflect the advances of GC/MS systems for the detection of organohalogen compounds. The authors also identified several chlorinated phenols in the fly ash and the stack gases. These chlorophenols may have been the precursors to the PCDD formed during incineration. Also in 1978, the occurrence of PCDD isomers in incinerator fly ash was reported. High resolution GC was used for the separation of more than thirty individual PCDD isomers. However, the highly toxic isomers such as the 2,3,7,8-tetra-CDD, the 1,2,3,7,8-penta-CDD, the 1,2,3,6,7,8- and the 1,2,3,7,8,9-hexa-CDD were the only minor constituents.

In the case of coal/refuse combustion, the few reports (8, 68,69,70) available reflect the limited studies of the organic emissions during the combustion of coal/refuse mixtures. In 1978, a report by Vick et al.(69) included identification and quantitation of organic materials in stack emissions and on fly ash and grate ash. Sixty-two organic compounds were identified in those emissions from a power plant which burned coal combined with RDF. No gross differences in the types and the amounts of the organic emissions were observed when coal alone or coal/refuse mixtures were used as the fuels.

The compounds which have been identified in the emissions from coal/RDF combustion are listed in Table 22 . In those cases where quantitative data are available, the maximum amounts observed in the stack emission (ng/m^3) or the fly ash (ng/g) are tabulated.

Polycyclic organic matter arise from a large range of combustion sources, including open burning of biomass and controlled combustion in mobile and stationary sources. The National Academy of Sciences (1972) estimated the following emissions of POM's from various sources as follows:

1. Heat and power production sources - 500 tons per year.
2. Refuse burning - 600 tons per year.
3. Coke production - 200 tons per year.
4. Motor vehicle sources - 20 tons per year.

Although polycyclic organic matter includes a wide range of organic compounds, the polycylic aromatic hydrocarbons (PAH) have drawn the most attention, and specifically, the compound benzo(a)pyrene, because of its dominant nature in the combustion process, and particularly because of its high carcinogenic potentional. Benzo(a)pyrene has appeared in the literature more frequently than any other compound with respect to cancer-related studies. The rate of production of benzo(a)pyrene from various combustion processes varies over a wide range of emission factors. The amount of B(a)P produced per unit of heat is indicated in Table 23 taken from the NAS 1972 report (71). It is evident, for example, that the emission from residential furnaces produces almost ten times as much B(a)P as all other emissions from heat and power sources. It is interesting that coal-fired power plants which generate the

TABLE 22

Organic Emissions from Coal/RDF Combustion (8,68-70)

Polycyclic Aromatics	Maximum Amount(a)	Fly Ash	Stack Emission
Benzo(c)phenanthrene		*	*
Benzo(a)pyrene		*	*
Chrysene	0.5 ng/m3	*	*
Dibenz(a,h)anthracene		*	*
7,12-Dimethylbenzo(a)anthracene		*	*
Fluoranthene	2 ng/m3	*	*
Fluorene	4 ng/g	*	
3-Methylcholanthrene		*	*
Phenanthrene	1 ng/m3	*	*
Pyrene	0.5 ng/m3	*	*
Aromatics			
Biphenyl		*	
t-Butylbenzene			*
Toluene		*	
o-Xylene		*	*
m-Xylene		*	*
p-Xylene		*	*
N,O,S,P Compounds			
Dibenzo(c,g)carbazole		*	*
Dibenzofuran		*	*
Diphenylamine		*	*
Tricresylphosphate(b)		*	
Dibenzofuran		*	*
Diphenylamine		*	*
Tricresylphosphate(b)		*	
Triphenylphosphate		*	*
Hydroyl Compounds			
6-t-Butyl-o-cresol			*
p-t-Butylphenol			*
Propylphenol(b)			*

TABLE 22 . (continued)

Polycyclic Aromatics	Maximum Amount(a)	Fly Ash	Stack Emission
Aliiphatics			
Dimethylcyclohexane(b)			*
Docosane		*	*
Dotriacontane		*	*
Eicosane		*	*
Ethane			*
Heneicosane		*	*
Heptadecane		*	*
Hexadecane		*	*
Hexatriacontane		*	*
Methane			*
Nonadecane		*	*
Octacosane		*	*
Octadecane		*	*
Octatriacontane		*	*
Pentacosane		*	*
Tetracontane		*	
Tetracosane		*	*
Triacontane		*	*
Tricosane		*	*
Trimethylcyclohexane(b)		*	
Carbonyl Compounds			
Butylphthalylbutylglycolate		*	
Decanoic acid		*	
Dibutylphthalate		*	*
Dicyclohexylphthalate		*	
Di-(2-ethylhexyl)-adipate		*	
Di-(2-ethylhexyl)-phthalate		*	*
Diethylphthalate		*	
Diisobutylphthalate		*	
Diphenylphthalate		*	
9-Fluorenone		*	*
Lauric acid		*	
Myristic acid		*	
Oleic acid		*	
Palmitic acid		*	
Phthalic acid		*	*
Stearic acid		*	

TABLE 22 . (continued)

Polycyclic Aromatics	Maximum Amount(a)	Fly Ash	Stack Emission
Halogenated Compounds			
Aroclor 1254	25 ng/m^3	*	*
2,2-Dichlorobiphenyl		*	*
Dichlorophenol*	5 ng/g	*	*
Hexachlorobenzene		*	*
Hexachlorobiphenyl	2 ng/m^3	*	*
Pentachlorobiphenyl	1 ng/m^3	*	*
Pentachlorophenol		*	
Tetrachlorobiphenyl		*	*
Trichlorophenol		*	*

(a) Total gas chromatographable organic matter emitted form the stack described in references (69) and (70) is estimated to be no more than 420 ug/m^3. Most all of this material is composed of hydrocarbons which are aliphatic.

(b) Isomer not specified.

largest amount of heat contribute the smallest amount of B(a)P emissions. This wide range of B(a)P emissions per unit of heat input is explained largely on the basis of combustion efficiency, with starved air combustion processes generating the largest amount of benzo(a)pyrene. The emission of B(a)P from refuse burning techniques is indicated in Table 24 from the NAS report (71). These estimates indicate that municipal incinerators produce only a fraction of one percent of all B(a)P generated through refuse burning, the largest sources being refuse fires and forest and agricultural open burning.

In summary, it is evident that power generation sources and refuse combustion account for only a very small percentage of the benzo(a)pyrene released and inventoried in the ambient atmosphere.

While B(a)P has been used as a tag or surrogate for polycyclic organic matter, the ratio of B(a)P to other polycyclic aromatic hydrocarbons in emission sources varies over a wide range, making the use of B(a)P as a surrogate questionable. Nonetheless, because of its extremely high carcinogenic potential in relationship to most other PAH's, the use of B(a)P to crudely assess the hazards of POM's has some justification.

In attempting to model the hazardous organic compounds emitted from RDF/Coal co-combustion sources, we have access to only crude and estimated emission factors. Table 23 of the NAS report (71) indicates emission factors for chain grate and spreader stokers as ranging from 15 to 40 micrograms per million BTUs, and coal-fired steam power plants

TABLE 23

Estimated Benzo(a)pyrene Emission from Heat and Power Generation Sources in the United States (71)

Type of Unit	Gross Heat, BTU/hr	Benzo[a]pyrene Emission Factor, $\mu g/10^6$ BTU	Benzo[a]-pyrene Emission, tons/year
Coal			
Hand-stoked residential furnaces	0.1×10^6	1,700,000–3,300,000	420
Intermediate units (chain-grate and spreader stokers)	$60–250 \times 10^6$	15–40	10
Coal-fired steam power plants	$1,000–2,000 \times 10^6$	20–400	1
Oil			
Low-pressure air-atomized	0.7×10^6	900	2
Other	$0.02–21 \times 10^6$	100	
Gas			
Premix burners	$0.01–9 \times 10^6$	20–200	2
Wood		50,000	40

TABLE 24

Estimated Benzo(a)pyrene Emission from Refuse-Burning in the United States (71)

Source of Benzo[a]pyrene	Benzo[a]pyrene Emission, tons/year
Enclosed incineration	
Municipal	<1
Commercial and industrial	23
Institutional	2
Apartment	8
Open burning	
Municipal	4
Commercial and industrial	10
Domestic	10
Forest and agricultural	140
Vehicle disposal	50
Coal refuse fires	340

ranging from 20 to 400 micrograms per million BTUs of benzo(a)pyrene. Using this range of emission factors, it is possible to estimate the total benzo(a)pyrene contribution nationally from co-firing RDF fuel in the model projected here.

The total annual heat value of RDF fuel has been indicated to range from 1.4 to 1.89 x 10^{+13} BTUs annually. In the range of emission factors previously indicated for power plants, that is, 15 to 400 micrograms per million BTU input, the range of total benzo(a)pyrene emissions would be between 200 grams and 8 kilograms annually. This is an extremely small fraction of the total benzo(a)pyrene emitted by all combustion sources.

Although this is a small fraction nationally, on a site-specific basis there may be some reason for concern. We have, therefore, modeled the dispersion of benzo(a)pyrene using the Hooker RDF/Coal co-firing operation, presently in its shakedown stage, at Niagara Falls, New York. This plant produces somewhat in excess of 100 megawatts and begins to approach the largest size of RDF/coal co-firing units expected by 1990. Table 21 indicates the emission rates and the dispersion dilution factor at the highest ground level concentration. The energy input rate at the Hooker operation is 750 million BTUs per hour, or 0.208 million BTUs per second. The emission factor for power plants in the NAS report covers a range of 20 to 400 micrograms per million BTUs. Thus, the benzo(a)pyrene release at a Hooker type installation would range from 4 to 80 micrograms per second at a design stack flow rate of 212 cubic meters per second. The stack gas concentration of B(a)P is 0.02 to 0.38 micrograms per cubic meter.

Since the model predicts that the maximum ground concentration dilution on an annual basis is 10.9 x 10^{-6}, the ambient annual concentration of B(a)P at this receptor point is in the range of 0.2 to 3.8 picograms per cubic meter. This concentration is 4-5 orders of magnitude below EPA's recommended AMEG (72) value for benzo(a)pyrene. Conservatively, this would represent less than one-tenth of one percent of urban air B(a)P levels.

Compared to alternative methods of refuse combustion, it is apparent that co-firing with coal is a cleaner process. According to the National Academy of Sciences figures (71), the municipal incinerators exhibit B(a)P emission factors about one order of magnitude greater. On the other hand, commercial incinerators and open burning have B(a)P emission factors three orders of magnitude greater than RDF/Coal combustion. It is apparent, then, that any re-routing of refuse from these less efficient incinerators can have a salutary effect on the urban air environment.

Solid Waste Disposal(73)

Conventional methods of handling and disposing of boiler ash and fly ash from power plants receiving RDF include wet sluicing to ash holding ponds and landfilling of dry residues. Wastewaters produced upon ash sluicing present two modes by which pollutants may be transported to the environment: seepage into groundwater reservoirs beneath the ponds and overflow from ponds into surface streams.

The magnitude of these two problems was estimated in two ways using the Ames, Iowa, facility as a case example:

1. Leaching columns were used to determine the amounts of materials that could leach from ash deposits; and
2. Direct measurements were made of the quality of waters that come into short-term contact with ashes and eventually could become overflow and surface runoff.

Analysis of the leaching test data shows that peak concentrations of certain conventional pollutants and heavy metals exceeded maximum allowable concentrations to groundwater resources as proposed by EPA under authority of the Resource Conservation and Recovery Act (74) (Table 25).

The amounts of water used per unit of ash in the leaching tests were much greater than would pass through the ash in a well-designed and well-operated landfill. Actual leachate concentrations, therefore, would be much greater and leachate volumes much less than in the leaching tests. Thus, it is likely that leachate control, such as collection and treatment or the use of liners, will be required if useable groundwater sources are located close to the landfill site.

Quality of ash pond overflow waters was assessed by collecting sluice waters directly from the sluice pipe discharge when the Ames power plant was operating at 100% load for a mixture of 80% coal and 20% RDF by BTU. Additional tests involved long-term contact of bottom ash and fly ash with the sluice water.

The analyses of sluice samples after short-term (24 hours) and long-term (39 days) contact are summarized in (Table 26). Most analyses showed relatively close agreement between short-term and long-term contact, but some differences are noteworthy. The COD and BOD increased

TABLE 25

Concentration of Contaminants in Leachate Potentially Produced Upon Landfilling of Ash from Co-firing Facilities (73)

Constituent	Ames boiler ash leachate (coal + RDF)[a] Concentrations, mg/l Peak	Average	Total leachable mg/g(S_d)	Ames boiler ash leachate (coal only) mg/l	Water quality standards Limits to groundwater (MCL)[b] mg/l	Toxic waste Threshold,[c] mg/l	Constituents of Concern
CONVENTIONAL POLLUTANTS							
pH	9.9						
Chemical oxygen demand	233	19.5	0.78(0.54)	8-11	N[d]	N	*,?
Biochemical oxygen demand	87	3.7	0.15(0.09)	1.6-1.7	N	N	*,?
Suspended solids	--	--	--	--	N	N	
Total dissolved solids	2579	312	12.5(7.6)	533-593	500[e]	50,000[e]	*,?
Volatile dissolved solids	508	68	2.7(0.44)	90-115	N	N	
Alkalinity	255	38	1.5(0.91)	19-75	N	N	
Calcium	--	--	--	--	N	N	
Magnesium	--	--	--	--	N	N	
Sodium	--	--	--	--	N	N	
Potassium	--	--	--	--	N	N	
Chloride	123	7.1	0.28(0.24)	38-44	250[e]	25,000[e]	
Sulfate	1610	124	5.0(3.69)	238-257	250[e]	25,000[e]	*,?
Fluoride	0.39	0.46	0.02(0.008)	0.51-0.70	1.4-2.4	140-240	
Nitrite + nitrate	0.29	0.09	0.003(0.005)	0.07	10[e]	100[e]	
Total Kjeldal nitrogen	47.1	1.09	0.043(-)	0.89-0.93	N	N	
Ammonia nitrogen	5.1	0.46	0.018(0.010)	0.63-0.69	N	N	
Total phosphate	1.85	0.21	0.008(0.008)	0.14-0.31	N	N	
Iron	--	--	--	7.5	0.3	30[e]	*
Manganese	--	--	--	0.31	0.05	5[e]	*

TABLE 25 . (continued)

	Ames boiler ash leachate (coal + RDF)[a]			Ames boiler ash leachate (coal only) mg/l	Water quality standards		
	Concentrations, mg/l		Total leachable		Limits to groundwater (MCL)[b] mg/l	Toxic waste Threshold,[c] mg/l	Constituents of Concern
Constituent	Peak	Average	mg/g(S_d)				
HEAVY METALS							
Arsenic	--	7×10^{-5}	1.3×10^{-6}	0.007	0.05	5.0	
Barium	--	0	0	0.50	1.0	100	
Cadmium	2×10^{-3}	9.2×10^{-5}	3.7×10^{-5}	<0.006	0.01	1.0	
Chromium	--	3.3×10^{-4}	6.7×10^{-6}	0.02	0.05	5.0	
Lead	0.175	0.037	1.5×10^{-3}	0.050	0.05	5.0	*,?
Mercury	--	0	0	0.0005	0.002	0.2	
Selenium	--	0	0	<0.0007	0.01	1.0	
Silver	--	4.7×10^{-4}	9.3×10^{-6}	0.010	0.05	5.0	
Copper				0.093	5.0	500	
Zinc				1.66	1.0	100	
PESTICIDES	(No pesticides, PCB's or organic priority pollutants found present)						

---

[a] When burning 80 to 90% coal + 10 to 20% RDF by Btu content.

[b] Based on limits established or proposed by EPA under authority of RCRA or assumed equivalency to Safe Drinking Water Act standards.

[c] Based on limits for toxicity as established or proposed by EPA under authority of RCRA.

[d] N = no specific standards established.

[e] Tentative or anticipated standard [14].

in the bottom ash samples upon long-term contact. No doubt, this increase was caused by hydrolysis or microbiological decomposition of the unburned organic materials in the samples. The sulfate concentration decreased, in all probability because of conversion to sulfides by bacterial action in the anaerobic environment. Total dissolved solids increased upon long-term contact because of the greater time available to dissolve salts contained in the ash.

There was little difference in the conventional pollutant concentrations when burning coal only and coal + RDF, indicating that the water pollution problems associated with burning RDF with coal are not measurably different from those when burning coal only. Similarly, heavy metals concentrations were not appreciably different when burning coal plus RDF as compared to when burning coal only.

No organic priority pollutants, pesticides, or PCB's were found in any of the sluice water samples or in the solid residues.

The data in Table 26 show clearly that ash pond overflow produced at power plants which burn coal alone or coal plus RDF have sufficiently high levels that direct discharge to surface streams is not likely to meet surface water standards as established by EPA or most states. Treatment also will be needed, if direct discharge is practiced, to reduce the soluble salt and heavy metal content. Some method of reducing the concentration of organic materials such as biological treatment, will be required if unburned organic matter exists in the bottom ash deposited in the ash ponds. However, recent tests at Ames

TABLE 26

Concentration of Contaminants in Overflow Waters from Ash Sluice Ponds When Co-firing (73)

Constituent	Ash pond overflow (coal-burn only), mg/l				Ash pond overflow (coal + RDF), mg/l						Quality requirements		
	Short-term contact		Long-term contact		Short-term contact				Long-term contact		Direct discharge[a] mg/l	Discharge to sewerage system[b] mg/l	Constituents of concern
	Bottom ash	Fly ash	Bottom ash	Fly ash	Mixed unsettled	Mixed settled	Bottom ash	Fly ash	Bottom ash	Fly ash			
CONVENTIONAL POLLUTANTS													
Chemical oxygen demand	8-11	4-9	11	6	--	--	33	2.9	201	6.8	>200+[c]	~300	
Biochemical oxygen demand	1.6-1.7	0.9-12	3	1.6	<1	<1	25	1.5	>47	0.83	10-30	~300	*
Suspended solids	--	--	--	--	242	80	--	--	31[d]	4[d]	10-30	~300	
Total dissolved solids	533-593	1,382-1,687	625	1,540	566	571	639	1,382	758	1,214	500[c]	50,000[c]	*
Volatile dissolved solids	90-115	108-129	49	100	257	253	92	113	198	249	N[e]	N	
Alkalinity	19-75	90-1,302	40	589	218	116	238	93	460	156	N	N	
Calcium	--	--	--	--	147	90	--	--	65[d]	135[d]	N	N	
Magnesium	--	--	--	--	36	33	--	--	20[d]	40[d]	N	N	
Sodium	--	--	--	--	26	25	--	--	256[d]	29[d]	N	N	
Potassium	--	--	--	--	66	6.7	--	--	68[d]	8.8[d]	N	N	
Chloride	38-44	26-29	42	24	38	39	44	37	72	49	<250[c]	<25,000[c]	
Sulfate	238-257	635	316	593	265	197	245	639	1.1	106	≤250[c]	<25,000[c]	
Fluoride	0.51-0.70	0.38-0.70	0.40	0.54	--	--	0.83	1.21	0.58	0.52	<1.4-2.4[c]	<140-240[c]	
Nitrite + nitrate	0.07	0.02-0.05	0.05	0.04	0.10	0.11	0.05	0.04	0.15	0.08	<10[c]	<1,000[c]	
Total Kjeldal nitrogen	0.89-0.93	0.88-1.27	0.72	0.95	1.8	1.2	0.69	0.18	1.48	0.93	N	N	
Ammonia nitrogen	0.63-0.69	0.70-0.78	0.58	0.87	0.83	0.73	0.25	0.68	0.27	0.60	2+	N	
Total phosphate	0.14-0.31	0.04-0.11	0.05	1.37	5.6	4.0	0.78	0.43	1.65	<0.26	N	N	

TABLE 26 . (continued)

Constituent	Ash pond overflow (coal-burn only), mg/l				Ash pond overflow (coal + RDF, mg/l						Quality requirements		Constituents of concern
	Short-term contact		Long-term contact		Short-term contact				Long-term contact				
	Bottom ash	Fly ash	Bottom ash	Fly ash	Mixed unsettled	Mixed settled	Bottom ash	Fly ash	Bottom ash	Fly ash	Direct discharge[a] mg/l	Discharge to sewerage system[b] mg/l	
CONVENTIONAL POLLUTANTS (continued)													
Iron	--	--	--	--	7.5	0.35	--	--	22.4	0.02	0.3[c]	3[c]	*
Manganese	--	--	--	--	0.31	0.04	--	--	0.19	0.02	0.05[c]	0.5[c]	*
HEAVY METALS													
Arsenic			0.07	<0.0005	0.014	0.008					0.05	<1	
Barium			0.50	0.70	0.70	0.50					1.0	<2.5	
Cadmium			<0.006	<0.006	0.005	0.02					0.01	<3	
Chromium			0.02	0.01	0.05	0.02					0.05	<8	
Lead			0.05	0.05	0.33	<0.06					0.05	<3	*
Mercury			0.0005	<0.0002	<0.0003	<0.0003					0.002	<0.1	
Selenium			<0.0007	<0.0007	0.0004	<0.0006					0.01	<1	
Silver			0.010	0.007	0.005	<0.005					0.05	<1	
Copper			0.093	0.020	0.46	0.068					1.0	<6	
Zinc			1.66	0.38	1.38	0.11					5.0	<8	
PESTICIDES	(No pesticides, PCB's or organic priority pollutants found present)												

---

[a] Based on stream discharge standards established under authority of the Clean Water Act or assumed equivalency to Safe Drinking Water Act standards.

[b] Based on limits for toxicity established by EPA under authority of RCRA or typical industrial pretreatment standards.

[c] Tentative or anticipated standard [14].

[d] These measurements were made on a settled but unfiltered sample.

[e] N = no specific standards established.

shows that boiler modifications can essentially eliminate the discharge of organic matter with the bottom ash.

Treatment Possibilities

Potential pollution problems with ash sluice water storage and disposal can be solved or reduced significantly in three ways:

1. Dry handling of the ash,
2. Lining or sealing of ash ponds and treatment of overflow waters, and
3. Recycle of ash pond overflow.

Dry handling is becoming more common especially with fly ash from electrostatic precipitators. This ash generally is placed in sanitary landfills along with boiler ash and is covered to reduce its movement and to minimize contact with water. This latter factor must be considered carefully because waters passing through buried ash residues can present possible groundwater contamination in much the same manner as water leaching from ash ponds. Most landfills, however, are designed to minimize the passage of water and should be acceptable for disposal of ash from refuse-burning plants by the same means as used for disposal of ash from coal-fired power plants. A significant amount of fly ash presntly is being used as a filler material for concrete and therefore has some market value. Bottom ash, however, has no widespread market value.

Ash pond overflow waters can be treated to meet discharge standards for most conventional pollutants. Biological treatment or addition of small amounts of activated carbon can be expected to reduce the BOD to below acceptable levels for direct discharge, but would add considerable expense to sluice water handling. However, removal of heavy metals and iron and manganese will require chemical treatment as used widely in metal processing industries. Treatment to reduce chlorides and total dissolved solids will be more difficult and would involve such processes as ion exchange and reverse osmosis or distillation. Such extreme treatment is considered to present unacceptable cost restrictions and the need for such treatment prior to discharge would be precluded by use of dry handling of ash or by complete recycle of sluicing waters.

Complete holding and recycle of ash sluice waters presents an alternative to discharge. Possible problems still exist, however, because as the number of reuses increases, the soluble salt content increases. This can cause significant corrosion of metal pipes, pumps and ash hoppers. Neutralization can help to reduce corrosiveness but may not eliminate the problem altogether. Corrosiveness also can be reduced by periodically wasting some of the water in inventory and replacing it with fresh water, but these blowdown waters may then themselves present disposal problems because of their high salt content.

Comments on Environmental Impacts

Data on effluents and emissions from RDF/coal plants indicate that the environmental impacts of these plants will not be quantitatively different from coal-fired powerplants. The small fraction which

RDF/coal plants contribute nationally to pollutant emissions make it almost impossible to separately assess their environmental impacts. Most of these plants are relatively small (more or less 100 megawatts) compared to coal-fired powerplants. They are also, for the most part, located in urban areas where, on a population basis, local effects are small when compared to the numerous pollutant sources within cities themselves. As pointed out (Table 21), the increment of pollutants which the average sized RDF/coal plant would add to urban air is very small.

The deposition of these pollutant emissions in urban areas and their transport to watersheds represents an almost immeasurable pollutant increment when all other emission sources in urban areas are considered.

In the case of new RDF plants such as the Hooker facility in Niagara Falls, and the Columbus, Ohio facility, which burn up to 80% RDF on a regular basis and occasionally 100% RDF, some limited health and environmental threats may arise because of particulate emissions enriched in certain toxic trace elements. This is purely speculative since no observations have yet been made on new facilities burning high percentages of RDF.

In the case of solid waste disposal, these RDF plants are very similar to coal-fired plants, and only slight differences have been detected in the leachability of the ash and the composition of wastewater effluents. The sites and manner of disposal for solid and liquid effluents from these RDF plants is similar to that of coal-fired power plants, that is, either ash pits or landfilled with other waste.

For the above reasons, it is not possible to attach any uniqueness to the environmental threats of RDF/coal-fired powerplants, rather, they should be included in the overall assessment of environmental impacts under coal burning facilities and evaluated according to their power rating.

On the other hand, modular and mass incineration do provide new considerations for environmental impact, especially since certain of these operations will take place in small towns or in a rural setting where wastewater and ash disposal may take place in as yet relatively undisturbed watersheds. These impacts will be treated in future reports.

The indirect environmental benefits of RDF combustion include benefits from the reduction of mass and the consequent smaller landfill requirements.

The loss of the combustible fraction of RDF may also reduce the leachate content of organic acids and decomposition products arising from anaerobic metabolism, as well as the quantity of leachate at landfill sites.

4. RECOMMENDATIONS

RDF FUEL SUPPLY

The unusually high incidence of accidents involved in the collection of municipal solid waste should be analyzed with a view toward mitigation. The present lack of uniformity in methods and equipment, training, and standards of safety probably results from the large diversity of private and public contracts individually negotiated by cities or towns. Efforts to improve this safety record could be expected if training programs were established and supported on a regional basis by associations of cities and towns with the assistance of EPA, the National Safety Council and other appropriate organizations. The detailed accident analyses survey reported by EPA (17) illuminates the considerable gains a safety program could produce.

RDF PROCESSING

The experimental nature of developments in the RDF processing industry has led to unusual hazards in the workplace. These include explosions due to flammable waste, respiratory hazards from high dust levels and volatile toxic compounds, and as yet incompletely assessed hazards from exposure to pathogenic organisms. Suggested mitigation procedures include safety barricades and monitoring systems, and appropriately designed ventilation systems already being introduced. Surveillance techniques designed to screen employees for sensitivities and allergies, to assess numbers and types of pathogens in workroom atmospheres and to improve injury/illness reporting systems are important measures to consider. The ASTM committee E138.07, Health and Safety Aspects of Resource Recovery, has prepared a set of recommendations in this regard which the industry should be encouraged to adopt.

RDF COMBUSTION

Combustion test firing of RDF/coal in retrofitted coal burning facilities has emphasized the importance of certain equipment modifications and limitations in maintaining acceptable or optimum pollutant emissions. These include dump grate facilities to assure complete combustion of RDF, optimal location of RDF firing ports to minimize stack emissions , careful observation of boiler loadings to minimize ESP overload and inefficiency due to particulate resistivity changes and changing particle size distribution. Such observations already made at Ames and St. Louis under limited RDF firing need to be repeated at the new facilities designed to burn 80 to 100% RDF at Hooker (Niagara Falls) and Columbus, Ohio. Stack studies under full operating conditions at these two facilities are necessary to provide data on toxic trace elements and organics and the particle size distribution of stack emissions under conditions of full RDF fuel input. Questions which remain unanswered on rates of toxic emissions and the efficiency and durability of particulate collection system can be resolved. This is of particular concern because of the urban location of RDF plants.

SOLID WASTE DISPOSAL

Solid waste disposal from RDF plants may pose long-range environmental and water quality problems because of toxic element leaching rates, particularly from fly ash which has become highly enriched in Pb, Cd, Cu and Cr. Inasmuch as coal and RDF ash are presently excluded from RCRA regulations on hazardous waste, it is recommended that field studies be undertaken to evaluate the leachate production and quality of RDF ash under conditions mimicking present disposal practices.

REFERENCES

1. U.S. EPA. 1979. Assmessment of the impact of resource recovery on the environment. Municipal Environmental Research Laboratory, Cincinnati, Ohio. 136 pp.

2. CEQ. 1979. Environmental Quality - 1979: The tenth annual report of the Council on Environmental Quality. U.S. Government Printing Office, Washington, D. C.

3. Wiles, Carlton C. 1981. Overview of resource recovery. In: Municipal Solid Waste: Resource Recovery: Proceedings of the Seventh Annual Research Symposium. U.S. EPA. Municipal Environmental Research Laboratory, Cincinnati, Ohio. pp 1-9.

4. NCRR. 1980. Resource recovery activities. NCRR Bulletin, 10, Number 3:57-65.

5. U.S. EPA. 1981. Resource recovery systems, A nationwide survey of programs recovering resources from municipal solid waste. U.S. EPA Office of Solid Waste, Draft.

6. U.S. EPA. 1981. Sources separation collection and processing equipment. U.S. EPA, Office of Water and Waste Management. U.S. EPA Report SW-192c, January.

7. Wilson, R., S. D. Colome, J. D. Spengler, D. G. Wilson. "Health Effects of Fossil Fuel Burning". Ballinger Pub. Co., Cambridge, Mass. 1980.

8. Oberaker, D., "News of Environmental Research in Cincinnati", U.S.E.P.A., U.S. Gov't. Printing Office: 1976-757-008/0010 (1976).

9. Hall, J. L. et al. Evaluation of the Ames Solid Waste Recovery System. Part III - Environmental Emissions of the Stoker Fired Steam Generators. 1979. EPA-600/7-79-222.

10. Joensen, A. W. et al., "Evaluation of the Ames Solid Waste Recovery System: Refuse Processing Plant and Suspension-Fired Steam Generators." Draft Report for EPA Grant No. R803903-01-0 (Undated).

11. Deg er, G. H., "A Field Test Using Coal: dRDF Blends in Spreader-stoker Fired Boilers", Final Report for EPA Project 68-03-2426, Systech, Zenia, Ohio.

12. Morris, S.C. et al, "Health and Environmental Effects of the National Energy Plan: A Critical Review of Some Selected Issues BNL 51300, Sept. 1980, Biomedical and Environmental Assessment Division, National Center for Analysis of Energy Systems, Brookhaven National Laboratory, Upton, NY 11973.

13. Morris, Samuel C., "Health Risks from Coal Energy Technologies" in "Health Risk Associated with Energy Technologies", C.C. Travis and E.L. Etnier, eds., Westview Press, 1981.

14. Morris, S.C. et al, "Coal Conversion Technologies+ Some Health and Environmental Effects", Science, v. 206, pp 654-662.

15. Rockette, H.. 1977A. Cause-Specific Mortality of Coal Miners. J. Occupational Medicine 19: 795-801.

16. Greenberg, R. R., W. H. Zoller, G. E. Gordon, "Composition and Size Distribution of Particles Released in Refuse Incineration". Env. Sci. & Tech. V. 12, pp 566-573.

17. U.S. EPA. 1979. Evaluation of an Injury Reporting and Information System for the Solid Waste Industry, Volume II: Data Analysis. Office of Solid Waste, Washington, DC.

18. National Safety Council. 1978. Fleet Accident Rates. Chicago, IL.

19. Bureau of Labor Statistics. 1979. Occupational Injuries and Ilnesses in the United States by Industry, 1976. U.S. Dept. of Labor, Washington, DC.

20. Zalosh, R. C., S. A. Weiner and J. L. Buckley, "Assessment of Explosion Hazards in Refuse Shredders". Report No. ERDA-76-71, U. S. Department of Energy, Washington, D. C.

21. Duckett, E. J., "Health and Safety Aspects of Resource Recovery". Proc. Seventh Annual Research Symposium, March 16-18, 1981. David Schultz, Ed. Report No. EPA-600/9-81-002c, March, 1981. U.S. Environmental Protection Agency, Cincinnati, Ohio 45268. p 215.

22. Ahlberg, N. R. and Boyko, B. I., "Explosions and Fires-Ontario Centre for Resource Recovery". Proceedings of 1980 National Waste Processing Conference, May, 1980. American Society of Mechanical Engineers, New York. p. 159.

23. Bluhm, D. D., "Grain Elevator Explosions", Report No. IS-EMPRI-8, Energy and Minerals Resources Research Institute. Iowa State University, Ames, Iowa. July 1978.

24. Duckett, E. J., "Approaches to Explosion Protection in Refuse Processing Facilities", Solid Waste Management, May, 1980. p. 18.

25. SCS Engineers. 1979. Health effects associated with wastewater treatment and disposal systems. State-of-the-art. Review Vol. I. EPA-600/1-79-016. National Technical Information Service, Springfield, VA.

26. Clark, C. S., G. L. Van Meer, C. C. Limmeman, Jr., A. B. Bjoinson, P. S. Gartside, G. M. Schiff, S. E. Trimble, P. Alexander, E. J. Cleary. 1980. Health effects of occupational exposure to wastewater. In H. Pahren and W. Jakubowski (ed,) Wastewater aerosols and disease. EPA-600/9-80-028. National Technical Information Service, Springfield, VA.

27. Olver, W. R. Jr. 1979. The life and times of Aspergillus fumigatus. Compost Science. March/April.

28. Clark, C.S., H. S. Bjoinson, J. W. Holland, V. J. Elia, V. A. Majeti, C. R. Meyer, W. F. Balistreri, G. L. Van Meer, P. S. Gartside, B. L. Specker, C. C. Linneman Jr., R. Jaffa, P. V. Scarpino, K. Brenner, W. J. Davis-Hoover, G. W. Barrett, T. S. Anderson, and D. L. Alexander. 1981. Evaluation of the health risks associated with the treatment and disposal of municipal wastewater and sludge. EPA-600/1-80-030. National Technical Information Service, Springfield, VA.

29. Lundholm, M. and R. Rylander. 1980. Occupational symptoms among compost workers. J. of Occupational Med. 22:256-257.

30. Lacey, J. J., Pepys, and T. Cross. 1972. Actinomycete and Fungus Spores in Air as Respiratory Allergens. D. A. Shapton (ed.) Safety in Microbiology. Academic Press: New York.

31. Dutkiewicz, J. 1978. Exposure to dust-borne bacteria in agriculture. I. Environmental studies. Arch. Environ. Health 33:250-259

32. Dutkiewicz, J. 1978. Exposure to Dust-Borne Bacteria in Agriculture. I. Environmental Studies. Arch. Environ. Health. 33: 250-259.

33. Salvaggio, J. E., H. A. Buechmer, J. H. Seabury, and P. Arquenbourg. An. Internal Med. 64:748-758.

34. Kleyn, J. G., W. M. Johnson, and T. F. Wetzler. 1981. Microbial aerosols and actinomycetes in etiological considerations of mushroom workers' lungs. Appl. Microbial 41:1454-1460.

35. Haglind, P., M. Lundholm and R. Rylander. 1981. Prevalence of byssinosis in Swedish cotton mills. Brit. J. Ind. Med. 38: 138-143.

36. Fletcher, M. W., N. J. Lindsey, and A. M. Behbane. 1981. Industrial hygiene evaluation of microbiological aerosols generated at resource recovery facilities. Am. Soc. for Microbiol. Washington, D. C. Abstracts of the Annual Meeting.

37. Mansdorf, S.Z., M. A. Golembieuski, and M. W. Fletcher. 1981. Industrial hygiene characterization and aerobiology of resource recovery systems. Draft summary report. National Institute for Occupational Safety and Health, Morgantown, West VA.

38. Fiscus, D. E., P. G. Gorman, M. P. Schrag, and L. J. Shannon. 1978. Assessment of bacteria and virus emissions at a refuse derived fuel plant and other waste handling facilities. EPA-600/2-78-152. National Technical Information Service, Springfield, Va.

39. Duckett, E. J. 1978. Microbiological analysis of dusts at the equipment test and evaluation facility. TR 78-16, National Center for Resource Recovery, Inc., Washington, D. C.

40. Lembke, L. L. and R. N. Kniseley. 1980. Coliforms in aerosols generated by a municipal solid waste recovery system. Appl. Environ. Microbiol. 40: 888-891.

41. Lembke, L. L., R. N. Kniseley, R. C. Van Nostrand, and M. D. Hale. 1981. Precision of the all-glass impinger and the Andersen microbial impactor for air sampling in solid waste handling facilities. Appl. Environ. Microbiol. 42: 222-225.

42. Duckett, E. Joseph, Wagner, John, Walker, Roger, Rogens, Brian, Usdin, V. 1980. Physical/chemical and microbiological analyses of dusts at a resource recovery plant. American Industrial Hygiene Association Journal. 41:908-914.

43. Lembke, L. L. and R. N. Kniseley. 1981. Microbiological air Quality in a municipal solid waste recovery system. Submitted to Applied and Environmental Microbiology, September.

44. Hatch, T. F. 1961. Distribution and deposition of inhaled particles in respiratory tract. Bacteriological Reviews 25:237-240.

45. Hart, P. D., E. Russel, Jr. and J. S. Remington. 1969. The compromised host and infection. II. Deep fungal infection. J. of Infectious Diseases. 120:169-191.

46. Radian Corp., "Trace Metals and Stationary Conventional Combustion Sources". Vol. I, Technical Report, EPA-600/7-80-155a. Aug. 1980.

47. Krause, H. H., D. A. Vaughen, and W. K. Boyd. 1976. Corrosion and Deposits from Combustion of Solid Waste, Part 4. ASME J. of Eng. for Power. V 98(3), pp 369-74.

48. Jackson, Jerry W. and Ledbetter, Joe O. 1977. Stack Emissions from Refuse-Derived Fuel Admix to Boiler Boal. Journal of Environmental Science Health. A12(9), pp 465-473.

49. Hamilton, L. D. "Comparative Risks from Different Energy Systems: Evolution of the Methods of Sulfate". IAEA Bul., V. 22, pp 35-71.

50. EPA, "St. Louis Demonstration Final Report: Power Plant Equipment, Facilities and Environmental Evaluations". EPA-600/2-77-155b. Dec. 1977.

51. EPA, "Guidelines for Air Quality Maintenance Planning and Analysis" Vol. 10. "Procedures for Evaluating Air Quality Impact of New Stationary Sources". EPA-450/4-77-001. Oct. 1977.

52. International Commission on Radiological Protection. "Report of the Task Force on Reference Mean". ICRP, Pub. No. 23, Pergamon Press, NY, NY. 1975.

53. Junk, G. A. and C. S. Ford. 1980. A Review of Organic Emissions from Selected Combustion Processes. Ames Laboratory, Ames, Iowa, IS-4727.

54. Hangebrauck, R., D. vonLehmden and J. Meeker, J. Air Pollut. Control Assoc., 14, 267 (1964).

55. Diehl, E., F. Dubreuill and R. Glenn, Transactions of the ASME, Paper No. 66-Pwr-2, (1966).

56. Hermann, T., "Development of Sampling Procedures for Polycyclic Organic Matter and Polychlorinated Biphenyls", NTIS, Pub. No. PB-245-017-19BA (1975).

57. Cowherd, C., M. Marcus, C. Guenthes, and J. Spigarelli, "Hazardous Emissions Characteristics of Utility Boilers", NTIS, Pub. No. PB-245-017-19BA (1975).

58. Webb, R. and A. McCall, J. Chromatog. Sci., 11, 336 (1973).

59. Boettner, E., G. Bull and B. Weise, "Combustion Products from the Incineration of Plastics", NTIS, Pub. No. PB-222-0091/0 (1973).

60. Sebastian, F., G. Kroneberger, L. Lombana, and J. Napoleon, Proc. AIChE Workshop, 5, 67 (1974).

61. Suzuki, R. and M. Ito, "Determination of PCB in Dust, Ash and Combustion Gas from City Waste Incinerators", NTIS, Pub. No. PB-258-668-T (1974).

62. Michal, J. Nehorlauost Polyn. Mater., 129 (1976).

63. Davies, I., R. Harrison, R. Perry, R. Ratnayaka and R. Wellings, Environ. Sci. Technol., 10, 806 (1976).

64. Ahling, B., A. Lindskog, B. Jansson, and G. Sundstrom, Chemosphere, 6, 461 (1977).

65. Stehl, R. and L. Lamparski, Science, 197,

66. Olie, K., P. Vermeulen, and D. Hutzinger, Chemosphere, 6, 461 (1977).

67. K. Olie and O. Hutzinger, 4th International Symposium on Mass Spectrom. in Biochem. and Med., Riva, Italy, 555 (1977).

68. Gorman, P., L. Shannon, M. Schrag and D. Fiscus, "St. Louis Demonstration Project Final Report: Power Plant Equipment Facilities and Environmental Evaluations (Volumne II)", Midwest Research Inst. Report, No. 38216 and 4033-C,EPA Contract No. 68-02-1324 and 68-02-1871 (1976).

69. Vick, R., G. Junk, M. Avery, and H. Svec, Chemosphere, 7, 893(1978).

70. Richard, J. and G. Junk, Environ. Sci Technol.,15, 1095 (1981).

71. National Academy of Sciences. 1972. Particulate Polycyclic Organic Matter, Biologic Effects of Atmospheric Pollutants. National Academy of Sciences, Washington, D.C.

72. Kingsbury, G. L., J. B. White, and J. S. Watson. 1980. "Multimedia Environmental Goals for Environmental Assessment," Vol. 1 (Supplement A). Research Triangle Institute, Research Triangle Park, North Carolina. EPA-600/7-80-041.

73. Young, J. C., and L. D. Johnson. 1980. Water-related Environmental control requirements at municipal solid waste-to-energy conversion facilities. U.S. Department of Energy, Washington, D.C. 193 pp.

74. U.S. Environmental Protection Agency, "Criteria for Classification of Solid Waste Disposal Facilities and Practices," Federal Register, Vol. 44, No. 179 (September 13, 1979).

75. Busse, A. D., and J. R. Zimmerman, 1973: Users Guide to the Climatological Dispersion Model EPA-R4-73-024; PB 227 346 Available from NTIS, 131 pp.

76. Doty, S. R. 1978: Climatological Aids in Determining Air Pollution Potential - Where We are Today. Available from National Climatic Center, Asheville, NC. 25 pp.

77. Pasquill, F., 1962: Atmospheric Diffusion, Van Nostrand, London.

78. Holtzworth, G. C. 1972: Mixing Heights, Wind Speeds and Potential for Urban Air Pollution Throughout the Contiguous United States. US EPA Office of Air Programs, Publication AP-101.

79. Briggs, E. A., 1969: Plume Rise. AEC Critical Review Series, Oak Ridge, TN. USA Atomic Energy Commission, Division of Technical Information. 81 pp. Available from NTIS as T10- 2075.

80. Stevens, M. and R. E. Holden. 1978. Ambient Air Quality Analysis and Atmospheric Dispersion Modeling of the Proposed McIntosh Plant Unit No. 3 : Prepared for: City of Lakeland Utilities. Environmental Science and Engineering, Inc., Gainsville, FL.

Appendix A

CLIMATIOLOGICAL DISPERSION MODEL

The function of the Climatiological Dispersion Model (75) is to compute long-term average concentrations, usually seasonal or annual, of air pollutants in a region. Multiple area and point sources may be specified, each at its own effective height and horizontal position. A rectangular Cartesian coordinate system is used for the sources with units to be specified by the user. For area sources a numerical integration is done over the specified source region with each integration point in the region acting as a point source. We used the Universal Transverse Mercator (UTM) coordinates in kilometers for the horizontal and meters above ground level for the vertical.

The model computations presented here give the predicted increment in long-term average concentration caused by emissions from the RDF/coal burning facility in the area assuming an emission rate of 10 kg-S^{-1}. This emission rate, much higher than at any of the facilities considered was used to show more clearly the details of the concentration distributions. The computed increment may be multiplyed by the ratio of actual emission rate to 10 kg-S^{-1} and added to the background concentration taken from air quality measurements in the region made before the plant was in operation. In the accompanying figures, except for Madison, WI where the RDF plant was converted from an existing coal-fired unit, both the forecast increment assuming 10 kg-S^{-1} and the measured background without this increment are given.

The model assumes a Gaussian plume shape in the horizontal and determines the vertical distribution using a mixing depth. If the plume vertical half width " $\sigma_z(\zeta)$ " is less than eight tenths of this depth, a Gaussian shape is assumed for the vertical. If " $\sigma_z(\zeta)$ " is greater than this the concentration is assumed to be constant in the vertical. Here " ζ " is the distance from the source to the receptor of interest.

The mean transporting wind is taken from the Stability Array; (STAR) (76), a joint frequency distribution of wind speed, wind direction and Pasquill-Gifford stability class (77) available from the National Climatic Center, Asheville, NC. The mixing depth is given by the mean afternoon depth for daytime, and the mean morning urban mixing depth for nighttime computations (78). The means are seasonal or annual as appropriate with night and day distinquished by the stability class. Unstable conditions are assumed to occur only during the day, and stable conditions only at night. Neutral conditions are split between day and night in some of the STAR tabulations, but not in those we used for Madison, Buffalo (Niagara Falls) or Tampa (Lakeland). We divided the neutral stability class for these into two equal parts for annual arrays.

The model permits area and point sources to be at any height above ground and determines plume rise for point sources from the Briggs (79) formula. The formula uses stack height, diameter, exit speed and exit temperature along with ambient air temperature as parameters. No distinction is made in the model between day and night ambient temperature. Provision is made for decay of the pollutant, but this feature was not used in the present computations since dispersion distances are short (10 km).

The model computes concentrations for a maximum of 200 receptors which can be at any location in horizontal or vertical. Each receptor is treated individually with its concentration given as the sum of contribution from all area and point sources. We assume all receptors to be at ground level.

Receptors may be individually specified, or a grid may be computed by the model given

1. The coordinates of the southwest corner
2. The number of receptors in the north-south and east-west directions
3. The receptor spacing

We used the second option with 14 receptors in each direction at a spacing of 1.4 km giving a receptor grid 18.2 km square approximately centered on the source. This is the largest number of receptors in a square array which is permitted without increasing array sizes in the program. The accompanying Tables and Figures show the results of the computations.

<u>Star Dates</u>

Columbus	January 1974 - December 1974
Tampa	January 1960 - December 1964
Buffalo	January 1964 - December 1973
Madison	January 1964 - December 1973

TABLE 27

Madison,WI CDMQC Input Paramaters

```
                         CLIMATOLOGICAL   DISPERSION   MODEL

                       CDMQC    MADISON, WISCONSIN              ANNUAL
                                                RUN    1

POLLUTANTS TO BE MODELED:

    1) SO2
    2) PART

OPERATING PARAMETERS:

    X-MINIMUM OF AREA EMISSION INVENTORY MAP GRID (XG) ..............................     296.00000
    Y-MINIMUM OF AREA EMISSION INVESTORY MAP GRID (YG) ..............................    4762.00000

    WIDTH OF BASIC AREA SOURCE SQUARE (TXX) .........................................    1000.00000 METERS

    INITIAL SIGMA Z (METERS) FOR AREA SOURCES (SZA):

         STABILITY CLASS:     1 .....................................................      30.00000
                              2 .....................................................      30.00000
                              3 .....................................................      30.00000
                              4 .....................................................      30.00000
                              5 .....................................................      30.00000
                              6 .....................................................      30.00000

    NUMBER OF SUBSECTORS CONSIDERED IN A 22.5 DEGREE SECTOR (DINT) ..................       4.00000
    ANGULAR WIDTH OF A SUBSECTOR (THETA) ............................................       5.62500 DEGREES

    INITIAL RADIAL INCREMENT (DELR) .................................................     250.00000 METERS

    RATIO OF EMISSION GRID TO MAP GRID (RAT) ........................................       1.00000
    GRID CONVERSION FACTOR (CV) .....................................................    1000.00000

    INITIAL SIGMA-Z FACTORS FOR POINT SOURCES
         MAXIMUM STACK HEIGHT FOR ADJUSTMENTS (AJP) .................................         15.00 METERS
         MAXIMUM INITIAL VALUE (AJP1) ...............................................          7.00 METERS

MISCELLANEOUS METEOROLOGICAL DATA:

    AVERAGE AFTERNOON MIXING HEIGHT (HT) ............................................    1200.00000 METERS
    AVERAGE NOCTURNAL MIXING HEIGHT (HMIN) ..........................................     470.00000 METERS
    MEAN ATMOSPHERIC TEMPERATURE (TOA) ..............................................       8.19995 DEGREES CELSIUS

    DECAY HALF LIFE FOR SO2  (GB(1)) ................................................   99999.00000 HOURS
    DECAY HALF LIFE FOR PART (GB(2)) ................................................   99999.00000 HOURS

RATIO (YD) OF AVERAGE DAYTIME EMISSION RATE TO THE 24-HOUR EMISSION RATE AVERAGE ....       1.00000
RATIO (YN) OF AVERAGE NIGHTTIME EMISSION RATE TO THE 24-HOUR EMISSION RATE AVERAGE ..       1.00000

BACKGROUND CONCENTRATION (BKGR), ARITHMETIC MEAN, FOR:

    SO2  ............................................................................       0.0      MICROGRAMS/CU. METER
    PART ............................................................................       0.0      MICROGRAMS/CU. METER

ANY CULPABILITY LIST(S) WILL INDIVIDUALLY LIST SOURCES CONTRIBUTING GREATER
THAN OR EQUAL TO  0.0 ( (CTOF) OF TOTAL CALIBRATED CONCENTRATION

(IOCAL=0) REGRESSION EQUATION CONSTANTS INPUT WILL BE USED TO CALIBRATE COMPUTED CONCENTRATIONS:

               INPUT CONSTANTS FOR SO2 :
                   POINT SLOPE (CBP(1)) ....         1.00000
                   AREA SLOPE ((CBA(1)) ....         1.00000
                   Y-INTERCEPT (CA(1)) .....         0.0      MICROGRAMS/CU. METER
                   BACKGROUND (BKGR(1)) ....         0.0      MICROGRAMS/CU. METER

               INPUT CONSTANTS FOR PART:
                   POINT SLOPE (CBP(2)) ....         1.00000
                   AREA SLOPE ((CBA(2)) ....         1.00000
                   Y-INTERCEPT (CA(2)) .....         0.0      MICROGRAMS/CU. METER
                   BACKGROUND (BKGR(2)) ....         0.0      MICROGRAMS/CU. METER

LARSEN'S STATISTICAL MODEL WILL BE APPLIED FOR THE FOLLOWING AVERAGING TIMES (PAV):

    SO2
       3.0 HOURS
       8.0 HOURS
      24.0 HOURS
    PART
       3.0 HOURS
       8.0 HOURS
      24.0 HOURS
```

Figure 1: Madison,WI Isopleths

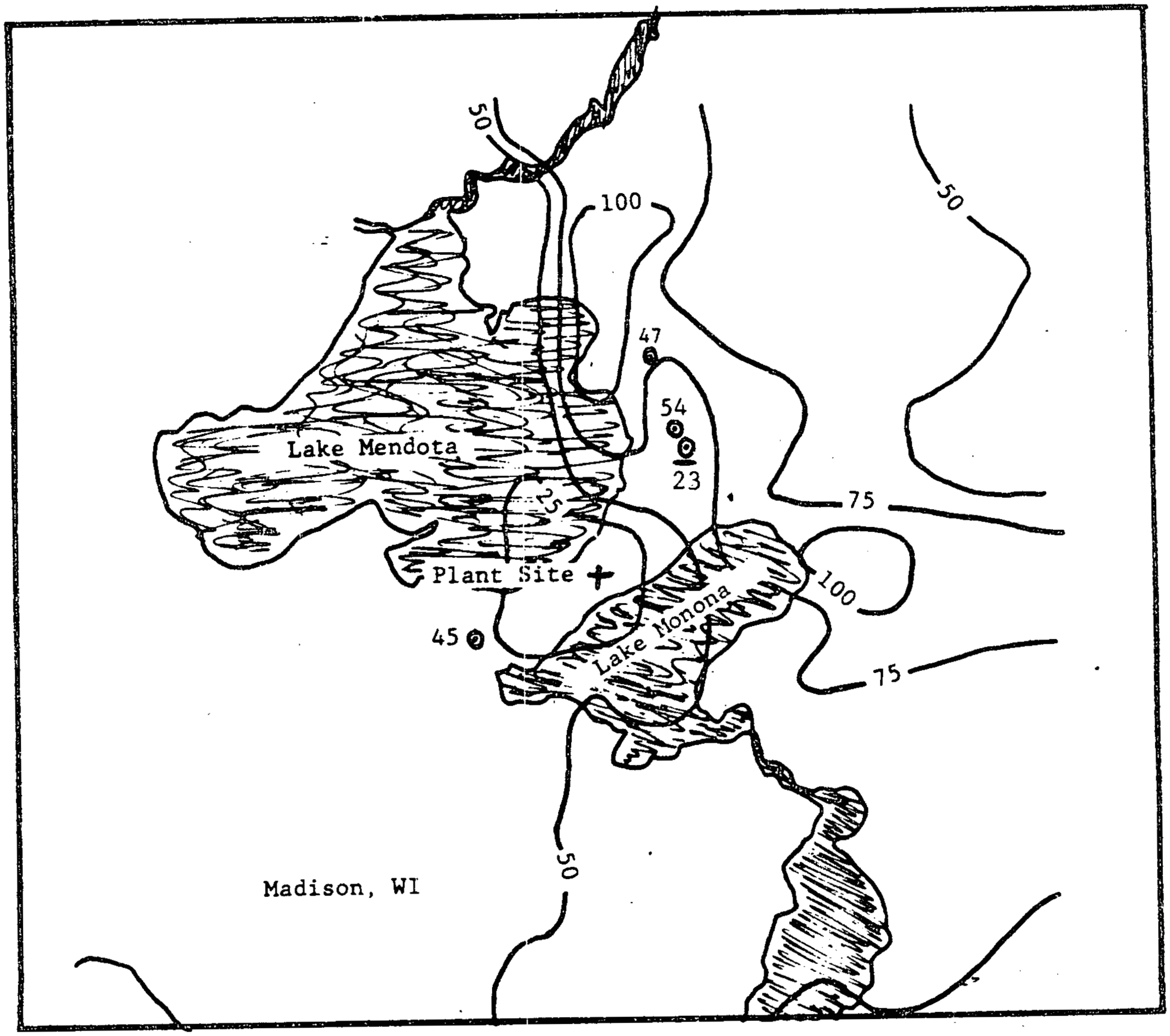

Figure 1 . Climatological Dispersion Model - Groundlevel concentrations using 10,000 gm/sec emission source at Madison Gas & Electric plant site and meteorological data from met. data - Madison.

Isopleths are in $\mu g/m^3$.

⊚ indicates existing air quality monitoring site. Adjacent # is annual geometric mean for suspended particulate concentration in $\mu g/m^3$. Bottom # (if there is one) is annual arithmatic mean for sulfur dioxide.

TABLE 28

Lakeland,FL CDMQC Input Paramaters

```
                         C L I M A T O L O G I C A L   D I S P E R S I O N   M O D E L

                         CDMQC    LAKELAND, FLORIDA              ANNUAL
                                                  RUN     4

POLLUTANTS TO BE MODELED:

    1) SO2
    2) PART

OPERATING PARAMETERS:

    X-MINIMUM OF AREA EMISSION INVENTORY MAP GRID (XG) ..............................        0.0
    Y-MINIMUM OF AREA EMISSION INVENTORY MAP GRID (YG) ..............................        0.0

    WIDTH OF BASIC AREA SOURCE SQUARE (TXX) ........................................     1000.00000 METERS

    INITIAL SIGMA Z (METERS) FOR AREA SOURCES (SZA):

         STABILITY CLASS:      1 ...................................................       30.00000
                               2 ...................................................       30.00000
                               3 ...................................................       30.00000
                               4 ...................................................       30.00000
                               5 ...................................................       30.00000
                               6 ...................................................       30.00000

    NUMBER OF SUBSECTORS CONSIDERED IN A 22.5 DEGREE SECTOR (DINT) ..................        4.00000
    ANGULAR WIDTH OF A SUBSECTOR (THETA) ............................................        5.62500 DEGREES

    INITIAL RADIAL INCREMENT (DELR) .................................................      250.00000 METERS

    RATIO OF EMISSION GRID TO MAP GRID (RAT) ........................................        1.00000
    GRID CONVERSION FACTOR (CV) .....................................................     1000.00000

    INITIAL SIGMA-Z FACTORS FOR POINT SOURCES
         MAXIMUM STACK HEIGHT FOR ADJUSTMENTS (AJP) .................................          50.00 METERS
         MAXIMUM INITIAL VALUE (AJP1) ...............................................           0.0  METERS

MISCELLANEOUS METEOROLOGICAL DATA:

    AVERAGE AFTERNOON MIXING HEIGHT (HT) ............................................     1410.00000 METERS
    AVERAGE NOCTURNAL MIXING HEIGHT (HMIN) ..........................................      630.00000 METERS
    MEAN ATMOSPHERIC TEMPERATURE (TOA) ..............................................       22.39990 DEGREES CELSIUS

    DECAY HALF LIFE FOR SO2  (GB(1)) ................................................    99999.00000 HOURS
    DECAY HALF LIFE FOR PART (GB(2)) ................................................    99999.00000 HOURS

RATIO (YD) OF AVERAGE DAYTIME EMISSION RATE TO THE 24-HOUR EMISSION RATE AVERAGE ....        1.00000
RATIO (YN) OF AVERAGE NIGHTTIME EMISSION RATE TO THE 24-HOUR EMISSION RATE AVERAGE ..        1.00000

BACKGROUND CONCENTRATION (BKGR), ARITHMETIC MEAN, FOR:

    SO2  ............................................................................        0.0       MICROGRAMS/CU. METER
    PART ............................................................................        0.0       MICROGRAMS/CU. METER
ANY CULPABILITY LIST(S) WILL INDIVIDUALLY LIST SOURCES CONTRIBUTING GREATER
THAN OR EQUAL TO  0.0 ( (CTOF) OF TOTAL CALIBRATED CONCENTRATION

(IOCAL=0) REGRESSION EQUATION CONSTANTS INPUT WILL BE USED TO CALIBRATE COMPUTED CONCENTRATIONS:

              INPUT CONSTANTS FOR SO2 :
                  POINT SLOPE (CBP(1)) ....           1.00000
                  AREA SLOPE ((CBA(1)) ....           1.00000
                  Y-INTERCEPT (CA(1)) .....           0.0      MICROGRAMS/CU. METER
                  BACKGROUND (BKGR(1)) ....           0.0      MICROGRAMS/CU. METER

              INPUT CONSTANTS FOR PART:
                  POINT SLOPE (CBP(2)) ....           1.00000
                  AREA SLOPE ((CBA(2)) ....           1.00000
                  Y-INTERCEPT (CA(2)) .....           0.0      MICROGRAMS/CU. METER
                  BACKGROUND (BKGR(2)) ....           0.0      MICROGRAMS/CU. METER

LARSEN'S STATISTICAL MODEL WILL BE APPLIED FOR THE FOLLOWING AVERAGING TIMES (PAV):

    SO2
       3.0 HOURS
       8.0 HOURS
      24.0 HOURS
    PART
       3.0 HOURS
       8.0 HOURS
      24.0 HOURS
```

Figure 2: Lakeland,FL Isopleths (80)

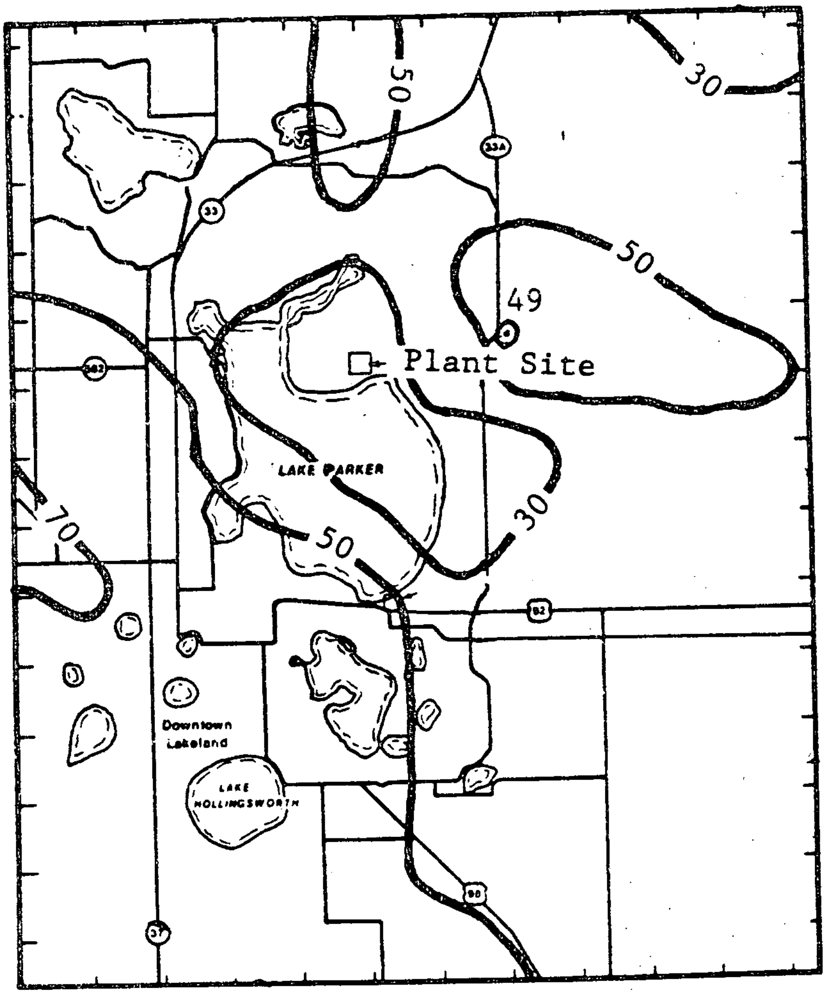

Figure 2. Climatogocial Disperison Model - Groundlevel concentrations using 10,000 gm/sec emission source at Lakeland Utility - McIntosh plant site and meteorological data from met. data - Tampa, Florida.

Isopleths are in µg/m^3.

θ indicates existing air quality monitoring site. Adjacent # is annual geometric mean for suspended parituclate concentration in µg/m^3. Bottom # (if there is one) is annual arithmatic mean for sulfur dioxide.

TABLE 29

Buffalo,NY CDMQC Input Paramaters

```
                          C L I M A T O L O G I C A L   D I S P E R S I O N   M O D E L
                          CDMQC    NIAGRA FALLS, NEW YORK          ANNUAL
                                                  RUN     3

POLLUTANTS TO BE MODELED:

    1) SO2
    2) PART


OPERATING PARAMETERS:

    X-MINIMUM OF AREA EMISSIOM INVENTORY MAP GRID (XG) ..............................          0.0
    Y-MINIMUM OF AREA EMISSION INVESTORY MAP GRID (YG) ..............................          0.0

    WIDTH OF BASIC AREA SOURCE SQUARE (TXX) ..........................................    1000.00000 METERS

    INITIAL SIGMA Z (METERS) FOR AREA SOURCES (SZA):

         STABILITY CLASS:      1 ....................................................      30.00000
                               2 ....................................................      30.00000
                               3 ....................................................      30.00000
                               4 ....................................................      30.00000
                               5 ....................................................      30.00000
                               6 ....................................................      30.00000

    NUMBER OF SUBSECTORS CONSIDERED IN A 22.5 DEGREE SECTOR (DINT) ...................       4.00000
    ANGULAR WIDTH OF A SUBSECTOR (THETA) .............................................       5.62500 DEGREES

    INITIAL RADIAL INCREMENT (DELR) ..................................................     250.00000 METERS

    RATIO OF EMISSION GRID TO MAP GRID (RAT) .........................................       1.00000
    GRID CONVERSION FACTOR (CV) ......................................................    1000.00000

    INITIAL SIGMA-Z FACTORS FOR POINT SOURCES
         MAXIMUM STACK HEIGHT FOR ADJUSTMENTS (AJP) ..................................         50.00 METERS
         MAXIMUM INITIAL VALUE (AJP1) ................................................          0.0  METERS


MISCELLANEOUS METEOROLOGICAL DATA:

    AVERAGE AFTERNOON MIXING HEIGHT (HT) .............................................    1200.00000 METERS
    AVERAGE NOCTURNAL MIXING HEIGHT (HMIN) ...........................................     625.00000 METERS
    MEAN ATMOSPHERIC TEMPERATURE (TOA) ...............................................       8.19995 DEGREES CELSIUS

    DECAY HALF LIFE FOR SO2  (GB(1)) .................................................   99999.00000 HOURS
    DECAY HALF LIFE FOR PART (GB(2)) .................................................   99999.00000 HOURS


RATIO (YD) OF AVERAGE DAYTIME EMISSION RATE TO THE 24-HOUR EMISSION RATE AVERAGE ....       1.00000
RATIO (YN) OF AVERAGE NIGHTTIME EMISSION RATE TO THE 24-HOUR EMISSION RATE AVERAGE ..       1.00000


BACKGROUND CONCENTRATION (BKGR), ARITHMETIC MEAN, FOR:

    SO2  ...........................................................................          0.0       MICROGRAMS/CU. METER
    PART ...........................................................................          0.0       MICROGRAMS/CU. METER
ANY CULPABILITY LIST(S) WILL INDIVIDUALLY LIST SOURCES CONTRIBUTING GREATER
THAN OR EQUAL TO  0.0 ( (CTOF) OF TOTAL CALIBRATED CONCENTRATION


(IOCAL=0) REGRESSION EQUATION CONSTANTS INPUT WILL BE USED TO CALIBRATE COMPUTED CONCENTRATIONS:


               INPUT CONSTANTS FOR SO2 :
                   POINT SLOPE (CBP(1)) ....          1.00000
                   AREA SLOPE ((CBA(1)) ....          1.00000
                   Y-INTERCEPT (CA(1)) .....          0.0      MICROGRAMS/CU. METER
                   BACKGROUND (BKGR(1)) ....          0.0      MICROGRAMS/CU. METER

               INPUT CONSTANTS FOR PART:
                   POINT SLOPE (CBP(2)) ....          1.00000
                   AREA SLOPE ((CBA(2)) ....          1.00000
                   Y-INTERCEPT (CA(2)) .....          0.0      MICROGRAMS/CU. METER
                   BACKGROUND (BKGR(2)) ....          0.0      MICROGRAMS/CU. METER


LARSEN'S STATISTICAL MODEL WILL BE APPLIED FOR THE FOLLOWING AVERAGING TIMES (PAV):

    SO2
       3.0 HOURS
       8.0 HOURS
      24.0 HOURS
    PART
       3.0 HOURS
       8.0 HOURS
      24.0 HOURS
```

Figure 3: Buffalo,NY Isopleths

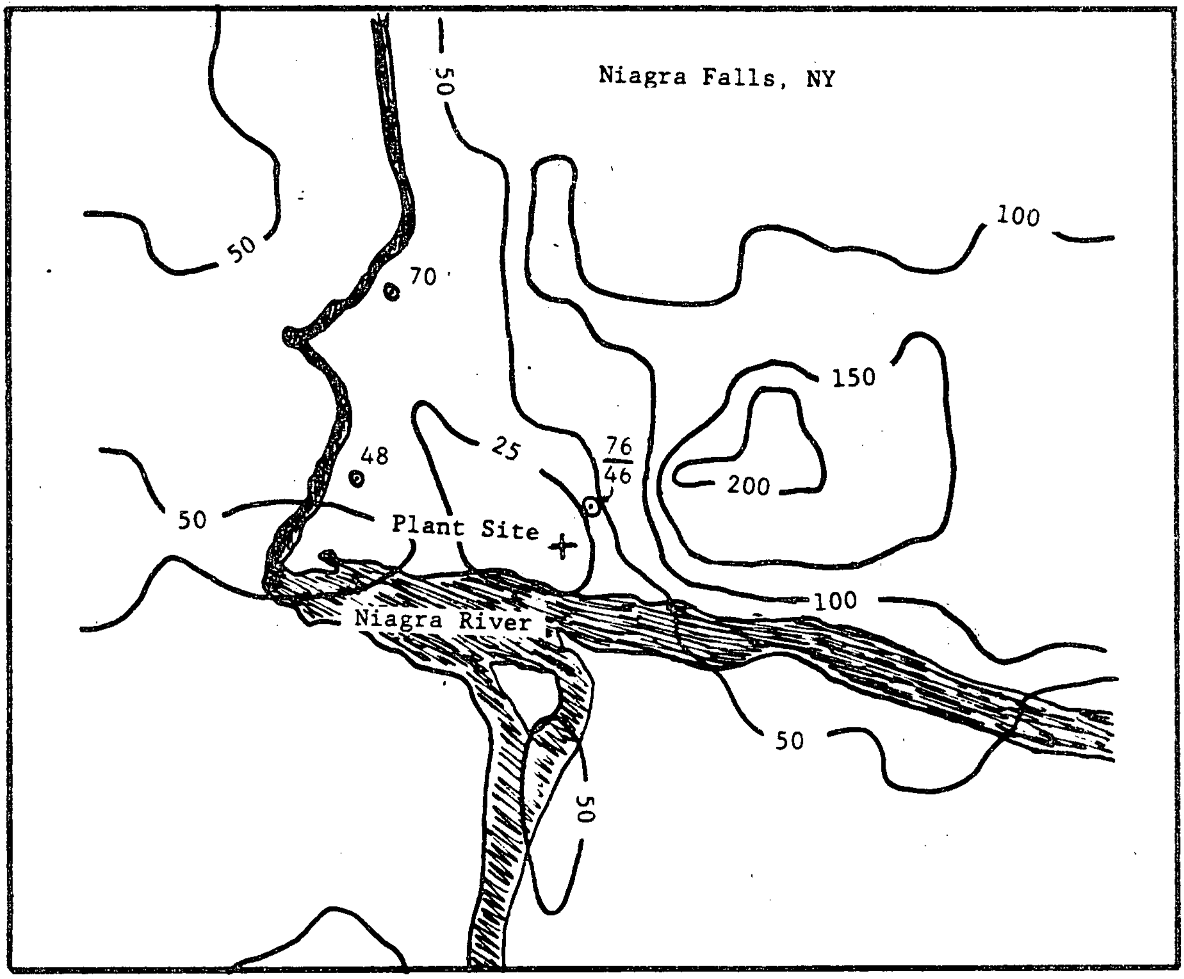

Figure 3 . Climatological Dispersion Model - Groundlevel concentrations using 10,000 gm/sec emission source at Niagra Falls, Hooker Chemical plant site and meteorological data from met. data - Buffalo, New York.

Isopleths are in µg/m^3.

⊙ indicates existing air quality monitoring site. Adjacent # is annual geometric mean for suspended particulate concentration in µg/m^3. Bottom # (if there is one) is annual arithmatic mean for sulfur dioxide.

TABLE 30

Columbus,OH CDMQC Input Paramaters

```
                         C L I M A T O L O G I C A L   D I S P E R S I O N   M O D E L
                         CDMQC    COLUMBUS, OHIO                  ANNUAL
                                                  RUN     3

POLLUTANTS TO BE MODELED:

   1) SO2
   2) PART

OPERATING PARAMETERS:

   X-MINIMUM OF AREA EMISSION INVENTORY MAP GRID (XG) ..............................        317.00000
   Y-MINIMUM OF AREA EMISSION INVESTORY MAP GRID (YG) ..............................       4409.00000

   WIDTH OF BASIC AREA SOURCE SQUARE (TXX) .........................................       1000.00000 METERS

   INITIAL SIGMA Z (METERS) FOR AREA SOURCES (SZA):

        STABILITY CLASS:     1 .....................................................         30.00000
                             2 .....................................................         30.00000
                             3 .....................................................         30.00000
                             4 .....................................................         30.00000
                             5 .....................................................         30.00000
                             6 .....................................................         30.00000

   NUMBER OF SUBSECTORS CONSIDERED IN A 22.5 DEGREE SECTOR (DINT) ..................          4.00000
   ANGULAR WIDTH OF A SUBSECTOR (THETA) ............................................          5.62500 DEGREES

   INITIAL RADIAL INCREMENT (DELR) .................................................        250.00000 METERS

   RATIO OF EMISSION GRID TO MAP GRID (RAT) ........................................          1.00000
   GRID CONVERSION FACTOR (CV) .....................................................       1000.00000

   INITIAL SIGMA-Z FACTORS FOR POINT SOURCES
        MAXIMUM STACK HEIGHT FOR ADJUSTMENTS (AJP) .................................            50.00 METERS
        MAXIMUM INITIAL VALUE (AJP1) ...............................................             0.0  METERS

MISCELLANEOUS METEOROLOGICAL DATA:

   AVERAGE AFTERNOON MIXING HEIGHT (HT) ............................................       1390.00000 METERS
   AVERAGE NOCTURNAL MIXING HEIGHT (HMIN) ..........................................        520.00000 METERS
   MEAN ATMOSPHERIC TEMPERATURE (TOA) ..............................................         11.09985 DEGREES CELSIUS

   DECAY HALF LIFE FOR SO2  (GB(1)) ................................................      99999.00000 HOURS
   DECAY HALF LIFE FOR PART (GB(2)) ................................................      99999.00000 HOURS

RATIO (YD) OF AVERAGE DAYTIME EMISSION RATE TO THE 24-HOUR EMISSION RATE AVERAGE ....          1.00000
RATIO (YN) OF AVERAGE NIGHTTIME EMISSION RATE TO THE 24-HOUR EMISSION RATE AVERAGE ..          1.00000

BACKGROUND CONCENTRATION (BKGR), ARITHMETIC MEAN, FOR:

   SO2 .............................................................................          0.0     MICROGRAMS/CU. METER
   PART ............................................................................          0.0     MICROGRAMS/CU. METER

ANY CULPABILITY LIST(S) WILL INDIVIDUALLY LIST SOURCES CONTRIBUTING GREATER
THAN OR EQUAL TO  0.0 ( (CTOF) OF TOTAL CALIBRATED CONCENTRATION

(IOCAL=0) REGRESSION EQUATION CONSTANTS INPUT WILL BE USED TO CALIBRATE COMPUTED CONCENTRATIONS:

               INPUT CONSTANTS FOR SO2 :
                   POINT SLOPE (CBP(1)) ....            1.00000
                   AREA SLOPE ((CBA(1)) ....            1.00000
                   Y-INTERCEPT (CA(1)) .....            0.0     MICROGRAMS/CU. METER
                   BACKGROUND (BKGR(1)) ....            0.0     MICROGRAMS/CU. METER

               INPUT CONSTANTS FOR PART:
                   POINT SLOPE (CBP(2)) ....            1.00000
                   AREA SLOPE ((CBA(2)) ....            1.00000
                   Y-INTERCEPT (CA(2)) .....            0.0     MICROGRAMS/CU. METER
                   BACKGROUND (BKGR(2)) ....            0.0     MICROGRAMS/CU. METER

LARSEN'S STATISTICAL MODEL WILL BE APPLIED FOR THE FOLLOWING AVERAGING TIMES (PAV):

   SO2
       3.0 HOURS
       8.0 HOURS
      24.0 HOURS
   PART
       3.0 HOURS
       8.0 HOURS
      24.0 HOURS
```

Figure 4: Columbus,OH Isopleths

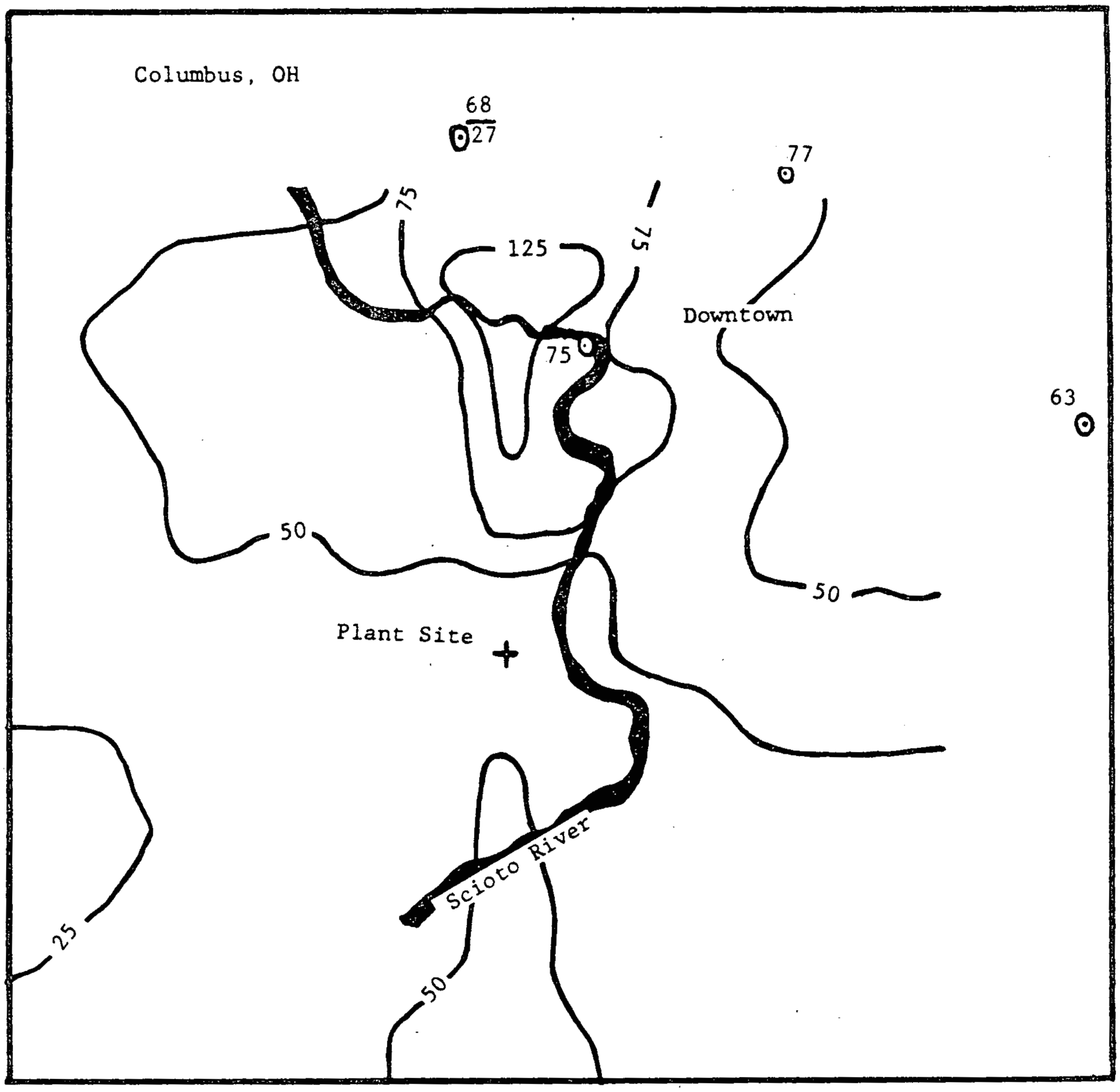

Figure 4. Climatological Dispersion Model - Groundlevel concentrations using 10,000 gm/sec emission source at Columbus Refuse Disposal plant site and meteorological data from met. data - Columbus.

Isopleths are in $\mu g/m^3$.

θ indicates existing air quality monitoring site. Adjacent # is annual geometric mean for suspended parituclate concentration in $\mu g/m^3$. Bottom # (if there is one) is annual arithmatic mean for sulfur dioxide.