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AIR EMISSIONS FROM SCRAP TIRE COMBUSTION

Prepared for:

Office of Air Quality Planning and Standards
and
U.S. - Mexico Border Information Center on Air Pollution
Centro Información sobre Contaminación de Aire

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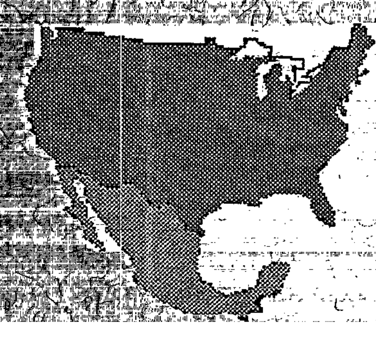

FOREWORD

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E. Timothy Oppelt, Director
National Risk Management Research Laboratory

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ABSTRACT

Two to three billion (2-3 x10^9) scrap tires are in landfills and stockpiles across the United States, and approximately one scrap tire per person is generated every year. Scrap tires represent both a disposal problem and a resource opportunity (e.g., as a fuel and in other applications). Of the many potential negative environmental and health impacts normally associated with scrap tire piles, the present study focuses on (1) examining air emissions related to open tire fires and their potential health impacts, and (2) reporting on emissions data from well designed combustors that have used tires as a fuel.

Air emissions from two types of scrap tire combustion are addressed: uncontrolled and controlled. Uncontrolled sources are open tire fires, which produce many unhealthful products of incomplete combustion and release them directly into the atmosphere. Controlled combustion sources (combustors) include boilers and kilns specifically designed for efficient combustion of solid fuel.

Very little data exist for devices that are not well-designed and use scrap tires for fuel. These sources include fireplaces, wood stoves, small kilns, small incinerators, or any device with poor combustion characteristics. Air emissions from these types of devices are likely between that of open burning and a combustor. However, there is serious concern that the emissions are much more similar to those of an open tire fire than a combustor.

Open tire fires are discussed. Data from a laboratory test program on uncontrolled burning of tire pieces and ambient monitoring at open tire fires are presented and the emissions are characterized. Mutagenic emission data from open burning of scrap tires are compared to mutagenic data for other fuels from both controlled and uncontrolled combustion.

A list of 34 target compounds representing the highest potential for health impacts from open tire fires is presented. The list can be used to design an air monitoring plan in order to evaluate the potential for health risks in future events.

Methods for preventing and managing tire fires are reviewed. Recommendations are presented for storage site design, civilian evacuation, and fire suppression tactics.

Air emissions data from the use of tires as fuel are discussed. The results of a laboratory test program on controlled burning of tire-derived fuel (TDF) in a Rotary Kiln Incinerator Simulator (RKIS) are presented. Based on the results of the RKIS test program, it was concluded that, with the exception of zinc emissions, potential emissions from TDF are not expected to be very much different than from other conventional fossil fuels, as long as combustion occurs in a well-designed, well-operated, and well-maintained combustion device.

Source test data from 22 industrial facilities that have used TDF are presented: 3 kilns (2 cement and 1 lime) and 19 boilers (utility, pulp and paper, and general industrial applications). In general, the results indicate that properly designed existing solid fuel combustors can supplement their normal fuels (coal, wood, and various combinations of coal, wood, oil, coke, and sludge) with 10 to 20% TDF and still satisfy environmental compliance emissions limits. Furthermore, results from a dedicated tires-to-energy (100% TDF) facility indicate that it is possible to have emissions much lower than produced by existing solid-fuel-fired boilers (on a heat input basis), when properly designed and the facility is controlled.

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ABBREVIATIONS AND ACRONYMS

ATSDR	Agency for Toxic Substances and Disease Registry
AWMA	Air and Waste Management Association
BaP	benzo(a)pyrene
BTU	British thermal unit
CTPV	coal tar pitch volatiles
EPA	U.S. Environmental Protection Agency
ERT	EPA's Emergency Response Team
ESP	electrostatic precipitator
GC/MS	gas chromatography/mass spectroscopy
HAP	hazardous air pollutant
HPLC	high-pressure liquid chromatography
IAFC	International Association of Fire Chiefs
IDLH	Immediately Dangerous to Life and Health
NAAQS	National Ambient Air Quality Standard
NIOSH	National Institute for Occupational Safety and Health
NSP	Northern States Power
PAH	polynuclear aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCDD	polychlorinated p-dibenzodioxins
PCDF	polychlorinated dibenzofurans
PIC	product of incomplete combustion
PM	particulate matter
PM_{10}	particulate matter less than 10 µm in aerodynamic diameter
PNA	polynuclear aromatic hydrocarbon
RfC	inhalation reference concentration
RKIS	rotary kiln incinerator simulator
STMC	Scrap Tire Management Council
TDF	tire-derived fuel
TLV	threshold limit value
TPCHD	Tacoma-Pierce County Health Department
TSP	total suspended particulate
TWA	time-weighted average
UPA	United Power Association
VOC	volatile organic compound
VOST	Volatile Organic Sampling Train
WDNR	Wisconsin Department of Natural Resources
WP&L	Wisconsin Power and Light

EXECUTIVE SUMMARY

Two to three billion (2-3 x10^9) scrap tires are in landfills and stockpiles across the United States, and approximately one scrap tire per person is generated every year. Scrap tires represent both a disposal problem and a resource opportunity (e.g., as a fuel and in other applications). Of the many potential negative environmental and health impacts normally associated with scrap tire piles, the present study focuses on (1) examining air emissions related to open tire fires and their potential health impacts, and (2) reporting on emissions data from well designed combustors that have used tires as a fuel.

Air emissions from two types of scrap tire combustion are addressed: uncontrolled and controlled. Uncontrolled sources are open tire fires, which produce many unhealthful products of incomplete combustion and release them directly into the atmosphere. Controlled combustion sources (combustors) are, for example, boilers and kilns specifically designed for efficient combustion of solid fuel. Combustor emissions are much lower and more often than not, these sources also have appropriate add-on air pollution control equipment for the control of particulate emissions.

Very little data exist for devices that are not well-designed and use scrap tires for fuel. These sources include fireplaces, wood stoves, small kilns, small incinerators, or any device with poor combustion characteristics. Air emissions from these types of devices are likely between that of open burning and a combustor. There is serious concern that emissions would be more like those of an open tire fire than a well-designed combustor; however, emissions testing would have to be conducted to confirm this.

Open Tire Fires

Air emissions from open tire fires have been shown to be more toxic (e.g., mutagenic) than those of a combustor, regardless of the fuel. Open tire fire emissions include "criteria" pollutants, such as particulates, carbon monoxide (CO), sulfur oxides (SO_x), oxides of nitrogen (NO_x), and volatile organic compounds (VOCs). They also include "non-criteria" hazardous air pollutants (HAPs), such as polynuclear aromatic hydrocarbons (PAHs), dioxins, furans, hydrogen chloride, benzene, polychlorinated biphenyls (PCBs); and metals such as arsenic, cadmium, nickel, zinc, mercury, chromium, and vanadium. Both criteria and HAP emissions from an open tire fire can represent significant acute (short-term) and chronic (long-term) health hazards to firefighters and nearby residents. Depending on the length and degree of exposure, these health effects could include irritation of the skin, eyes, and mucous membranes, respiratory effects, central nervous system depression, and cancer. Firefighters and others working near a large tire fire should be equipped with respirators and dermal protection. Unprotected exposure to the visible smoke plume should be avoided.

Data from a laboratory test program on uncontrolled burning of tire pieces and ambient monitoring at open tire fires are presented and the emissions are characterized. Mutagenic emission data from open burning of scrap tires are compared to other types of fuel combustion. Open tire fire emissions are estimated to be 16 times more mutagenic than residential wood combustion in a fireplace, and 13,000 times more mutagenic than coal-fired utility emissions with good combustion efficiency and add-on controls.

A list of 34 target compounds representing the highest potential for inhalation health impacts from open tire fires was developed by analyzing laboratory test data and open tire fire data collected at nine tire fires. The list can be used to design an air monitoring plan in order to evaluate the potential for health risks in future events.

Methods for preventing and managing tire fires are presented. Recommendations are presented for storage site design, civilian evacuation, and fire suppression tactics. For example, tire piles should not exceed 6 m (20 ft) in height; maximum outside dimensions should be limited to 76 m (250 ft) by 6 m (20 ft). Interior fire breaks should be at least 18 m (60 ft) wide. Civilians should be evacuated when they may be subject to exposure by the smoke plume. Fire suppression tactics are site and incident-specific and firefighters should have specialized training to deal effectively with them.

Other Impacts from Open Tire Burning

The scope of this report is limited to airborne emissions. However, significant amounts of liquids and solids containing dangerous chemicals can be generated by melting tires. These products can pollute soil, surface water, and ground water and care must be taken to properly manage these impacts as well.

Controlled Combustion

The results of a laboratory test program on controlled burning of tire-derived fuel (TDF) in a Rotary Kiln Incinerator Simulator (RKIS) are presented. In all, 30 test conditions were run, with the TDF feed rate varying from 0 to 21.4% of heat input. The test conditions were achieved by varying kiln firing rate, combustion air flow rate, and tire feed rate. The majority of the tests were conducted with a steady-state feed of TDF. However, variations in the mode of TDF feeding were simulated in two tests to evaluate the impact of transient operation on air emissions.

Based on the results of the RKIS test program, it can be concluded that, with the exception of zinc emissions, potential emissions from TDF are not expected to be very much different than from other conventional fossil fuels, as long as combustion occurs in a well-designed, well-operated and well-maintained combustion device. However, as with most solid fuel combustors, an appropriate particulate control device would likely be needed in order to obtain an operating permit in most jurisdictions in the United States.

Test data, from 22 industrial facilities that have used TDF are presented: 3 kilns (2 cement and 1 lime) and 19 boilers (utility, pulp and paper, and general industrial applications). All sources had some type of particulate control. In general, the results indicate that properly designed existing solid fuel combustors can supplement their normal fuels, which typically consist of coal, wood, coke and various combinations thereof, with 10 to 20% TDF and still satisfy environmental compliance emissions limits. Furthermore, results from a dedicated tires-to-energy (100% TDF) facility indicate that it is possible to have emissions much lower than produced by existing solid-fuel-fired boilers (on a heat input basis) with a specially designed combustor and add-on controls.

Depending on the design of the combustion device, some tire processing is usually necessary before it is ready to be used as a fuel. Processing includes dewiring and shredding and/or other sizing techniques. Some specially designed boilers and cement kilns have had their feed systems designed to accept whole tires.

TDF has been used successfully in properly designed combustors with good combustion control and appropriate add-on controls, particularly particulate controls, such as electrostatic precipitators or fabric filters. The resultant air emissions can usually satisfy environmental compliance limits even with TDF representing up to 10 to 20% of the fuel requirements. Twenty percent supplemental TDF is perceived as an upper limit in most existing boilers because of boiler limitations on fuel or performance. However, dedicated tire-to-energy facilities specifically designed to burn TDF as their only fuel have been demonstrated to achieve emission rates much lower than most solid fuel combustors.

Conclusion

Air emissions have been documented from open burning of scrap tires and from TDF in well-designed combustors. Laboratory and field studies have confirmed that open burning produces toxic gases that can represent significant acute and chronic health hazards. However, field studies have also confirmed that TDF can be used successfully as a 10 - 20% supplementary fuel in properly designed solid-fuel combustors with good combustion control and add-on particulate controls, such as electrostatic precipitators or fabric filters. Furthermore, a dedicated tire-to-energy facility specifically designed to burn TDF as its only fuel has been demonstrated to achieve emission rates much lower than most solid fuel combustors.

No field data were available for well-designed combustors with no add-on particulate controls. Laboratory testing of an RKIS indicated that efficient combustion of supplementary TDF can destroy many volatile and semi-volatile air contaminants. However, it is not likely that a solid fuel combustor without add-on particulate controls could satisfy air emission regulatory requirements in the U.S.

No data were available for poorly designed or primitive combustion devices with no add-on controls. Air emissions from these types of devices would depend on design, fuel type, method of feeding, and other parameters. There is serious concern that emissions would be more like those of an open tire fire than a well-designed combustor. Stack emissions test data would need to be collected and analyzed to confirm this.

1.0 INTRODUCTION

The purpose of this study is to summarize available information on air emissions and potential health impacts from scrap tire combustion. The study addresses uncontrolled burning, such as from tire fires, and controlled burning, where processed tires, or tire-derived fuel (TDF) are used as a fuel supplement in a combustion device such as a boiler or kiln. Controlled burning implies that the system is adequately designed to effect efficient combustion and may have other add-on air pollution controls, most likely for particulate control.

Air emissions from open burning of tires include "criteria" pollutants, such as particulates, carbon monoxide (CO), sulfur oxides (SO_x), oxides of nitrogen (NO_x), and volatile organic compounds (VOCs). They also include "non-criteria" hazardous air pollutants (HAPs), such as polynuclear aromatic hydrocarbons (PAHs), dioxins, furans, hydrogen chloride, benzene, polychlorinated biphenyls (PCBs); and metals such as arsenic, cadmium, nickel, zinc, mercury, chromium, and vanadium. In open fire situations, these emissions can represent significant acute (short term) and chronic (long-term) health hazards to firefighters and nearby residents. These health effects include irritation of the skin, eyes, and mucous membranes, central nervous system depression, respiratory effects, and cancer.

TDF has been used successfully in properly designed combustors with good combustion control and appropriate add-on controls, particularly particulate controls, such as electrostatic precipitators (ESPs) or fabric filters. Air emissions characteristic of TDF combustion are typical of most solid fuels, such as coal and wood. The resultant air emissions can usually satisfy environmental compliance limits even with TDF representing up to 10 to 20% of the fuel requirements. Twenty percent supplemental TDF is perceived as an upper limit in most existing boilers because of boiler limitations on fuel or performance (Clark et al., 1991). However, dedicated tire-to-energy facilities specifically designed to burn TDF as their only fuel have been demonstrated to achieve emission rates much less than most solid fuel combustors.

2.0 EMISSIONS FROM OPEN TIRE FIRES

Airborne missions from open tire fires have long been suspected of representing a serious impact to health and the environment. However, due to the lack of sufficient data, it was uncertain as to exactly what was being emitted, how much was being emitted, and how dangerous these emissions were, especially to sensitive individuals (e.g., children and the elderly). In recent years, a number of laboratory and field test programs have been conducted to identify and quantify these emissions. This section summarizes the results of a number of key studies in this area and briefly discusses certain aspects of preventing and managing tire fires.

2.1 LABORATORY EMISSIONS TESTING

A controlled simulation test program designed to identify and quantify organic and inorganic emission products during the simulated open combustion of scrap tires was conducted by EPA (Ryan, 1989) and further documented in an Air and Waste Management Association Paper [(AWMA) Lemieux and Ryan, 1993]. This important study is summarized in detail below.

Small quantities of 4.5 to 9 kilograms {kg [10 to 20 pounds (lb)]} of scrap tire material were burned under two controlled conditions in a 2.4 x 2.4 x 2.4 m [8 x 8 x 8 foot (ft)] ventilated, instrumented burn hut. Two sizes of tire material were burned: "chunk," about 1/6 to 1/4 of an entire tire and "shred", where the tire pieces were 5 x 5 centimeters {cm [2 x 2 inches (in)]}. EPA's Hazardous Air Pollutants Mobile Laboratory was used to monitor fixed combustion gases. Organics were collected using the volatile organic sampling train and a semi-volatile collection system using XAD-2 resin and particulate filters. Particulate was also collected to assess airborne metals and to measure the amount of particulate less than 10 microns (µm) in aerodynamic diameter (PM_{10}). The organic constituents were analyzed using gas chromatography/mass spectroscopy (GC/MS), gas chromatography/flame ionization detection, and high pressure liquid chromatography (HPLC).

The results of the test program are presented in Tables 1 through 4. Table 1 presents an averaging of the three sets of volatile organic sampling train (VOST) samples taken at each run condition, each taken at different periods during the burn. Benzene is emitted in large quantities under both conditions. The majority of the volatile organic emissions are aliphatic-, olefinic-, or acetylenic-substituted aromatics. Cyclic alkanes, alkenes, and dienes were also present. Butadiene, a major constituent of the tire fabrication process was also present. The estimated emissions were calculated assuming that dilution air was added at a constant volume flow and the amount of air entering equaled the amount exiting the burn hut. A well-mixed condition is also assumed (i.e., the sample collected at the duct is representative of the gas mixture in the hut).

Semi-volatile organic emissions data are presented in Table 2. Substituted mono-

TABLE 1. OPEN BURNING EMISSIONS: VOLATILE ORGANICS[a,b] (LABORATORY SIMULATION)

Compound	Chunk			Shred		
	Exhaust Conc. (mg/m^3)	Emission Factor (mass/mass tire)		Exhaust Conc. (mg/m^3)	Emission Factor (mass/mass tire)	
		mg/kg	lb/ton		mg/kg	lb/ton
Benzaldehyde	0.260	299.2	0.5984	0.215	330	0.660
Benzene	1.910	2,156.3	4.3126	1.40	2,205	4.410
Benzodiazine	0.017	13.7	0.0274	0.014	17.4	0.0348
Benzofuran	0.049	25.1	0.0502	ND	ND	ND
Benzothiophene	0.014	26.3	0.0526	0.011	14.7	0.0294
1,3-Butadiene	0.152	308.4	0.6168	0.096	160	0.320
Cyclopentadiene	0.081	48.6	0.0972	ND	ND	ND
Dihydroindene	0.013	40.6	0.0812	0.021	42.8	0.0856
Dimethyl benzene	0.413	779.7	1.559	0.629	1,078	2.156
Dimethyl hexadiene	0.008	28.3	0.0566	0.049	90.9	0.182
Dimethyl methyl propyl benzene	ND	ND	ND	0.008	14.9	0.298
Dimethyl dihydroindene	0.007	22.0	0.0440	0.008	17.7	0.0354
Ethenyl benzene	0.678	941.8	1.88	0.395	611.4	1.223
Ethenyl cyclohexane	0.006	26.2	0.0524	0.060	107.6	0.2152
Ethenyl dimethyl benzene	0.014	7.2	0.014	0.014	23.7	0.0474
Ethenyl methyl benzene	0.016	14.1	0.0282	0.014	19.5	0.0390
Ethenyl dimethyl cyclohexane	ND	ND	ND	0.193	350.4	0.7008
Ethenyl methyl benzene	0.129	221.6	0.4432	0.028	40.9	0.0818
Ethyl benzene	0.182	460.8	0.9216	0.164	295.1	0.5902
Ethyl methyl benzene	0.120	334.5	0.6690	0.262	475.8	0.9516
Ethynyl benzene	0.322	190.0	0.3800	0.110	131.5	0.2630
Ethynyl methyl benzene	0.562	530.6	1.061	0.226	258.7	0.5174
Heptadiene	0.009	25.4	0.051	0.028	51.4	0.103

(Continued)

TABLE 1. OPEN BURNING EMISSIONS: VOLATILE ORGANICS[a,b] (LABORATORY SIMULATION) (Cont.)

Compound	Chunk			Shred		
	Exhaust Conc. (mg/m^3)	Emission Factor (mass/mass tire)		Exhaust Conc. (mg/m^3)	Emission Factor (mass/mass tire)	
		mg/kg	lb/ton		mg/kg	lb/ton
Isocyanobenzene	0.341	348	0.696	0.191	290	0.580
Limonene	0.011	27.5	0.055	0.513	893	1.79
Methyl benzene	0.976	1,606	3.21	0.714	1,129	2.26
Methyl cyclohexane	0.005	21.1	0.420	0.023	40.1	0.080
Methyl hexadiene	0.021	71.3	0.143	0.068	127	0.254
Methyl indene	0.138	316	0.632	0.087	140	0.280
Methyl naphthalene	0.287	312	0.624	0.135	197	0.394
Methyl thiophene	0.006	5.5	0.011	0.007	12.6	0.025
Methyl ethenyl benzene	0.027	55.7	0.111	0.045	76.6	0.153
Methyl methylethenyl benzene	0.046	98.0	0.196	0.373	683	1.37
Methyl methylethyl benzene	0.041	111	0.222	0.165	283	0.566
Methyl methylethyl cyclohexane	ND	ND	ND	0.086	170	0.340
Methyl propyl benzene	ND	ND	ND	0.020	41.6	0.083
Methylene indene	0.038	48.5	0.097	0.022	34.4	0.069
Methylethyl benzene	0.045	135	0.270	0.092	169	0.338
Naphthalene	1.29	1,130	2.26	0.607	824	1.65
Pentadiene	0.077	164	0.388	0.680	1,163	2.33
Phenol	0.002	0.5	0.001	0.016	14.3	0.029
Propyl benzene	0.026	72.4	0.145	0.046	84.2	0.168
Tetramethyl benzene	ND	ND	ND	0.130	256	0.512
Thiophene	0.023	54.6	0.109	0.021	27.9	0.056
Trichlorofluoromethane	0.158	57.6	0.115	ND	ND	ND
Trimethyl benzene	0.022	46.9	0.0938	0.042	74.9	0.150
TOTALS	8.53	11,182	22.364	8.03	13,068	26.136

[a] Concentrations determined using system responses to toluene.
[b] These data are averaged over six sets of VOST tubes taken over 2 days.
ND = None detected.

TABLE 2. OPEN BURNING EMISSIONS: SEMI-VOLATILE ORGANICS (LABORATORY SIMULATION)

Compound	Chunk			Shred		
	Exhaust Conc. (mg/m³)	Emission Factor (mass/mass tire)		Exhaust Conc. (mg/m³)	Emission Factor (mass/mass tire)	
		mg/kg	lb/ton		mg/kg	lb/ton
1-Methyl naphthalene	0.292	330.7	0.6614	0.133	227.6	0.4552
1,1' Biphenyl,methyl	0.013	11.1	0.0222	ND	ND	ND
1H fluorene	0.187	210.3	0.4206	0.183	308.4	0.6168
2-Methyl naphthalene	0.314	350.7	0.7014	0.255	429.2	0.8584
Acenaphthylene	0.580	633.8	1.267	0.318	531.1	1.062
Benzaldehyde	0.218	244.1	0.4482	0.180	333.9	0.6678
Benzisothiazole	ND	ND	ND	0.094	173.9	0.3478
Benz(b)thiophene	0.050	44.2	0.0884	ND	ND	ND
Biphenyl	0.186	209.5	0.4190	0.193	330.1	0.6602
Cyanobenzene	0.199	223.7	0.4474	0.300	516.8	1.034
Dimethyl benzene	0.254	305.0	0.6100	0.544	935.1	1.870
Dimethyl-naphthalene	0.034	41.1	0.082	0.096	178.1	0.3562
Ethyl benzene	0.181	205.2	0.4104	0.197	337.6	0.6752
Ethyl dimethyl benzene	ND	ND	ND	0.158	272.4	0.5448
Ethynyl benzene	0.254	275.8	0.5516	0.112	187.4	0.3748
Hexahydro-azepinone	0.062	75.1	0.150	0.445	748.5	1.497
Indene	0.462	503.4	1.007	0.201	339.2	0.6784
Isocyano- naphthalene	0.011	9.4	0.019	ND	ND	ND
Limonene	0.047	56.1	0.112	1.361	2,345.5	4.6910
Methyl benzaldehyde	ND	ND	ND	0.047	86.6	0.173
Methyl benzene	1.105	1,212.2	2.4244	0.816	1,390.1	2.7802
Methyl indene	0.093	111.8	0.02360	0.234	400.7	0.8014

(Continued)

TABLE 2. OPEN BURNING EMISSIONS: SEMI-VOLATILE ORGANICS (LABORATORY SIMULATION) (Cont.)

Compound	Chunk			Shred		
	Exhaust Conc. (mg/m³)	Emission Factor (mass/mass tire)		Exhaust Conc. (mg/m³)	Emission Factor (mass/mass tire)	
		mg/kg	lb/ton		mg/kg	lb/ton
Methyl methylethyl benzene	0.107	127.9	0.2558	0.821	1,426.1	2.8522
Methylethyl benzene	0.040	48.3	0.0966	0.133	229.1	0.4582
Naphthalene	1.578	1,697.9	3.3958	0.671	1,130.7	2.2614
Phenanthrene	0.173	183.7	0.3674	0.119	187.0	0.3740
Phenol	0.330	365.9	0.7318	0.412	700.2	1.400
Propenyl naphthalene	0.027	23.5	0.0470	ND	ND	ND
Propenyl methyl benzene	ND	ND	ND	0.282	523.6	1.047
Propyl benzene	ND	ND	ND	0.127	219.6	0.4392
Styrene	0.605	659.9	1.320	0.380	645.5	1.291
Tetramethyl benzene	ND	ND	ND	0.049	91.9	0.184
Trimethyl benzene	ND	209.4	0.4188	0.446	751.4	1.502
Trimethyl naphthalene	ND	ND	ND	0.185	315.8	0.6316
TOTALS	**7.593**	**8,369.7**	**16.739**	**9.492**	**16,293.1**	**32.5862**

ND - None detected.

TABLE 3. OPEN BURNING: TOTAL ORGANICS EMISSION SUMMARY (LABORATORY SIMULATION)

Organic Component	Chunk			Shred		
	Exhaust Conc. (mg/m^3)	Emission Factor (mass/mass tire)		Exhaust Conc. (mg/m^3)	Emission Factor (mass/mass tire)	
		mg/kg	lb/ton		mg/kg	lb/ton
Volatile	8.53	11,182	22.364	8.03	13,068	26.136
Semi-Volatile	3,514.6	9,792.0	19.584	8,473.0	31,686.0	63.3720
Particulate	4,048.0	11,223.5	22.4470	4,151.9	14,888.0	29.7760
TOTALS	**7,571.1**	**32,197.5**	**64.3950**	**12,632.93**	**59,642.0**	**119.284**

TABLE 4. OPEN BURNING: PAH EMISSIONS (LABORATORY SIMULATION)

Compound	Chunk			Shred		
	Exhaust Conc. (mg/m³)	Emission Factor (mass/mass tire)		Exhaust Conc. (mg/m³)	Emission Factor (mass/mass tire)	
		mg/kg	lb/ton		mg/kg	lb/ton
Naphthalene	0.786	815.9	1.632	0.289	486.0	0.9720
Acenaphthylene	0.802	861.3	1.722	0.334	561.8	1.124
Acenaphthene	0.282	290.3	0.5806	1.404	2,445.7	4.8914
Fluorene	0.243	260.5	0.5210	0.112	186.8	0.3736
Phenanthrene	0.225	237.5	0.4750	0.149	252.5	0.5050
Anthracene	0.053	56.3	0.113	0.029	49.6	0.099
Fluoranthene	0.324	338.7	0.6774	0.273	458.0	0.9160
Pyrene	0.030	33.8	0.0676	0.090	151.7	0.3034
Benz(a)anthracene	0.076	82.2	0.164	0.062	102.4	0.2048
Chrysene	0.068	70.8	0.142	0.056	91.6	0.183
Benzo(b)fluoranthene	0.064	69.4	0.139	0.053	88.4	0.177
Benzo(k)fluoranthene	0.069	74.3	0.149	0.059	99.4	0.199
Benzo(a)pyrene	0.08	84.8	0.170	0.068	113.9	0.2278
Dibenz(a,h)anthracene	0.001	1.1	0.0022	ND	ND	ND
Benzo(g,h,i)perylene	0.060	66.0	0.132	0.095	159.4	0.3188
Indeno(1,2,3-cd)pyrene	0.049	51.6	0.103	0.051	85.5	0.171
TOTALS	**3.212**	**3,394.5**	**6.7890**	**3.124**	**5,332.7**	**10.665**

and polyaromatics were also the predominant products of incomplete combustion (PICs). The data represent an average of three samples taken over the entire course of the day's run. The organic emissions summary is presented in Table 3.

PAH emissions data are presented in Table 4. The 16-PAHs include several compounds known to be carcinogenic. In particular, the presence and magnitude of benzo(a)pyrene (BaP) is of major concern. BaP is often a highly-scrutinized compound during evaluations of combustion processes, due to its high cancer potency.

Particulate was collected using three separate systems, a semi-volatile organic system, airborne metals particulate collection, and a medium volume ambient PM_{10} sampler located inside the burn hut [operated at 0.11 cubic meters per minute (m^3/min) or 4 cubic feet per minute (ft^3/min)]. The particulate emissions data generated from the use of these three systems are presented in Table 5. The authors found that the particulate emissions rate decreases with decreasing burn rate, and that nearly 100 g of particulate is emitted for every kilogram of tire combusted.

A separate particulate collection system was used to analyze 17 metals found in combusted-tire ash residues. The results of the metals analysis are presented in Table 6. The only significant metals emissions compared to blank samples were lead and zinc emissions. The authors concluded that both average gaseous concentration and estimated emissions of zinc increase with increasing burn rates.

2.2 MUTAGENICITY OF TIRE FIRE EMISSIONS

In a follow-up study to the 1989 Ryan report, Lemieux and DeMarini (1992) analyzed the air emissions data collected in the laboratory study to evaluate potential health impacts. An experimental technique called bioassay-directed fractionation combined with additional GC/MS analyses was used to evaluate quantity and potency of airborne mutagens from the PICs emitted during open tire burning. The method of bioassay-directed fractionation uses mutagenic assays of chemical fractions of complex mixtures such as PICs to identify chemical classes and species responsible for mutagenic activity. It was concluded that: "The mutagenic emission factor for open tire burning is the greatest of any other combustion emission studied previously. For example, it is 3-4 orders of magnitude greater than the mutagenic emission factors for the combustion of oil, coal, or wood in utility boilers" (Lemieux and DeMarini, 1992). A mutagen is defined as a substance that causes mutations. A mutation is a change in the genetic material in a body cell. These mutations can lead to birth defects, miscarriages, or cancer (ATSDR, 1990). Mutagens are of concern because "the induction of genetic damage may cause an increased incidence of genetic disease in future generations and contribute to somatic cell diseases, including cancer, in the present generation" (Amdur, 1991).

Mutagenic emission factors are compared in the bar chart presented as Figure 1 for various combustion processes [units: revertants per kilogram (revertants/kg) of fuel. A revertant is represented by a bacterial colony that forms after the organic effluent from a tire burn is mixed with a specific bacteriological strain. The number of colonies are

TABLE 5. OPEN BURNING: PARTICULATE EMISSIONS (LABORATORY SIMULATION)

Sample	Chunk: Exhaust Conc. (mg/m^3)	Chunk: Emission Factor (mass/mass tire) mg/kg	Chunk: Emission Factor (mass/mass tire) lb/ton	Chunk: Extractable Organic (%)	Shred: Exhaust Conc. (mg/m^3)	Shred: Estimated Emissions mg/kg	Shred: Estimated Emissions lb/ton	Shred: Extractable Organic (%)
Organic Particulate Filter	93	97,100	1,940	10.6	43.75	73,400	147	19.65
Metal Particulate Filter	111.55	105,000	210	N/A	37.9	64,500	129	N/A
PM_{10} Filter [a]	444.14	113,500	227.0	N/A	92.85	149,000	298	N/A

N/A = not analyzed.

[a] The PM_{10} sampling filter became heavily loaded during the initial part of each run. The results are biased high due to higher burning rates that occurred during this portion of the run.

TABLE 6. OPEN BURNING: METALS EMISSIONS (LABORATORY SIMULATION)

Metals	Chunk			Shred		
	Exhaust Conc. (mg/m³)	Emission Factor (mass/mass tire)		Exhaust Conc. (mg/m³)	Emission Factor (mass/mass tire)	
		mg/kg	lb/ton		mg/kg	lb/ton
Aluminum	ND	ND	ND	ND	ND	ND
Antimony	ND	ND	ND	ND	ND	ND
Arsenic	ND	ND	ND	ND	ND	ND
Barium	ND	ND	ND	ND	ND	ND
Calcium	0.0079	8.54	0.0171	0.0028	4.80	0.00960
Chromium	ND	ND	ND	ND	ND	ND
Copper	ND	ND	ND	ND	ND	ND
Iron	ND	ND	ND	ND	ND	ND
Lead	0.0004	0.47	0.0094	0.0001	0.10	0.00020
Magnesium	0.0012	1.26	0.00252	0.0005	0.75	0.0015
Nickel	ND	ND	ND	ND	ND	ND
Selenium	ND	ND	ND	ND	ND	ND
Sodium	0.0084	9.51	0.0190	0.0035	5.80	0.0116
Titanium	ND	ND	ND	ND	ND	ND
Vanadium	ND	ND	ND	ND	ND	ND
Zinc	0.0409	31.17	0.06234	0.0146	24.35	0.04870

ND = Not detected.

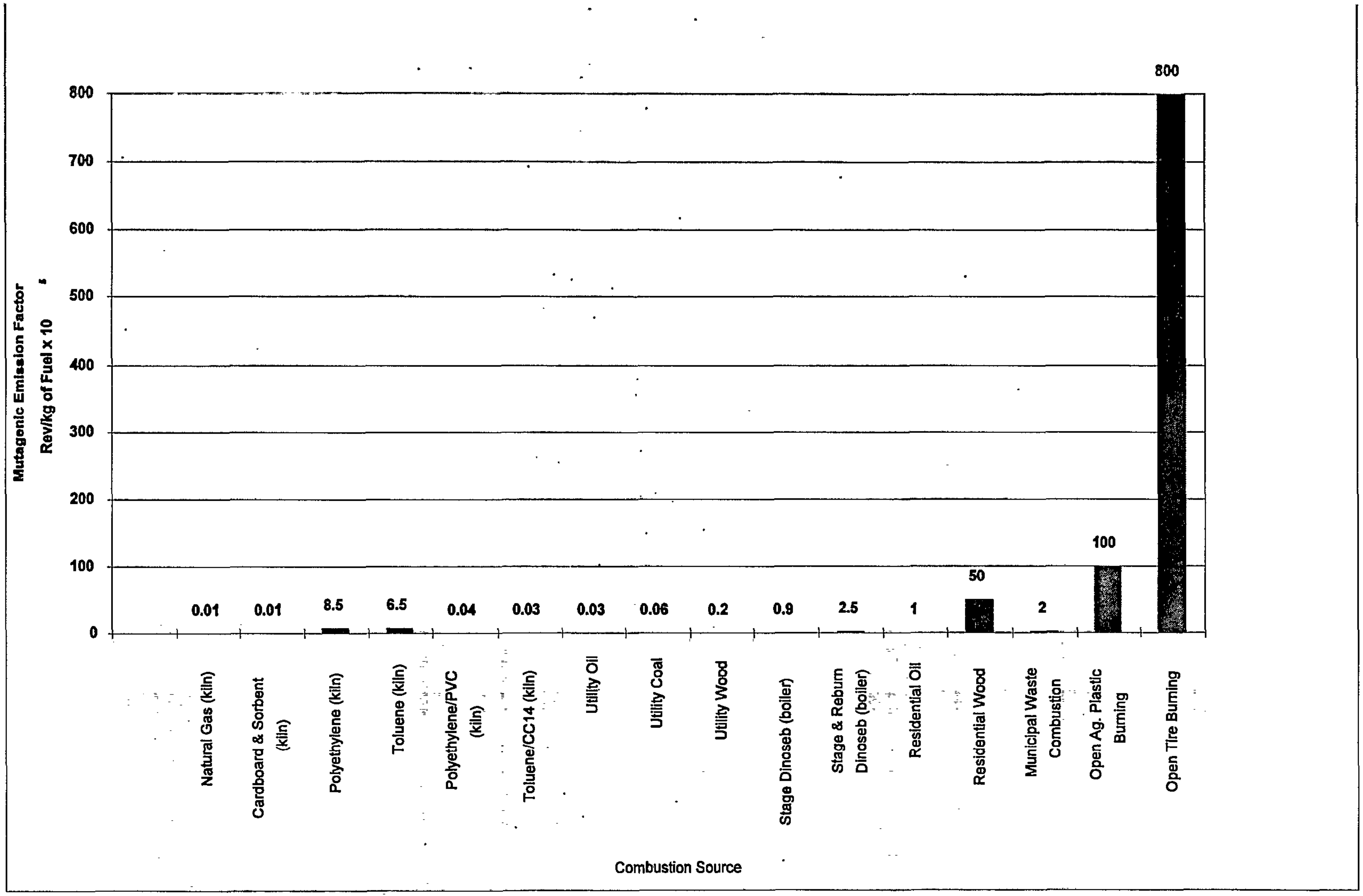

FIGURE 1. MUTAGENIC EMISSION FACTORS FOR VARIOUS COMBUSTION PROCESSES

counted to determine the number of revertants per mass of organics. The authors concluded that open burning of tires, wood, and plastic results in exceptionally high mutagenic emission factors and that "open burning, regardless of the feed stock or fuel, results in greater mutagenic emission factors than does controlled combustion provided by various types of incinerators or boilers" (Lemieux and DeMarini, 1992).

The authors found similar mutagenic emission factors of semi-volatile organics produced by the large (chunk) and small (shred) tire pieces. They also found that the mutagenic emission factors for the particulate organics were much greater than those for organics.

The report's final conclusion serves as a potentially serious warning: "Considering the (a) relatively high mutagenic potency of the particulate organics, (b) high mutagenic emission factors, and (c) presence of many mutagens/carcinogens, especially PAHs, in the effluent from the open burning of tires, such burns pose a genuine environmental and health hazard" (Lemieux and DeMarini, 1992).

2.3 FIELD SAMPLING - AIR MONITORING DATA NEAR TIRE FIRES

Field sampling data from uncontrolled open tire fires is lacking. This is a result of the inherent difficulties encountered in obtaining the data due to safety concerns and the variable nature of the event (e.g., fire size and duration, meteorological conditions, terrain effects, combustion conditions and fire-fighting activities). Furthermore, the primary concern on the part of officials in charge is to provide for the safety and welfare of those who may be affected by the heat and smoke from the fire.

TRC Environmental Corporation collected, evaluated, and documented air monitoring data from 22 actual tire fire emergencies for the EPA (TRC, 1993). The concentration data that was collected were intended primarily for use by public officials to determine evacuation areas. Seventeen analytes common to tire fire incidents were analyzed, all VOCs.

The ambient concentration data were extremely scattered. This is not unexpected, given the difficulties in obtaining reliable field data during an open tire fire. The summary data are presented in two groups, concentrations measured within 305 m (1000 feet) of the fire and concentrations measured beyond 305 m (1000 feet). Summary statistics are presented in Tables 7 and 8. Of the 17 analytes studied, benzene, toluene, and styrene had the highest overall concentrations. The report acknowledges that particulate matter containing PAHs and heavy metals are known tire fire emissions, however because of the lack of PM monitoring data, these compounds were not addressed. Therefore, the available data are not fully representative of the potential health risks from exposure to open tire fire emissions.

TABLE 7. OPEN BURNING: AMBIENT CONCENTRATIONS ≤305 m (1000 FT) DOWNWIND

Analyte	n[1]	No. Fires where meas. taken	Concentrations (µg/m³)					
			Median	90% LCL[2]	90% UCL[2]	a[3]	90th Pcnt[4]	Max
Benzene	101	21	121	33	525	17	6,375	79,693
Toluene	94	21	220	38	527	16	3,766	206,753
Styrene	86	14	85	20	174	15	2,320	2,705
Xylenes[5]	41	9	17	ND	607	11	1,424	3,809
m,p-Xylene	30	6	76	1	282	9	912	999
o-Xylene	49	10	35	1	109	12	336	564
Methylene chloride	39	10	8	ND	89	10	565	836
Chloroform	33	9	42	ND	197	9	533	1,085
Ethyl benzene	57	12	49	ND	204	12	502	1,477
Trichloroethene[5]	45	11	ND	ND	41	11	425	881
1,1,2-Trichloroethane	33	7	ND	ND	82	9	316	542
1,1,1-Trichloroethane	43	12	ND	ND	10	11	39	817
1,1-Dichloroethane	26	10	ND	ND	ND	8	16	42
Chlorobenzene	33	11	ND	ND	ND	9	2	11
Trichloroethane[5]	17	7	ND	ND	1	7	1	1
Carbon tetrachloride	31	10	ND	ND	ND	9	ND	44
Tetrachloroethene	28	9	ND	ND	ND	9	ND	ND

[1] n = number of measurements
[2] The 90 percent confidence limits lower and upper as determined for the median.
[3] Where a is the number of data values from the median to the upper and to the lower 90 percent confidence limits.
[4] The analytes in this table are arranged in order of 90th percentile (except for the o-xylene isomer).
[5] Contains mixed isomers.
ND = Not detected.

TABLE 8. OPEN BURNING: AMBIENT CONCENTRATIONS >305 m (1000 FT) DOWNWIND

Analyte	n[1]	No. Fires where meas. taken	Concentrations (μg/m³)					
			Median	90% LCL[2]	90% UCL[2]	a[3]	90th Pcnt[4]	Max
Styrene	45	5	1	ND	16	11	554	2,705
Ethyl benzene	18	5	3	ND	172	7	172	1,390
Toluene	45	10	5	1	37	11	156	634
Benzene	47	10	4	ND	29	11	67	524
Xylene[5]	20	4	ND	ND	ND	7	4	20
m,p-Xylene	28	3	2	1	9	9	14	999
o-Xylene	38	6	1	1	5	10	13	521
Chlorobenzene	29	5	1	ND	1	9	1	1
1,1,1-Trichloroethane	30	5	1	ND	1	9	1	7
Trichloroethane[5]	34	4	1	ND	1	10	1	3
Carbon tetrachloride	8	4	ND	ND	ND	4	ND	ND
Trichloroethene[5]	6	4	ND	ND	18	3	ND	18
1,1-Dichloroethane	7	3	ND	ND	ND	3	ND	ND
1,1,2-Trichloroethane	6	2	ND	ND	ND	3	ND	ND
Chloroform	3	3	ND	ND	ND	1	ND	ND
Methylene chloride	14	3	ND	ND	ND	6	ND	660
Tetrachloroethene	8	4	ND	ND	ND	4	ND	ND

[1] n = number of measurements
[2] The 90 percent confidence limits lower and upper as determined for the median.
[3] Where a is the number of data values from the median to the upper and to the lower 90 percent confidence limits.
[4] The analytes in this table are arranged in order of 90th percentile (except for the o-xylene isomer).
[5] Contains mixed isomers.
ND = Not detected.

2.4 CASE STUDIES

2.4.1 Rhinehart Tire Fire - Winchester, VA

A fire of unknown origin began on October 31, 1983 in a dump in Winchester, Virginia. This event became known as the Rhinehart Tire Fire. The dump contained approximately 5 million scrap tires over a 1.6-hectare [ha (4-acre)] site. A black smoke plume rose to 910 m (3000 ft) and extended some 48 - 80 kilometers [km (30 - 50 miles)]. On November 2, 1983, EPA requested immediate technical assistance from the National Institute for Occupational Safety and Health (NIOSH) to evaluate site safety and worker exposure to potentially hazardous emissions from the tire fire.

NIOSH industrial hygienists collected air samples on November 4 and 9, 1983 (NIOSH, 1984). Because of varying meteorological conditions, it was not possible to collect air samples near the burning tires without being in the smoke plume. Analysis of the air samples taken in the plume indicated potentially hazardous levels of CO and PAHs. CO concentrations varied in the 50 to 100 parts per million (ppm) range. The NIOSH-recommended worker exposure limit, or Threshold Limit Value (TLV), for CO is 35 ppm [40 milligrams per cubic meter (mg/m^3)] over a 10-hour time-weighted average (TWA). The TLV refers to airborne concentrations that a healthy adult worker may be repeatedly exposed to for up to 10 hours per day, five days per week, without adverse health effects. TLVs are guidelines and not strict standards for determining safe or unsafe conditions for occupational exposures. The NIOSH TLV is not applicable to sensitive receptors such as children and the elderly, who may suffer health effects at lower levels.

Several PAH compounds were detected. Plume concentrations of PAHs are presented in Table 9 (NIOSH, 1984). The concentrations are averaged over approximately 405 minutes. No details are available concerning meteorological data and only a non-scaled sketch was presented in the report describing the monitoring location with respect to the fire area. Personal samples were also collected with personal portable sampling pumps attached to the clothing of line workers, equipment operators, and other personnel at the site. However, due to problems with the sampling and analysis, the authors concluded that the personal sampling results represented inaccurate (low) estimates of exposure. Therefore, personal sampling results are not reported here.

The concentrations of lead, iron, and zinc in the plume were 11 $\mu g/m^3$, 14 $\mu g/m^3$, and 122 $\mu g/m^3$, respectively. All other metals were present at less than 2 $\mu g/m^3$. Metals were sampled at a stationary location in the plume. The sampling method employed included the use of a low-volume sampling pump (flow rate of 1.0 liter per minute) and a cellulose ester membrane filter. The analytical method was low temperature ashing nitric acid digestion followed by inductively coupled argon plasmography, atomic emission spectroscopy (although no specific method was cited, the procedures are consistent with NIOSH Method 7300).

Analysis of the tire residue showed it to be extremely complex, containing thousands of individual compounds. The air space in a vial above a sample of the residue

TABLE 9. PAH PLUME CONCENTRATIONS - RHINEHART TIRE FIRE

PAH	Concentration ($\mu g/m^3$)*	Limit of Detection(μg)
Naphthalene	461	5
Acenaphthylene	ND	7
Acenaphthene	9	1
Fluorene	26	0.5
Phenanthrene	54	0.2
Anthracene	35	0.3
Fluoranthene	16	0.005
Pyrene	11	0.1
Benz(a)anthracene	6	0.005
Chrysene	18	0.10
Benzo(b)fluoranthene	1	0.003
Benzo(k)fluoranthene	1	0.005
Benzo(a)pyrene	3	0.005
Dibenz(a,h)anthracene	ND	0.05
Benzo(g,h,i)perylene	ND	0.05
Indenopyrene	3	0.02
TOTAL PAHs	**644**	–

*Sample duration = 405 min.
ND - Not detected
Sampling Method: Zefluor filter + ORBD 43 sorbent; flow rate 1.0 LPM.
Analytical Method: HPLC with UV detection.

was analyzed using GC/MS. Low concentrations of toluene, benzene, xylenes, and limonene were detected. More extensive GC/MS analysis also showed alkanes, substituted benzenes, substituted hydrazines, ketones, halogenated hydrocarbons, substituted phenols, nitriles, benzoic acids, and substituted benzene amines. Several PAHs were also detected including anthracene, pyrene, naphthalene, and fluoranthene. An Ames test for mutagenicity of the tire residue showed positive mutagenic activity.

2.4.2 Somerset, Wisconsin Tire Fire

Stofferahn and Simon (1987) present an overview of events surrounding a tire fire that began on October 13, 1986 near Somerset, Wisconsin. Approximately six million tires were consumed out of an estimated eight to nine million scrap tire stockpile. The stockpile occupied about 6 hectare (15 acres) on a 10 hectare (25 acres) property. The smoke plume was visible for "several miles downwind." An intense fire raged for three days, after which it subsided and the threat of the fire spreading off-site was eliminated. The fire burned itself out after a period of approximately two weeks.

A trailer park was approximately 0.8 km (one-half mile) north of the yard fence line. At the initial stage of the incident, a thick black smoke plume entered the park. Officials in charge decided to evacuate the trailer park, since the nature of potential health threats resulting from exposure to such a plume were not known. The evacuation remained in effect for one day, after which shifting wind patterns eliminated the heavy exposures that occurred on the first day.

Recommendations to the general public were broadcast via local radio stations:

- Those experiencing discomfort from the smoke should evacuate the area impacted by the plume or stay indoors in a sealed residence; and
- Outdoor items with which people might come into contact on a routine basis (e.g., autos, laundry, outdoor furniture) or that would be ingested (e.g., garden vegetables) should be washed thoroughly.

Air monitoring conducted by the US EPA Emergency Response Team (ERT) indicated a concentration of total suspended particulate (TSP) exceeding the 260 $\mu g/m^3$ primary National Ambient Air Quality Standard (NAAQS) in effect at that time. The ERT also concluded that the smoke became visible at about 250 $\mu g/m^3$ TSP. The rough correlation to the primary standard resulted in the recommendation to response personnel to don respiratory protection or to avoid areas where the smoke plume was visible. No details on the method of sampling or analysis were given.

Air samples collected by the Wisconsin Department of Natural Resources (WDNR) were analyzed for concentrations of total coal tar pitch volatiles (CTPV). At times, these concentrations exceeded the threshold limit value time-weighted average (TLV-TWA) of 0.2 mg/m^3.

The authors compared the air concentration levels measured by the ERT and WDNR at the Somerset site with concentrations reported at two other major tire fires, the Everest, Washington fire (September 25 - October 10, 1984) and the Rhinehart tire fire, Winchester, Virginia, 1984 (presented above). These results are presented in Table 10. For reference, the TLV-TWA and Immediately Dangerous to Life and Health (IDLH) values are also presented. IDLH concentrations represent the maximum concentration from which, in the event of a failure of a worker's respirator device, the worker could escape within 30 minutes without experiencing any escape-impairing (e.g., severe eye irritation) or irreversible health effects.

The authors conclude that "although no consistency with respect to sampling/monitoring methodologies or approach may be assumed among these three incidents, the data do not suggest that severe, acute health threats . . . were present at any of the three incidents." However, the authors also note that, as the mixture of carbon black and PAHs is considered carcinogenic, the smoke plume or its residues may present a chronic health threat.

2.5 PREVENTING AND MANAGING TIRE FIRES

The Scrap Tire Management Council [(Council, or STMC) Washington D.C.] is an independent advocacy organization created by the North American tire industry. The Council's goal is to create sufficient market capacity to consume all scrap tires generated annually. The Council provides assistance in developing and promoting the utilization of scrap tires as a valuable resource.

The Council offers a seminar (there is a fee for expenses and contribution to STMC Education and Research) on the prevention and management of scrap tire fires. At the seminar, the Council uses a document, which it developed in concert with the International Association of Fire Chiefs (IAFC), called *Guidelines for the Prevention and Management of Scrap Tire Fires* [(Guidelines) IAFC and STMC, 1992]. STMC also offers the document for sale. The seminar and guidelines were developed with the contribution of over a dozen experienced fire chiefs and emergency response personnel.

Preventing and managing tire fires is a complex subject and many site-specific issues must be considered. Only a few of these issues are reviewed here in the following subsections.

2.5.1 Storage Site Design

The Guidelines recommend the following storage site design requirements:

- tire piles be limited to 6 m (20 ft) in height with maximum outside dimensions of 76 m (250 ft) by 6 m (20 ft);
- the edges of the pile should be at least 15 m (50 ft) from the perimeter fence and this area should be free of debris or vegetation;
- interior fire breaks should be at least 18 m (60 ft) wide;
- the area extending 60 m (200 ft) from the outside perimeter of the piles should be devoid of any vegetation;

TABLE 10. COMPARISON OF DETECTED CONTAMINANTS TO ESTABLISHED TLV AND IDLH LIMITS (mg/m³)

Compound	TLV-TWA	IDLH	Wisconsin		Washington	Virginia
			ERT	DNR		
Sulfur dioxide	5	--	--	--	--	--
Carbon monoxide	55	--	--	--	--	--
Zinc	--	--	--	0.013	--	0.122
Lead	0.15	--	--	--	--	0.011
Iron	--	--	--	--	--	0.014
Cadmium	--	40	--	--	--	--
Chromium	--	--	--	--	--	--
Copper	--	--	--	--	--	--
Benzene	30	--	0.22	--	9.68-10.6	--
Toluene	375	--	0.140	--	0.03-6.70	--
Styrene	215	--	0.043	--	0.04-3.41	--
Xylenes	435	--	0.072	--	total styrene/ toluene	--
Ethyl benzene	435	--	0.047	--	--	--
Ethyl toluene	--	--	0.011	--	--	--
Methyl chloride	(350)	--	0.003	--	--	--
1,1,1-Trichloroethene	1,900		0.024	--	--	--
Acetone	1,780	--	--	--	0.55-0.57	--
Heptane	1,600	--	--	--	<0.02	--
Hexane	180	--	--	--	0.18-0.21	--
Hexene	--	--	--	--	<0.02	--
Naphthalene	50	--	--	--	0.82-1.32	0.461
Pentane	1,800	--	--	--	0.61-0.66	--
Ibiophene	--	--	--	--	0.25-0.30	--
Benzo(a)pyrene	--	--	--	0.013	--	0.003

(Continued)

TABLE 10. COMPARISON OF DETECTED CONTAMINANTS TO ESTABLISHED TLV AND IDLH LIMITS (mg/m^3) (Cont.)

Compound	TLV-TWA	IDLH	Wisconsin		Washington	Virginia
			ERT	DNR		
Pyrene	--	--	--	--	--	0.011
Chrysene	--	--	--	0.446	--	0.018
Flourene	--	--	--	--	--	0.026
Anthracene	--	--	--	--	--	0.033
Phenanthrene	--	--	--	--	--	0.054
Perylene	--	--	--	2.623	--	--
Coal tar pitch volatiles	0.2	400	--	4.218	--	--

-- = not measured.
+ = detected, value not reported.
( ) = estimated values in 1987.

- buildings, vehicles, etc. should also be at least 60 m (200 ft) from the piles;
- the site should be flat, with a concrete or hard clay surface and should be designed to capture and contain water run-off;
- scrap tire storage should not be on wetlands, floodplains, ravines, canyons, or on any steeply-graded surfaces;
- Any open-air burning should be at least 305 m (1000 ft) from the tire pile;
- heat generating devices (e.g., welders) should not be within 60 m (200 ft) of the pile; and
- lightning rods should be installed, but away from the tire piles.

2.5.2 Civilian Evacuation

Evacuation of civilians should be considered as the highest priority by the incident commander. The Guidelines suggest that areas subject to evacuation be anticipated during a pre-fire planning process (all scrap tire and rubber products storage facilities should be considered high-risk storage sites and be pre-planned accordingly). The Guidelines recommend that "any areas exposed to the smoke plume, or subject to such exposure from shifting winds, should be evacuated as a precaution."

Staging locations, transportation time, and equipment requirements must be carefully planned. Evacuees should not be allowed to return to the vicinity until appropriate environmental monitoring has been conducted and the area is deemed safe and habitable.

2.5.3 Fire Suppression Tactics

For a variety of reasons, conventional fire suppression tactics are only partially effective in controlling scrap tire fires. The unique shape of tires makes it extremely difficult to reach all burning surfaces and allows air to be trapped to continue support of combustion throughout the pile. The intense heat generated by burning tires further adds to the difficulty.

The Guidelines recommend that the major objective in addressing a tire fire is to separate the unburned tires (fuel) from the burning fuel. The burning fuel should be allowed to burn as freely as possible. Heavy equipment (i.e., front-end loaders, track excavators, mid-size bulldozers, etc.) are necessary for this type of work. Burning sections of rubber can be removed from the pile, isolated and extinguished using hand lines set on fog pattern (i.e., a wide disperse spray), or if a water reservoir is available, submerged.

Direct water application is not always effective, given the intense heat and burning characteristics of rubber. However, if a decision is made to use conventional techniques, constant pressure fog nozzles are more effective than solid streams.

In many cases, fire control has only been achieved by smothering the burning portions of the pile with dirt or fill material. However, even in this state, fires can continue to smolder deep in the base of the pile for weeks. Thus, continued observation and environmental monitoring is necessary.

It may be necessary to create fire breaks and/or access routes into the pile. These should be at least 18 m (60 ft) wide or wider if high winds are a factor. Also, as the piles tend to be unstable, sturdy platforms should be provided to fire fighters who are operating atop the pile. Wooden pallets work well for this purpose.

The summaries of several Guidelines issues presented above only address a small portion of the issues and problems of preventing and fighting a tire fire. To effectively protect public health, safety, and property, a fire-fighting management team trained to deal with tire fires should be in charge of planning and execution of such an event.

2.6 TIRE FIRE "TARGET" COMPOUNDS

Recognizing the dangers to health and environment associated with tire fires, the Tacoma-Pierce County Health Department (TPCHD) conducted a study on hazardous airborne chemical compounds. TPCHD published a report that identified, through a series of screening steps, a subset of 34 target compounds (weighted based on toxicity and expected ambient air concentrations) that should be considered for air monitoring during a tire fire (Adolfson Associates, 1994).

There is a potential for a wide range of health effects from exposure to the hydrocarbons, metals, and inorganic gases and vapors identified. The health effects include irritation of the skin, eyes, and mucous membranes, central nervous system depression, respiratory effects, and cancer.

In developing the target list, the authors gathered air monitoring data collected by EPA at nine tire fire locations (Wisconsin, Washington, Virginia, Arkansas, Colorado, North Carolina, New York, Pennsylvania, and Utah), as well as the data from the test burn discussed earlier in this report (Ryan, 1989; Lemieux and DeMarini, 1992). Compounds identified as either a suspected or confirmed human carcinogen were automatically listed as target compounds, regardless of recorded air concentration or emission level. As a group, PAHs in low concentration were not singled out, and CTPV was used to represent the PAH class of compounds. Individual PAHs with a concentration high enough to qualify as a target compound (see below) were listed separately, however.

The compounds were also evaluated based on whether their maximum measured airborne concentration exceeded 33% of the TLV for that compound. If so, the compound was considered a target compound. Thirty-three percent of the TLV was used, to approximate an equivalent worker inhalation dosage, because exposure to a tire fire could occur 24-hours per day, as opposed to the 8-hours that the TLV is based upon.

The last evaluation criteria the authors applied was to compare the ratio of detected value to the subchronic and chronic inhalation reference concentrations (RfC). The RfC is an estimate of the exposure concentration that would not result in appreciable risk of adverse health effects. Compounds were ordered by decreasing ratios (e.g., of detected concentration to subchronic RfC). Target compounds were determined by selecting the top 25% of compounds from each data set.

If a compound had not already been targeted according to the methods outlined above, further review was conducted. The decision process included evaluating other aspects of the compound's toxicology and potential concentrations. If information was lacking, the compound was not included as a target compound.

A list of all EPA field-monitored compounds considered and their maximum reported values is presented in Table 11. Data from the controlled test program for the "chunk" configuration (considered most representative of actual tire fire emissions by Adolfson in their evaluation) were presented in Tables 1 through 6 above and are not repeated in Table 11 (Ryan, 1989). In some cases, where data are available for the same compound, the laboratory test data may be higher than the EPA field data. The authors used the highest concentration of the two data sets in selecting the target compounds.

Some further clarification of the Adolfson Associates reference is necessary. The text of the report refers to 38 target compounds, however, only 37 were presented. Furthermore, concentration data for "chloride" and "fluoride" were presented. These are omitted in this report because these values represent the total concentration of each respective ion and not specific toxic compounds. Adolfson Associates assumed data for zinc was zinc chromate, a carcinogen, and reported it as a target compound. However, this was not substantiated based on a review of the tire fire data, which simply reported "zinc." Therefore zinc, which is not a carcinogen, was also eliminated from the Adolfson target list. The net result is that only 34 compounds are target compounds, using the Adolfson screening method.

The 34 target compounds and their criteria for selection are presented in Table 12. The carcinogenic target compounds and their maximum reported concentration are presented in Table 13 (the source of the data, i.e., "Field" for EPA field data, or "Lab" for controlled test data is indicated). Compounds that had reported concentrations exceeding 33% of their TLV are presented in Table 14. Compounds that had reported concentrations exceeding their subchronic and/or chronic reference concentrations are presented in Table 15.

The compilation of data reported in Tables 11 and 13 includes field monitoring data that is often hastily collected and is influenced by changing fire conditions, meteorological variations, and other factors. The quality of this data is questionable, and no detailed analyses of individual monitoring data were performed as part of this study. However, the data are useful in identifying those compounds that are clearly present during a tire fire.

It is recommended that ambient monitoring of air contaminants be conducted during the initial approach and over the course of the fire. This monitoring data will assist policy managers and fire management personnel in making decisions on the level of protective equipment to be worn and evacuation of civilians. Direct-reading instruments are recommended for the initial response to the fire. This type of equipment can be useful in providing immediate data on IDLH conditions, toxic levels of airborne contaminants, and flammable atmospheres. This data will allow the emergency response team to size up the situation and begin making informed decisions. For more complete information on the

TABLE 11. MAXIMUM CONCENTRATIONS FROM EPA DATASETS (mg/m³)

Compound	Concentration	Compound	Concentration
Acetone	0.3700	Iron	0.0140
Anthracene	0.0330	Lead	0.0110
Benz(a)anthracene	0.0018	Methyl ethyl ketone	0.5800
Benzene	10.59	Methylene chloride	2.1000
Benzo(a)pyrene	0.0130	3-Methylstyrene	0.0960
Benzylchloride	0.0190	4-Methylstyrene	0.0500
Bromochloromethane	1.1360	Methylstyrene, alpha-	0.0500
4-tert-Butyl toluene	0.1310	Naphthalene	1.3200
Carbon monoxide	114.00	n-Nitrate	220.00
Carbon tetrachloride	0.0500	Nitric acid	0.2550
Chloroform	2.0580	N-octane	0.0850
Chrysene	0.4460	Orthophosphate	280.00
Coal tar pitch volatiles	4.2180	Pentane	0.6600
Cumene	0.0940	N-pentane	0.2960
Cyclohexane	0.0630	Phenanthrene	0.0340
1,2-Dichlorobenzene	0.0696	Phosphoric acid	0.2650
1,4-Dichlorobenzene	0.1187	Pyrene	0.0001
1,2-Dichloropropane	0.0350	Pyrylene	2.6230
Ethyl benzene	0.1554	Styrene	5.4100
Ethyl toluene	0.0540	Sulfate	230.00
Ethylene dichloride	0.3230	Sulfur dioxide	2.7000
Ethyltoluene, meta	0.5800	Sulfuric acid	0.7900
Fluoranthene	0.0040	Thiophene	0.3000
Fluorene	0.0260	Toluene	6.7000

(Continued)

TABLE 11. MAXIMUM CONCENTRATIONS FROM EPA DATASETS (mg/m^3) (Cont.)

Compound	Concentration	Compound	Concentration
Heptane	0.0200	1,1,1-Trichloroethane	0.0760
n-Heptane	0.0830	1,1,2-Trichloroethane	0.0030
Hexachloroethane	0.2980	Trichloroethylene	1.5600
Hexane	0.2100	Trichlorofluoromethane	0.0510
n-Hexane	0.1580	m,p-Xylene	131.00
Hexene	0.0200	m-Xylene	0.8400
Hydrobromic acid	0.2550	o-Xylene	1,564.00
Hydrochloric acid	4.0000	Zinc	0.0130
Hydrofluoric acid	0.2700		

Note: Above data was taken directly from reference; no adjustment was made to significant digits.

TABLE 12. TARGET COMPOUNDS BY CRITERIA

Target Compound	Criteria			
	CA	TLV	Subchronic RfC	Chronic RfC
Acenaphthene	X			
Acenaphthylene	X			
Arsenic	X			
Barium				X
Benz(a)anthracene	X			
Benzene	X			
Benzo(a)pyrene	X			
Benzo(b)fluoranthene	X			
Benzylchloride	X			
Butadiene	X			
Carbon monoxide		X		
Carbon tetrachloride	X			
Chloroform	X			
Chromium	X			
Chrysene	X			
Coal tar pitch volatiles	X	X		
Cumene			X	X
1,2-Dichloropropane	X		X	X
Dibenz(a,h)anthracene	X			
Ethylene dichloride	X			
Hexachloroethane	X			
Hexane			X	X
Lead	X			
Methylene chloride	X			
Nickel	X			
Phenol	X			
Styrene	X			X
Sulfur dioxide		X		
Sulfuric acid		X		X
Toluene			X	X
1,1,2-Trichloroethane	X			
Trichloroethylene	X			
Vanadium		X		
o-Xylene		X		

CA = Suspected or Confirmed Human Carcinogen.
TLV = Reported Value is 33% of Threshold Limit Value.
RfC = Inhalation Reference Concentration.

TABLE 13. MAXIMUM REPORTED CARCINOGENS CONCENTRATIONS

Compound	Concentration (mg/m^3)	Data Source
Acenaphthene	1.027	Lab
Acenapthylene	0.897	Lab
Arsenic	0.0002	Lab
Benz(a)anthracene	0.226	Lab
Benzene	10.59	Field
Benzene	3.872	Lab
Benzo(a)pyrene	0.481	Lab
Benzo(a)pyrene	0.013	Field
Benzo(b)fluoranthene	0.344	Lab
Benzyl chloride	0.019	Field
Butadiene	0.314	Lab
Carbon tetrachloride	0.052	Field
Chloroform	2.058	Field
Chromium (Assumed to be all Cr VI^+)	0.012	Lab
Chrysene	0.446	Field
Chrysene	0.368	Lab
Coal tar pitch volatiles	4.218	Field
Dibenz(a,h)anthracene	0.007	Lab
1,2-Dichloropropane	0.035	Field
Ethylene dichloride	0.323	Field
Hexachloroethane	0.298	Field
Lead (inorganic dust)	0.0007	Lab
Lead (inorganic dust)	0.011	Field
Methylene chloride	0.210	Field
Nickel	0.007	Lab
Phenol	0.473	Lab
Styrene	5.41	Field
Styrene	0.795	Lab
1,1,2-Trichloroethane	0.003	Field
Trichloroethylene	1.6	Field

TABLE 14. COMPOUNDS WITH MAXIMUM REPORTED CONCENTRATIONS EXCEEDING 33% OF THEIR TLVs

Compound	Concentration mg/m^3	TLV mg/m^3	% TLV
Carbon monoxide	116.0000	29	400.00
Coal tar pitch volatiles	4.2180	0.2	2,109
Sulfur dioxide	2.7500	5	52.00
Sulfuric acid	0.7900	1	79.00
Vanadium (as pentoxide)	0.0175	0.05	35.00

TABLE 15. COMPOUNDS WITH MAXIMUM REPORTED CONCENTRATIONS EXCEEDING A SUBCHRONIC OR CHRONIC RFC (mg/m^3)

Compound	Concentration	Subchronic RfC	Chronic RfC
Barium	0.0035	0.005	0.0005
Cumene	0.094	0.09	0.009
1,2-Dichloropropane	0.035	0.013	0.004
Hexane	0.21	0.2	0.2
Styrene	5.41	none	1
Toluene	6.7	2	0.4

type and concentration of specific air contaminants over the course of the fire, the data obtained with direct-reading instruments must be supplemented by collecting and analyzing air samples.

A tire fire can smolder for months. The smoldering phase can produce excessive emissions due to the fact that it is not a hot burning phase and does not result in complete combustion. Therefore, air sampling should continue, and data reviewed, during the smoldering phase as well to ensure that appropriate health and safety decisions can be made.

Developing an air monitoring plan and/or recommending air sampling equipment and methods are beyond the scope of this document, however Adolfson et al., (1994) present a detailed discussion of this topic.

3.0 TIRES AS FUEL

Tire-derived fuel (TDF) has been successfully utilized as a source of energy in cement and lime manufacturing, steam generation for electricity, and other industrial processes. Results of source test reports have been collected and are summarized by source type. Typical sources that have been successful in integrating TDF with other fuels are:

- Cement Kilns;
- Pulp and Paper Mills;
- Utilities (including dedicated Tire-to-Energy facilities); and
- General Industrial Boilers.

TDF has long been recognized as a potential fuel. It compares favorably to coal, as presented in Table 16. It has a higher heating value than coal, and less moisture content. TDF contains more carbon, about as much sulfur as medium-sulfur coal, but much less fuel-bound nitrogen.

Whether burning TDF in a new facility or as a modification to an existing facility, several issues must be considered. One consideration is the need convert scrap tires into a useable fuel. This requires a system to dewire, and shred, or otherwise size the tires so they can accommodated by a combustor. In addition to aiding in feeding, the sized fuel generally allows for more efficient combustion. However, some large combustor configurations, such as cement kilns, wet-bottom boilers, and stoker-grate boilers can be modified to accept whole tires. Modifications to hardware, combustion practices and/or other operating practices may also be necessary in order to burn TDF. These modifications are case-specific, and must be addressed by engineering staff when considering using TDF.

3.1 Laboratory Simulation of TDF Emissions

Pilot-scale emissions testing of TDF was conducted in a 73 kW (250,000 BTU/hr) rotary kiln incinerator simulator (RKIS) in EPA's Environmental Research Center in Research Triangle Park, NC (Lemieux, 1994). This size simulator has been established as exhibiting the salient features of full-scale units with ratings 20 to 40 times larger.

The test program was undertaken to provide assistance to state and local pollution agencies in establishing permitting guidelines and evaluating permit applications for facilities seeking to supplement its fuel with tires or TDF. A list of analytes would defer some of the expenses of stack sampling.

The purposes of the test program were to (1) generate a profile of target analytes for guidance in preparing a full-scale stack sampling program and (2) provide insight into the technical issues related to controlled combustion of scrap tires. Because of the differences in scaling, such as gas-phase mixing phenomena and other equipment-specific factors, Lemieux specifically states that emission factors from the RKIS cannot be directly

TABLE 16. COMPARATIVE FUEL ANALYSIS BY WEIGHT (JONES, 1990)

Fuel	Composition (percent)							Heating Value	
	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash	Moisture	kJ/kg	Btu/lb
TDF	83.87	7.09	2.17	0.24	1.23	4.78	0.62	36,023	15,500
Coal	73.92	4.85	6.41	1.76	1.59	6.23	5.24	31,017	13,346

extrapolated to full-scale units. Furthermore, there are significant differences between kilns and other combustion devices, such as boilers, and the study does not address these issues. Nevertheless, the simulator is useful in examining the fundamental phenomena of TDF combustion and to gain an understanding of the qualitative trends that would be found in a full-scale rotary kiln.

The TDF tested was wire-free crumb rubber sized to <0.64 cm (<1/4 in.). It was combusted at several combinations of feed rate, temperature, and kiln oxygen concentration. The TDF was combusted with natural gas as the primary fuel. Samples were taken to examine volatile and semi-volatile organics, PCDD/PCDF, and metal aerosols. Data were collected to determine the effects of feed rates, type of feeding, i.e., continuous versus batch, and combustion controls on emissions. The data were taken in the exhaust stream prior to any add-on air pollution control devices.

The study addressed two issues: (1) the influence of the mode of tire feeding, for example, whole tires versus shredded tires, on the PICs, and (2) the potential for air toxic emissions not normally found when burning conventional fuels.

The TDF material used in the test program was analyzed and the proximate and ultimate analyses and metals analysis results are presented in Table 17. TDF contains significant amounts of zinc, since zinc is used extensively in the tire manufacturing process.

In all, thirty test conditions were run, with the TDF feed rate varying from 0% to 21.4% of heat input. The test conditions were achieved by varying kiln firing rate, combustion air flow rate, and tire feed rate. The majority of the tests were conducted with a steady-state feed of TDF. Variations in the mode of TDF feeding were evaluated in two tests. In one test, the kiln air flow rate was ramped up and down every 10 minutes ("ramp") to change the kiln oxygen concentration to simulate transient operation. In the other, TDF was introduced in 300 g batches spaced ten minutes apart ("batch") to simulate transient operation, such as feeding whole tires at periodic intervals.

VOCs were collected by a Volatile Organic Sampling Train (VOST) and analyzed with a gas chromatograph/mass spectrometer (GC/MS). The majority of the VOCs were very near to or below the detection limits of the equipment. Estimated emissions of VOCs for five representative test runs are presented in Table 18.

PAHs were analyzed with a Continuous Emission Monitor (CEM) PAH analyzer. PAH emissions were fairly insensitive to temperature and oxygen for the range of conditions studied, however, increasing TDF feed rates tended to increase PAH emissions for all oxygen levels. Overall, it was observed that supplementing natural gas with TDF tended to increase PAH emissions, but not dramatically, provided that steady-state operation is maintained.

Semi-volatile organic compounds (SVOC) and bulk particulate were collected by isokinetic sampling protocols with a Modified Method 5 (MM5) train. Data from the analyses did not indicate that SVOC were present in detectable concentrations. Lemieux

TABLE 17. PROXIMATE AND ULTIMATE ANALYSIS OF RKIS TEST TDF

Proximate Analysis	
Moisture	0.84%
Volatile Matter	65.52%%
Ash	7.20%
Fixed Carbon	26.44%
Ultimate Analysis	
Moisture	0.84%
Carbon	76.02%
Hydrogen	7.23%
Kjeldahl Nitrogen l Nitrogen Nitro	0.34%
Sulfur	1.75%
Total Halogens (calculated as chlorine)	0.31%
Ash	7.20%
Metals	
Cadmium	<5 ppm
Chromium	<5 ppm
Iron	295 ppm
Lead	51 ppm
Zinc	2.14%
Heating Value	37,177 kJ/kg

TABLE 18. ESTIMATED EMISSIONS OF VOCS - RKIS TEST RESULTS (BASE FUEL - NATURAL GAS)

Compound	0% TDF (Natural Gas Only)		7% TDF (steady-state)		17% TDF (steady-state)		19% TDF (ramp)		15% TDF (batch)	
	ng/J	lb/MMBtu	ng/J	lb/MMBtu	ng/J	lb/MMBtu	ng/J	lb/MMBtu	ng/J	lb/MMBtu
1,1,1 Trichloroethane	2.24E-04	5.21E-07	3.75E-04	8.72E-07	4.41E-04	1.03E-06	2.24E-04	5.21E-07	2.17E-04	5.05E-07
2-Methyl propene	9.60E-04	2.23E-06	2.30E-03	5.35E-06	1.94E-03	4.51E-06	7.37E-04	1.71E-06	2.33E-04	5.42E-07
2-Methyl-2-propanol benzene	2.13E-04	4.95E-07	2.15E-04	5.00E-07	1.81E-03	4.21E-06	2.24E-04	5.21E-07	2.33E-04	5.42E-07
Benzene	6.71E-04	1.56E-06	1.25E-04	2.91E-07	1.25E-04	2.91E-07	7.36E-03	1.71E-05	2.19E-02	5.09E-05
Bromomethane	2.00E-04	4.65E-07	2.15E-04	5.00E-07	2.58E-04	6.00E-07	1.22E-03	2.84E-06	3.82E-04	8.88E-07
Carbon disulfide	2.13E-04	4.95E-07	3.43E-04	7.98E-07	2.30E-04	5.35E-07	2.24E-04	5.21E-07	9.43E-04	2.19E-06
Chlorobenzene	2.13E-04	4.95E-07	2.15E-04	5.00E-07	2.30E-04	5.35E-07	2.24E-04	5.21E-07	2.20E-04	5.12E-07
Chloromethane	2.40E-04	5.58E-07	7.15E-04	1.66E-06	3.90E-03	9.07E-06	2.38E-02	5.53E-05	5.16E-02	1.20E-4
Ethylbenzene	2.13E-04	4.95E-07	2.15E-04	5.00E-07	2.70E-04	6.28E-07	2.24E-04	5.21E-07	4.96E-04	1.15E-06
Heptane	2.13E-04	4.95E-07	2.83E-04	6.58E-07	2.48E-04	5.77E-07	2.24E-04	5.21E-07	2.33E-04	5.42E-07
Hexane	2.01E-04	4.67E-07	2.45E-04	5.70E-07	2.45E-04	5.70E-07	2.24E-04	5.21E-07	2.36E-04	5.49E-07
Iodomethane	2.13E-04	4.95E-07	2.15E-04	5.00E-07	2.30E-04	5.35E-07	2.35E-04	5.47E-07	2.33E-04	5.42E-07
m,p-Xylene	6.21E-04	1.56E-06	4.17E-04	9.70E-07	1.06E-03	2.47E-06	2.64E-04	6.14E-07	1.78E-03	4.14E-06
Nonane	2.77E-04	6.44E-07	7.29E-04	1.70E-06	4.25E-04	9.88E-07	2.24E-04	5.21E-07	2.71E-04	6.30E-07
o-Xylene	1.85E-04	4.30E-07	2.15E-04	5.00E-07	3.18E-04	7.40E-07	2.24E-04	5.21E-07	5.24E-04	1.22E-06
Styrene	2.63E-04	6.12E-07	7.85E-04	1.83E-06	7.16E-04	1.67E-06	7.03E-04	1.63E-06	7.80E-04	1.81E-06
Toluene	3.97E-04	9.23E-07	5.02E-04	1.17E-06	4.64E-04	1.08E-06	3.48E-04	8.09E-07	1.29E-03	3.00E-06

(1994) concludes that when TDF is combusted in a well-designed and well-operated facility, emissions of SVOCs are not significantly different from natural gas.

PCDD and PCDF were collected during two test conditions: 0% TDF and 17% TDF (steady-state). No PCDD/PCDF were detected in either test.

Metal aerosol samples were collected during two test conditions; 0% TDF and 17% TDF (steady-state). Estimated metals emissions from these tests are presented in Table 19. The TDF-only column is a linear extrapolation and was calculated by dividing the values in the TDF+natural gas column by 17% (0.17). Elevated emissions of arsenic, lead, and zinc were found in the stack gas. Zinc was present in significant concentrations.

Total particulate matter (PM) measurements were made from the MM5 and MultiMetals trains. The PM results are presented in Table 20. The PM emissions represent uncontrolled emissions, such as found prior to any installed PM control device. As expected, the PM emissions during TDF combustion are higher than those from natural gas combustion alone.

The PM results from the batch feed run are significantly higher than for any of the others. This may suggest that burning TDF in batches, which roughly approximates feeding of whole tires, has the potential to form significant transient emissions. This phenomenon could be exacerbated in a system that exhibits significant vertical gas-phase stratification, or operates at low excess air levels, such as cement kilns. However, Lemieux (1994) believes that the size of the facility will serve to mitigate the intensity of transient emissions resulting from batch charging of tires of TDF, because for an extremely large facility, a constant stream of whole tires may roughly approximate steady-state operation. Even so, Lemieux (1994) cautions that the potential for generation of large transients should not be ignored, especially in smaller facilities.

Based on this test program, it is concluded that, with the exception of zinc emissions, potential emissions from TDF are not expected to be very much different than from other conventional fossil fuels, as long as combustion occurs in a well-designed, well-operated and well-maintained combustion device. If unacceptable particulate loading occurs as a result of zinc emissions, an appropriate particulate control device would need to be installed.

3.2 Source Test Data - Utility and Industrial Facilities

Source test data from a variety of source types have been collected and are presented in Table 21 and Appendix Tables A-1 through A-22. Test data of criteria pollutant emissions from seven utility boilers are summarized in Table 21. In general, particulates and NO_x decreased as the percent TDF increased. Emissions of SQ did not follow a pattern. There are insufficient data on CO emissions from utilities to draw a conclusion.

Data summaries from field source tests are presented in the Appendix. Beginning with Table A-1, each table is divided into two parts. Part "a" presents a summary of

TABLE 19. ESTIMATED EMISSIONS OF METALS - RKIS TEST RESULTS (BASE FUEL - NATURAL GAS)

Metal	0% TDF (Natural Gas Only)		17% TDF (steady-state)		TDF Only (estimated)	
	ng/J	lb/MMBTU	ng/J	lb/MMBTU	ng/J	lb/MMBTU
Antimony	7.72E-05	1.80E-07	9.05E-04	2.10E-06	5.32E-03	1.24E-05
Arsenic	4.80E-04	1.12E-06	1.59E-02	3.70E-05	9.35E-02	2.17E-04
Beryllium	nd	nd	2.14E-05	4.98E-08	1.26E-04	2.93E-07
Cadmium	1.76E-04	4.09E-07	4.54E-04	1.06E-06	2.67E-03	6.21E-06
Chromium	2.78E-04	6.46E-07	1.66E-03	3.86E-06	9.76E-03	2.27E-05
Lead	3.45E-03	8.02E-06	2.83E-02	6.58E-05	1.66E-01	3.86E-4
Manganese	1.21E-03	2.81E-06	2.48E-03	5.77E-06	1.46E-02	3.40E-05
Nickel	3.00E-04	6.98E-07	1.50E-03	3.29E-06	8.82E-03	2.05E-05
Selenium	3.56E-04	8.28E-07	1.93E-03	4.49E-06	1.14E-02	2.65E-05
Zinc	1.23E-01	2.86E-04	15.21	3.54E-02	89.47	2.08E-01

TABLE 20. PARTICULATE MATTER (PM) LOADING - RKIS TEST PROGRAM

% TDF	Feed Type	Particulate Loading (mg/Nm^3)[1]
0.00	Steady-state	4.14
0.00	Steady-state	17.37
14.97	Batch	285.46
15.50	Steady-state	95.28
16.95	Steady-state	43.67
17.14	Steady-state	137.24
17.30	Steady-state	101.01
19.18	Ramp	132.95

[1] Nm^3 is a normal cubic meter of gas at 0° C and 1 atmosphere pressure.

TABLE 21. CRITERIA POLLUTANT EMISSIONS AT UTILITIES USING TDF

Power Plant	Particulates (Total)		Sulfur Oxides		Nitrogen Oxides		Carbon Monoxide	
	g/MJ	lb/MMBTU	g/MJ	lb/MMBTU	g/MJ	lb/MMBTU	g/MJ	lb/MMBTU
Facility A								
100% Tires	9.5×10^{-7}	2.2×10^{-6}	6.0×10^{-6}	1.4×10^{-5}	4.2×10^{-5}	9.8×10^{-5}	3.1×10^{-5}	7.2×10^{-5}
Facility B								
0% TDF	0.090	0.21	0.606	1.41	0.34	0.78	NT	NT
5% TDF	0.0064	0.015	0.774	1.80	0.25	0.58	NT	NT
10% TDF	0.004	0.009	0.658	1.53	0.13	0.30	NT	NT
Facility C								
0% TDF	0.22	0.52	0.490	1.14	0.34	0.79	0.654	1.52
7% TDF	0.060	0.14	0.37	0.87	0.39	0.91	3.12	7.26
Facility D								
0% TDF	0.027	0.063	2.28	5.30	0.258	0.601	NT	NT
5% TDF	0.0308	0.0717	2.46	5.73	0.219	0.510	NT	NT
10% TDF	0.0242	0.0564	2.46	5.71	0.188	0.436	NT	NT
15% TDF	0.0350	0.0815	2.35	5.47	0.190	0.443	NT	NT
20% TDF	0.0195	0.0453	2.30	5.34	0.166	0.387	NT	NT
Facility E								
0% TDF	0.036	0.083	0.0090	0.021	0.082	0.19	NT	NT
7% TDF	0.133	0.310	0.032	0.074	0.0537	0.125	NT	NT
Facility F								
2% TDF	0.073	0.17	2.49	5.78	NT	NT	NT	NT

NT = Not tested or data not available.

Note: Above data taken directly from reference; no adjustment was made to significant digits.

information on the facility, source type, baseline fuels, air pollution controls, test conditions, test methods, and fuel handling/feed data, as available. Part "b" of the table presents the source test data.

Individual power plant test data are presented in Tables A-1 through A-8. Table A-1 presents emissions data from utility "A", the only dedicated tires-to-energy facility examined in this report. Data for utilities B through H are given in Tables A-2 through A-8, respectively. All plants are coal-fired, except for plant E, which burns wood, plant G, which burns coal and wood, and plant H, which burns coal and/or petroleum coke.

Data from two cement kilns and one lime kiln are presented in Tables A-9 through A-11. Cement kilns burn a variety of fuels. Facility I burns natural gas and coal, while facility J burns a mixture of coal and coke. Facility K, a lime kiln, burns natural gas. The combination of long residence time and high temperatures make cement kilns an ideal environment for TDF. Emissions are not adversely affected compared to baseline fuels and often represent an improvement (Clark, et al., 1991).

Emissions data from pulp and paper mills are presented in Tables A-12 through A-17 for facilities L through Q, respectively. Pulp and paper mills burn various mixtures of wood, coal, oil, and sludge from onsite wastewater treatment facilities. For the pulp and paper boilers reported here, particulate, zinc, and SO_x emissions tended to increase with percent TDF added. Emissions of PAHs from facility M decreased, while those from facility L varied. Zinc is used in the tire manufacturing process, and is expected to increase with increasing TDF supplementation. Furthermore, zinc oxide has a small particle size and may not be controlled efficiently by venturi scrubbers.

Emissions from general industrial boiler applications are presented in Tables A-18 through A-22 for facilities R through V, respectively. These facilities are coal-fired, except for facility V which burns wood. They cover cogeneration and process heat for manufacturing and food processing.

The data presented in the appendix tables are taken from many data sources and are presented in various formats. Some source data are expressed in an emission factor format, i.e., mass of pollutant per unit of heat input [e.g., grams per megajoule (g/MJ) or pounds per million British Thermal Units (lb/MMBTU)]. The emission factor format is the most useful, because these results can be compared to a similar combustion/control system. However, these data should not be considered as recognized emission factors, because they have not undergone all the rigors of quality assurance and statistical analysis that are necessary before EPA will consider them valid emission factors.

Because many of the source tests were conducted in response to an environmental compliance requirement, they are reported in the source test as an emission limit on a mass per unit time basis (e.g., kg/hr or lb/hr). This type of data is less useful for comparison between facilities. In these cases, often the best information that can be inferred is how the TDF emission rate compares with the baseline (no TDF) emission rate for any given pollutant.

In the summary, or "a" section of the tables, the "Test Methods" entry may indicate "Unknown." While the details may be unavailable, all facilities with the reference "Clark, et al., (1991)," refer to the EPA report *Burning Tires for Fuel and Tire Pyrolysis: Air Implications,* and have had their methods procedures evaluated and accepted as creditable by EPA as a condition of being included in that report.

It is extremely difficult to establish a universal emission factor, or even a range of emission factors as a function of TDF added, because of the limited amount of emissions data when compared to all the other variables influencing the emission rate of any pollutant, such as:

- Baseline fuel type and variability, such as sulfur, nitrogen, ash, metals, chlorine, moisture content, etc. Furthermore, many sources were tested with multiple fuels (e.g., coal and wood), making it even more difficult to identify the impact of TDF.

- Air pollution control device efficiency varies with the type of fuel. For example, the efficiency of a venturi scrubber typically falls when handling the smaller particulate common to TDF. Fabric filters and electrostatic precipitators (ESPs) are preferable for particulate control for TDF exhaust streams.

- Combustor design. There are several boiler design types; suspension (fluidized bed and cyclone types) and grate firing (traveling, reciprocating, and chain stokers; stokers may be either spreader, underfeed, or overfeed). TDF combustion efficiency varies for each design type. For example, TDF is typically difficult to burn in suspension (e.g., in fluidized bed and cyclone-type boilers), because of its size and weight. However, this problem may be remedied with further research and development. To date, the spreader stoker is the most successful and widely used boiler configuration with TDF. However, with consistent and well-controlled processing of TDF (i.e., sizing and de-wiring), most well-maintained solid fuel combustors can successfully accommodate TDF as a supplemental fuel.

- The amount and type of processing/sizing that is used to convert a scrap tire to TDF. Size of TDF (whole tires, chunk, shredded, or crumb rubber) and type (wire-included or de-wired) influences the rate and type of air emissions.

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APPENDIX: EMISSIONS DATA FROM CONTROLLED TIRE BURNING

LIST OF TABLES

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(Continued)

LIST OF TABLES (Cont.)

Table A-1a. Facility A - Dedicated Tires-to-Energy Power Plant

Source Description

Facility Name, Location:	Modesto Energy Company Westley, CA
Facility Type:	Utility - Dedicated Tires-to-Energy
Source Type:	Two Boilers (designed for 100% TDF).
Test Dates:	December 4-5, 1987, January 9 - 12, 1988, October 9-11, 1990
Other fuel(s):	None
Air pollution control device(s) used:	NO_x: Selective non-catalytic reduction (ammonia injection). PM: Fabric filter with Gore-Tex® bags. SO_x: Wet scrubber with lime injection.
Test Conditions:	100% TDF
Test Methods:	CARB Methods 5, 8, 100, 421, Method 5 (metals), Modified Method 5 (Semi-VOST), Modified Method 6 (NH_3)
Fuel Handling/Feeding:	Whole tires up to 4 feet in diameter, 350 to 400 tires per hour feed rate (assuming 20 lb/tire; approximately 7,000 to 8,000 lbs/hr), total energy feed rate 190 MMBtu.
Testing Company:	Radian (1988), The Almega Corp. (1990)
Environmental Agency:	Stanislaus County APCD (now San Joaquin Valley Unified APCD)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form	X		
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates	X		
Multiple Baseline Fuels		X	
Test Witnessed by or Prepared for Governmental Agency	X		

Table A-1b. Facility A - Dedicated Tires-to-Energy Power Plant

Pollutant	Limit		1988		October 9-11, 1990[a]		October 9-11, 1990[a]	
	kg/day	lb/day	kg/day	lb/day	kg/day	lb/day	g/MJ	lb/MMBtu
Criteria								
CO	157.4	346.4	112.6	247.8	141.6	311.5	3.1×10^{-5}	7.2×10^{-5}
NO_x	227.2	500.0	174.7	384.3	193.0	424.6	4.2×10^{-5}	9.8×10^{-5}
PM	51.36	113.0	14.2	31.2	42.32	93.12	9.4×10^{-6}	2.2×10^{-5}
SO_x	113.6	250.0	57.7	127	28.1[b]	61.9[b]	6.0×10^{-6}[b]	1.4×10^{-5}[b]
HC	67.44	148.4	0.294	0.646	NT	NT	NT	NT
Metals								
Lead	N/A	N/A	0.012	0.026	0.003[c]	0.006[c]	5.5×10^{-7}[c]	1.3×10^{-6}[c]
Cadmium	N/A	N/A	0.00082	0.0018	0.0073	0.016	1.6×10^{-6}	3.7×10^{-6}
Chromium (total)	N/A	N/A	0.00050	0.0011	0.0091	0.020	2.0×10^{-6}	4.7×10^{-6}
Mercury	N/A	N/A	<0.00001	<0.00003	0.001	0.003	2.9×10^{-7}	6.7×10^{-7}
Arsenic	N/A	N/A	0.0012	0.0026	ND	ND	ND	ND
Zinc	N/A	N/A	3.52	7.75	0.283	0.623	6.0×10^{-4}	1.4×10^{-4}
Chromium (hex)	N/A	N/A	NT	NT	ND	ND	ND	ND
Copper	N/A	N/A	0.0068	0.015	0.015[c]	0.032[c]	3.2×10^{-6}	7.5×10^{-6}
Manganese	N/A	N/A	0.011	0.023	0.003	0.007	6.9×10^{-7}[c]	1.6×10^{-6}[c]

(Continued)

Table A-1b. Facility A - Dedicated Tires-to-Energy Power Plant (Cont.)

Pollutant	Limit		1988		October 9-11, 1990[a]		October 9-11, 1990[a]	
	kg/day	lb/day	kg/day	lb/day	kg/day	lb/day	g/MJ	lb/MMBtu
Nickel	N/A	N/A	NT	NT	0.012[c]	0.027[c]	2.7 x10$^{-6(c)}$	6.3 x10$^{-6(c)}$
Tin	N/A	N/A	NT	NT	0.0082	0.018	1.8 x10^{-6}	4.2 x10^{-6}
Aluminum	N/A	N/A	0.13	0.28	0.0459[c]	0.101[c]	9.9 x10$^{-6(c)}$	2.3 x10$^{-5(c)}$
Iron	N/A	N/A	0.28	0.62	0.144[c]	0.316[c]	3.1 x10$^{-5(c)}$	7.3 x10$^{-5(c)}$
Beryllium	N/A	N/A	NT	NT	ND	ND	ND	ND
<u>Organics</u>								
	N/A	N/A	<10.1	<22.3	NT	NT	NT	NT
Dioxin and Furan	N/A	N/A	1.9 x10^{-7}	4.2 x10^{-7}	NT	NT	NT	NT
PAH	N/A	N/A	0.0054	0.012	NT	NT	NT	NT
PCB	N/A	N/A	2.60 x10^{-4}	5.71 x10^{-4}	NT	NT	NT	NT
Naphthalene	N/A	N/A	NT	NT	0.002[c]	0.005[c]	5.1 x10$^{-7(c)}$	1.2 x10$^{-6(c)}$
Acenaphthylene	N/A	N/A	NT	NT	ND	ND	ND	ND
Acenaphthene	N/A	N/A	NT	NT	1.1 x10$^{-5(c)}$	2.4 x10$^{-5(c)}$	2.4 x10$^{-9(c)}$	5.6 x10$^{-9(c)}$
Fluorene	N/A	N/A	NT	NT	3.3 x10$^{-5(c)}$	7.2 x10$^{-5(c)}$	7.3 x10$^{-9(c)}$	1.7 x10$^{-8(c)}$
Anthracene	N/A	N/A	NT	NT	2.2 x10$^{-5(c)}$	4.8 x10$^{-5(c)}$	4.7 x10$^{-9(c)}$	1.1 x10$^{-8(c)}$
Fluoranthene	N/A	N/A	NT	NT	3.3 x10$^{-5(c)}$	7.2 x10$^{-5(c)}$	7.3 x10$^{-9(c)}$	1.7 x10$^{-8(c)}$

(Continued)

Table A-1b. Facility A - Dedicated Tires-to-Energy Power Plant (Cont.)

Pollutant	Limit		1988		October 9-11, 1990[a]		October 9-11, 1990[a]	
	kg/day	lb/day	kg/day	lb/day	kg/day	lb/day	g/MJ	lb/MMBtu
Pyrene	N/A	N/A	NT	NT	$4.4 \times 10^{-5(c)}$	$9.6 \times 10^{-5(c)}$	$9.5 \times 10^{-9(c)}$	$2.2 \times 10^{-8(c)}$
Benz(a)anthracene	N/A	N/A	NT	NT	ND	ND	ND	ND
Chrysene	N/A	N/A	NT	NT	ND	ND	ND	ND
Benzo(b)fluoranthene	N/A	N/A	NT	NT	$1.1 \times 10^{-5(c)}$	$2.4 \times 10^{-5(c)}$	$2.4 \times 10^{-9(c)}$	$5.6 \times 10^{-9(c)}$
Benzo(k)fluoranthene	N/A	N/A	NT	NT	ND	ND	ND	ND
Benzo(a)pyrene	N/A	N/A	NT	NT	ND	ND	ND	ND
Dibenzo(a,h) anthracene	N/A	N/A	NT	NT	ND	ND	ND	ND
Benzo(g,h,i)perylene	N/A	N/A	NT	NT	ND	ND	ND	ND
Indeno (1,2,3-cd)pyrene	N/A	N/A	NT	NT	ND	ND	ND	ND
Phenanthrene	N/A	N/A	NT	NT	$1.1 \times 10^{-4(c)}$	$2.4 \times 10^{-4(c)}$	$2.4 \times 10^{-9(c)}$	$5.6 \times 10^{-9(c)}$
Phenol	N/A	N/A	NT	NT	ND	ND	ND	ND
Formaldehyde	N/A	N/A	NT	NT	0.334[c]	0.735[c]	$7.3 \times 10^{-5(c)}$	$1.7 \times 10^{-4(c)}$
Benzene	N/A	N/A	NT	NT	ND	ND	ND	ND
Monochlorobiphenyl	N/A	N/A	NT	NT	ND	ND	ND	ND

(Continued)

Table A-1b. Facility A - Dedicated Tires-to-Energy Power Plant (Cont.)

Pollutant	Limit		1988		October 9-11, 1990[a]		October 9-11, 1990[a]	
	kg/day	lb/day	kg/day	lb/day	kg/day	lb/day	g/MJ	lb/MMBtu
Dichlorobiphenyl	N/A	N/A	NT	NT	ND	ND	ND	ND
Trichlorobiphenyl	N/A	N/A	NT	NT	ND	ND	ND	ND
Tetrachlorobiphenyl	N/A	N/A	NT	NT	ND	ND	ND	ND
Pentachlorobiphenyl	N/A	N/A	NT	NT	ND	ND	ND	ND
Hexachlorobiphenyl	N/A	N/A	NT	NT	ND	ND	ND	ND
Heptachlorobiphenyl	N/A	N/A	NT	NT	ND	ND	ND	ND
Nonachlorobiphenyl	N/A	N/A	NT	NT	ND	ND	ND	ND
Decachlorobiphenyl	N/A	N/A	NT	NT	ND	ND	ND	ND
Vinyl chloride	N/A	N/A	NT	NT	ND	ND	ND	ND

[a] Assumed 24 hr/day operation.
[b] As sulfur trioxide; sulfur dioxide not reported.
[c] MQL or trip blank showed significant measurement.
N/A = Not applicable.
NT = Not tested or data not available.
ND = Data not determined.

Table A-2a. Facility B - Coal-Fired Power Plant

Source Description

Facility Name, Location:	United Power Association Elk River, MN
Facility Type:	Utility
Source Type:	Three boilers, TDF tested in 2 stoker-fired with traveling grate, 135,000 lb steam/hr; 12 MW capacity.
Test Dates:	May, 1979
Other fuel(s):	Coal
Air pollution control device(s) used:	Fabric filter
Test Conditions:	100% coal 95% coal, 5% TDF 90% coal, 10% TDF
Test Methods:	Unknown
Fuel Handling/Feeding:	Coal/TDF blending system at reclaim hoppers. Variable speed conveyor belt used to control mixture during fuel reclaim. System worked well up to 10% TDF.
Testing Company:	Burns & McDonnell
Environmental Agency:	Illinois Department of Commerce and Community Affairs has been spearheading efforts to support the use of TDF.
Reference:	Clark, et al (1991)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form	X		
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates			X
Multiple Baseline Fuels		X	
Test Witnessed by or Prepared for Governmental Agency			X

Table A-2b. Facility B - Coal-Fired Power Plant

Pollutant	0% TDF				5% TDF				10% TDF			
	kg/ hr	lb/hr	g/MJ	lb/ MMBtu	kg/ hr	lb/hr	g/MJ	lb/ MMBtu	kg/hr	lb/hr	g/MJ	lb/ MMBtu
Particulate	2.50	5.49	0.0090	0.021	1.61	3.55	0.0064	0.015	1.19	2.61	0.004	0.009
SO_2	173	380	0.606	1.41	206	454	0.774	1.80	195	430	0.645	1.53
NO_x	91.8	202	0.34	0.78	65.4	144	0.25	0.58	41	90	0.13	0.30
H_2SO_4	1.8	4.0	0.0065	0.015	1.6	3.6	0.0060	0.014	1.5	3.3	0.0052	0.012
Chloride (as Cl-) inlet to fabric filter	3.7	8.1	0.013	0.029	3.3	7.2	0.013	0.029	3.5	7.7	0.012	0.027

Table A-3a. Facility C - Coal-Fired Power Plant

Source Description

Facility Name, Location:	Wisconsin Power & Light (WP&L) - Rock River Generating Station, Beloit, WI
Facility Type:	Utility
Source Type:	Two Boilers, cyclone-fired, @ 75 MW capacity; 525,000 lb steam/hr.
Test Dates:	February/March 1991
Other fuel(s):	Coal
Air pollution control device(s) used:	ESPs
Test Conditions:	100% Coal 93% Coal, 7% TDF
Test Methods:	Unknown
Fuel Handling/Feeding:	Initially, existing coal crushers did not significantly reduce size of TDF and magnets pulled small crumb rubber from conveyor. Additional coal yard conveyor was added to safely blend TDF with coal downstream from coal crushing equipment.
Testing Company:	Unknown
Environmental Agency:	Wisconsin DNR
Reference:	Clark, et al (1991), Malcolm Pirnie (1991)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form	some		
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates			X
Multiple Baseline Fuels		X	
Test Witnessed by or Prepared for Governmental Agency	X		

Table A-3b. Facility C - Coal-Fired Power Plant

Pollutant	Emissions Units	100% Coal	7% TDF	% Change
Particulate Matter	g/MJ	0.22	0.060	-73
	lb/MMBtu	0.52	0.14	-73
Sulfur Dioxide	g/MJ	0.490	0.37	-24
	lb/MMBtu	1.14	0.87	-24
Nitrogen Oxides	g/MJ	0.34	0.39	+16
	lb/MMBtu	0.79	0.91	+16
Carbon Monoxide	kg/hr	0.691	3.30	+377
	lb/hr	1.52	7.26	+377
Hydrocarbons (as CH_4)	kg/hr	2.35	4.668	+99
	lb/hr	5.16	10.27	+99
HCl	kg/hr	11.71	9.040	-23
	lb/hr	25.77	19.89	-23
HF	kg/hr	0.845	0.609	-28
	lb/hr	1.86	1.34	-28

[a] Semivolatile organic samples at 4% TDF were lost in a lab accident; thus, baseline results are not included here.
[b] Baseline = 82% coal, 13% bark, 5% sludge, 0% TDF.
[c] TDF = 80% coal, 12% bark, 4% sludge, 4% TDF.

Table A-4a. Facility D - Coal-Fired Power Plant

Source Description

Facility Name, Location:	Ohio Edison Toronto, Ohio
Facility Type:	Utility
Source Type:	Boiler - Pulverized coal feed, front-fired, wet bottom, noncontinuous tap.
Test Dates:	May 21 - 25, 1990
Other fuel(s):	Coal
Air pollution control device(s) used:	ESP
Test Conditions:	0%, 5%, 10%, 15%, 20% TDF
Test Methods:	EPA Methods 2, 3, 5, 6, 7A
Fuel Handling/Feeding:	Pulverized coal-fired boiler required modifications; an additional opening was created in the boiler wall to feed whole tires into the boiler.
Testing Company:	Entropy Environmentalists
Environmental Agency:	Ohio EPA
Reference:	Ohio Edison (1990), Clark, et al (1991), Malcolm Pirnie (1991)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form	X		
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates	X		
Multiple Baseline Fuels		X	
Test Witnessed by or Prepared for Governmental Agency		X	

Table A-4b. Facility D - Coal-Fired Power Plant

		Tire Feed Rate	Particulate		SO_2		NO_x		Lead	
			g/MJ	lb/MMBtu	g/MJ	lb/MMBtu	g/MJ	lb/MMBtu	g/MJ	lb/MMBtu
Day 1	Run 1		0.0328	0.0764	2.03	4.71	0.327	0.761	4.03×10^{-6}	9.38×10^{-6}
0%	Run 2	None	0.0159	0.0370	2.21	5.15	0.257	0.598	4.00×10^{-5}	9.31×10^{-5}
Tires	Run 3		0.0327	0.0760	2.59	6.03	0.191	0.445	4.39×10^{-5}	1.02×10^{-4}
	Average		0.0271	0.0631	2.28	5.30	0.258	0.601	4.02×10^{-5}	9.63×10^{-5}
Day 2	Run 1	1 tire per	0.0203	0.0472	2.34	5.44	0.168	0.391	4.18×10^{-5}	9.73×10^{-5}
5%	Run 2	34 seconds	0.0412	0.0959	2.51	5.83	0.235	0.547	4.29×10^{-5}	9.97×10^{-5}
Tires	Run 3		0.0309	0.0719	2.55	5.93	0.255	0.593	4.34×10^{-5}	1.01×10^{-4}
	Average		0.0308	0.0717	2.46	5.73	0.219	0.510	4.27×10^{-5}	9.93×10^{-5}
Day 3	Run 1	1 tire per	0.0178	0.0414	2.42	5.62	0.139	0.324	4.20×10^{-5}	9.77×10^{-5}
10%	Run 2	17 seconds	0.0384	0.0892	2.48	5.76	0.206	0.478	4.15×10^{-5}	9.66×10^{-5}
Tires	Run 3		0.0166	0.0385	2.47	5.74	0.217	0.504	4.07×10^{-5}	9.47×10^{-5}
	Average		0.0243	0.0564	2.46	5.71	0.188	0.436	4.14×10^{-5}	9.63×10^{-5}
Day 4	Run 1	1 tire per	0.0336	0.0781	2.09	4.85	0.147	0.342	4.00×10^{-5}	9.31×10^{-5}
15%	Run 2	11.3 seconds	0.0334	0.0776	2.49	5.80	0.196	0.455	4.24×10^{-5}	9.86×10^{-5}
Tires	Run 3		0.0382	0.0889	2.47	5.75	0.228	0.531	4.22×10^{-5}	9.82×10^{-5}
	Average		0.0350	0.0815	2.35	5.47	0.191	0.443	4.15×10^{-5}	9.66×10^{-5}
Day 5	Run 1	1 tire per	0.0162	0.0377	2.16	5.03	0.135	0.313	3.79×10^{-5}	8.81×10^{-5}
20%	Run 2	8.5 seconds	0.0163	0.0380	2.31	5.38	0.175	0.407	4.02×10^{-5}	9.34×10^{-5}
Tires	Run 3		0.0259	0.0603	2.41	5.60	0.201	0.440	3.96×10^{-5}	9.21×10^{-5}
	Average		0.019	0.0453	2.30	5.34	0.166	0.387	3.92×10^{-5}	9.12×10^{-5}

Table A-5a. Facility E - Wood-Fired Power Plant

Source Description

Facility Name, Location:	Northern States Power Company, French Island Plant French Island, WI
Facility Type:	Utility
Source Type:	Bubbling Fluidized Bed Boiler, 150,000 lb steam/hr capacity.
Test Dates:	1982
Other fuel(s):	Wood waste
Air pollution control device(s) used:	Unknown
Test Conditions:	100% Wood waste 91% Wood waste, 9% Rubber Buffings 93% Wood waste, 7% TDF
Test Methods:	Unknown
Testing Company:	Unknown
Environmental Agency:	Wisconsin DNR
Reference:	Clark, et al (1991)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form	X		
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates			X
Multiple Baseline Fuels		X	
Test Witnessed by or Prepared for Governmental Agency			X

Table A-5b. Facility E - Wood-Fired Power Plant

Pollutant	100% Wood-Waste				9% Rubber Buffings				7% TDF			
	kg/hr	lb/hr	g/MJ	lb/ MMBtu	kg/hr	lb/hr	g/MJ	lb/ MMBtu	kg/hr	lb/hr	g/MJ	lb/ MMBtu
Particulate	NT	NT	0.036	0.083	NT	NT	0.11[a]	0.25[a]	NT	NT	0.13[a]	0.31[a]
SO_2	3	7	0.086	0.020	NT	NT	NT	NT	23	50	0.032	0.074
NO_x	41	90	0.082	0.19	NT	NT	NT	NT	22	48	0.0538	0.125
CO	1,050	2,300	NT	NT	1,200	2,700	NT	NT	1,000	2,200	NT	NT
Aldehydes	30.3	66.6	NT	NT	6.4	14	NT	NT	5.5	12	NT	NT
Benzene	8.2	18	NT	NT	NT	NT	NT	NT	11	25	NT	NT
Phenols	28	61	NT	NT	NT	NT	NT	NT	6.4	14	NT	NT
Polyaromatic hydrocarbons	59.1	130	NT	NT	NT	NT	NT	NT	77.3	170	NT	NT

[a] Exceeds Wisconsin limit of 0.15 lb/MMBtu.
NT = Not tested or data not available.

Table A-6a. Facility F - Coal-Fired Power Plant

Source Description

Facility Name, Location:	Illinois Power - Baldwin Generating Station Baldwin, IL
Facility Type:	Utility
Source Type:	Two cyclone fired boilers, universal pressure, balanced draft, turbine rated 560 MW, capacity: 4,199,000 lb steam/hr.
Test Dates:	March 21, 1991
Other fuel(s):	Coal
Air pollution control device(s) used:	ESP (Western Precipitation)
Test Conditions:	2% TDF
Test Methods:	Unknown
Fuel Handling/Feeding:	Mixing of coal and TDF occurs at front of closed conveyor system. TDF went through hammer mills at time of test, but size did not decrease appreciably.
Testing Company:	Burns & McDonnell
Environmental Agency:	Unknown
Reference:	Clark, et al (1991)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form		X	
Baseline Fuel Test Data Available		X	
Accurate Fuel Feed Rates			X
Multiple Baseline Fuels		X	
Test Witnessed by or Prepared for Governmental Agency			X

Table A-6b. Facility F - Coal-Fired Power Plant - 2% TD

Pollutant	kg/hr	lb/hr	g/MJ	lb/MMBtu
PM (ESP inlet)	8,147.790	17,926.93	1.478	3.438
PM (ESP outlet)	419.4	922.7	0.0740	0.1722
SO_2[a]	NT	NT	2.27	5.28
Beryllium	0.00439	0.00966	NT	NT
Cadmium	0.01085	0.02387	NT	NT
Total Chromium	0.25565	0.56249	NT	NT
Lead	0.03679	0.08095	NT	NT
Zinc (filter catch only)	0.00220	0.00484	NT	NT

[a] Stack concentration = 2,396.
NT = Not tested or data not available.

Table A-7a. Facility G - Coal and Wood-Fired Power Plant

Source Description

Facility Name, Location:	Northern States Power Company, Bay Front Plant Eau Claire, WI
Facility Type:	Utility
Source Type:	Boiler - two drum (Sterling) equipped with Detroit rotograte and spreader stoker (150,000 lb steam/hr capacity) .
Test Dates:	May 21 - 23, 1991
Other fuel(s):	Wood chips, coal
Air pollution control device(s) used:	Electrolyzed gravel bed filter (EFB, Inc., manufacturer)
Test Conditions:	100% wood chips, 95% wood chips, 5% coal, 95% wood chips, 5% TDF
Test Methods:	For PM, SO2, CO: EPA Methods 1 - 6 and 10 CFR Title 40, Part 60, Appendix A (rev. July 1, 1990). (Method 5; front and backhalf extraction.) For benzene: EPA Method 18 For formaldehyde: Modified NIOSH 3500. For PAHs: EPA Method 0010, using modified method 5 sampling train. Analyzed in accordance with EPA Method 8270.
Testing Company:	Interpoll Laboratories, Inc.
Environmental Agency:	Wisconsin DNR
Reference:	Interpoll (1991)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form	some		
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates			X
Multiple Baseline Fuels	X		
Test Witnessed by or Prepared for Governmental Agency	X		

Table A-7b. Facility G - Coal and Wood-Fired Power Plant

Compound		Emission Factor or Rate		
		100% Wood Chips	Wood Chips + 5% Coal	Wood Chips +5% TDF
PM	g/MJ	0.0490	0.037	0.040
	lb/MMBtu	0.114	0.085	0.093
SO_2	g/MJ	0.003	0.001	0.001
	lb/MMBtu	0.006	0.003	0.003
CO	kg/hr	188	50.4	34.5
	lb/hr	414	111	76.0
Formaldehyde	kg/hr	0.0773	0.0727	0.0477
	lb/hr	0.170	0.160	0.105
Benzene	kg/hr	0.0741	≤0.010	≤0.011
	lb/hr	0.163	≤0.022	≤0.023
Benzo(a)anthracene	ug/sec	>66	>66	>66
Benzo(b)flouranthene	ug/sec	>36	>37	>37
Benzo(a)pyrene	ug/sec	>14	>14	>14
Dibenzo(a,h)anthracene	ug/sec	>32	>33	>33
Indeno(1,2,3)pyrene	ug/sec	>33	>33	>33
Dibenzo(a,h)acridine	ug/sec	>552	>553	>553

(Continued)

Table A-7b. Facility G - Coal and Wood-Fired Power Plant (Cont.)

Compound		Emission Factor or Rate		
		100% Wood Chips	Wood Chips + 5% Coal	Wood Chips +5% TDF
Dibenzo(a,j)acridine	ug/sec	>552	>553	>553
7H-dibenzo(c,g)carbazole	ug/sec	>44	>44	>44
Dibenzo(a,h)pyrene	ug/sec	>737	>738	>738
Dibenzo(a,i)pyrene	ug/sec	>737	>738	>738
Idenol(1,2,3-cd)pyrene	ug/sec	NT	>33	>33

[a] Semivolatile organic samples at 4% TDF were lost in a lab accident; thus, baseline results are not included here.
[b] Baseline = 82% coal, 13% bark, 5% sludge, 0% TDF.
[c] TDF = 80% coal, 12% bark, 4% sludge, 4% TDF.
NT = Not tested or data not available.

Table A-8a. Facility H - Coal and Petroleum Coke-Fired Power Plant

Source Description

Facility Name, Location:	Manitowoc Power Station Manitowoc, WI
Facility Type:	Utility
Source Type:	Circulating fluidized bed boiler (220,000 lb steam/hr capacity).
Test Dates:	May 30-31, 1991, September 25-26, 1991, October 29-30, 1991
Other fuel(s):	Coal, petroleum coke
Air pollution control device(s) used:	Pulse jet baghouse with air-to-cloth ratio of 3:1.
Test Conditions:	Test 1: 100% Coal Test 2: 100% Petroleum coke Test 3: 80% Petroleum coke, 20% TDF
Test Methods:	Unknown
Fuel Handling/Feeding:	Unknown
Testing Company:	Clean Air Engineering
Environmental Agency:	Wisconsin DNR
Reference:	CAE (1991)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form		X	
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates			X
Multiple Baseline Fuels	X		
Test Witnessed by or Prepared for Governmental Agency		X	

Table A-8b. Facility H - Coal and Petroleum Coke-Fired Power Plant

Pollutant	Test 1 - Coal 5/30-31/91	Test 2 - Pet. Coke 9/25-26/91	Test 3 - Pet. Coke/TDF 10/29-30/91	Limit						Compl.
				g/MJ	lb /MMBtu	kg/yr	lb/yr	kg/hr	lb/hr	
TSP	0.0089	0.0069	0.003	0.01	0.03	NT	NT	NT	NT	Y
SO_2	0.47	0.66	0.51	0.38	0.89	NT	NT	NT	NT	Y
NO_2	0.061	0.063	0.032	0.24	0.55	NT	NT	NT	NT	Y
CO	0.067	0.013	0.032	0.3	0.74	NT	NT	NT	NT	Y
VOC	0.0012	NT	0.0004	0.069	0.16	NT	NT	NT	NT	Y
HCOH	<124	<32.4	<150	NT	NT	113	250	NT	NT	Y
Benzene	<33	<18.4	10.5	NT	NT	136	300	NT	NT	Y
<u>Metals</u>										
Be	$<1.38 \times 10^{-6}$	$<1.0 \times 10^{-7}$	$<9.9 \times 10^{-7}$	NT	NT	NT	NT	1.8×10^{-5}	4.0×10^{-5}	Y
Hg	$<7.10 \times 10^{-4}$	$<1.57 \times 10^{-2}$	$<1.59 \times 10^{-2}$	NT	NT	NT	NT	7.7×10^{-3}	1.7×10^{-2}	Y
Lead	$<2.67 \times 10^{-3}$	$<4.05 \times 10^{-3}$	$<5.87 \times 10^{-3}$	NT	NT	NT	NT	9.1×10^{-5}	2.0×10^{-4}	N
Ni	$<3.94 \times 10^{-3}$	$<3.42 \times 10^{-3}$	$<3.2 \times 10^{-3}$	NT	NT	NT	NT	1.8×10^{-4}	4.0×10^{-4}	N
As	$<3.13 \times 10^{-4}$	$<1.35 \times 10^{-4}$	$<5.25 \times 10^{-4}$	NT	NT	NT	NT	1.8×10^{-3}	4.0×10^{-3}	Y
Cd	$<1.61 \times 10^{-3}$	$<1.01 \times 10^{-3}$	$<1.19 \times 10^{-3}$	NT	NT	NT	NT	6.4×10^{-3}	1.4×10^{-2}	Y
Cr	$<2.5 \times 10^{-4}$	$<2.06 \times 10^{-3}$	$<2.35 \times 10^{-3}$	NT	NT	NT	NT	0.13	0.29	Y

NT = Not tested or not available.

Table A-9a. Facility I - Cement Kiln

Source Description

Facility Name, Location:	Ash Grove Cement Durkee, OR
Facility Type:	Cement Plant
Source Type:	Cement Kiln
Test Dates:	October 18 - 20, 1989
Other fuel(s):	Natural gas and coal
Air pollution control device(s) used:	ESP
Test Conditions:	Unknown
Test Methods:	Unknown
Fuel Handling/Feeding:	Unknown
Testing Company:	Unknown
Environmental Agency:	Oregon DEQ
Reference:	Clark, et al (1991)

Source Test Data Evaluation

	Yes	**No**	**Unknown**
Data Expressed in Emission Factor Form	some		
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates		X	
Multiple Baseline Fuels	X		
Test Witnessed by or Prepared for Governmental Agency	X		

Table A-9b. Facility I - Cement Kiln

Pollutant		Baseline, 0% TDF	9-10% TDF	% Change
Particulate	g/MJ	0.417	0.382	-8
	lb/MMBtu	0.969	0.888	-8
SO_2	g/MJ	0.119	0.0950	-20
	lb/MMBtu	0.276	0.221	-20
CO	ppm	0.046	0.036	-27
Aliphatic compounds	g/MJ	0.00047	0.0004	-18
	lb/MMBtu	0.0011	0.0009	-18
Nickel	ug	30	ND	NA
Cadmium	ug	3.0	2.0	-33
Chromium	ug	30	ND	NA
Lead	ug	ND	ND	NA
Zinc	ug	35	35	0
Arsenic	ug	0.2	0.2	0
Chloride	kg/hr	0.122	0.0895	-26
	lb/hr	0.268	0.197	-26
Copper	ug	37	13	-65
Iron	ug	400	200	-50

ND = Not detected.
NA = Not applicable.

Table A-10a. Facility J - Cement Kiln

Source Description

Facility Name, Location:	Holnam Incorporated Industries Seattle, WA
Facility Type:	Cement Plant
Source Type:	Cement Kiln
Test Dates:	October 15 - 19 1990
Other fuel(s):	Coal/coke
Air pollution control device(s) used:	ESP
Test Conditions:	0%, 11%, 14% TDF (as heat input)
Test Methods:	EPA Methods 1, 2, 3A, 4, 5 (front and backhalf extraction), 6C, 7E, 10, 12, 0010 (Semi-Volatile Organic Sampling Train), TO-14.
Fuel Handling/Feeding:	Tire chips
Testing Company:	Am Test, Inc.
Environmental Agency:	Washington DOE
Reference:	Am Test (1991), Clark, et al (1991)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form	X		
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates			X
Multiple Baseline Fuels		X	
Test Witnessed by or Prepared for Governmental Agency	X		

Table A-10b. Facility J - Cement Kiln

Pollutant	Baseline, 100% Coal, 0% TDF		11% TDF			14% TDF		
	10^{-6} g/MJ	10^{-6} lb /MMBtu	10^{-6} g/MJ	10^{-6} lb /MMBtu	% Change	10^{-6} g/MJ	10^{-6} lb /MMBtu	% Change
Acenaphthalene	1.19	2.76	0.864	2.01	-27	0.886	2.06	-26
Acenaphthylene	0.095	0.22	ND	ND	-100	ND	ND	-100
Anthracene	1.06	2.46	ND	ND	-100	ND	ND	-100
Benzo(b)anthracene	4.25	9.88	ND	ND	-100	ND	ND	-100
Benzoic Acid	4.498	10.46	ND	ND	-100	ND	ND	-100
Benzo(a)pyrene	0.877	2.04	ND	ND	-100	ND	ND	-100
Benzo(g,h,i)perylene	ND	ND	1.34	3.11	NA	4.442	10.33	NA
Bis(2-chloroethoxy)methane	95.641	222.42	74.583	173.45	-22	118.57	275.75	+24
Butyl Benzyl Phthalate	2.57	5.98	ND	ND	-100	ND	ND	-100
Dibenz(g,h)phthracene	45.877	106.69	20.50	47.67	-55	28.88	67.17	-37
Di-N-Butylphthalate	0.959	2.23	ND	ND	-100	ND	ND	-100
1,2-Dichlorobenzene	1.38	3.21	ND	ND	-100	ND	ND	-100
2,4-Dinitrotoluene	5.749	13.37	4.29	9.97	-25	3.87	9.00	-33
Fluorene	3.29	7.65	3.02	7.03	-8	3.06	7.12	-7

(Continued)

Table A-10b. Facility J - Cement Kiln (Cont.)

Pollutant	Baseline, 100% Coal, 0% TDF		11% TDF			14% TDF		
	10^{-6} g/MJ	10^{-6} lb /MMBtu	10^{-6} g/MJ	10^{-6} lb /MMBtu	% Change	10^{-6} g/MJ	10^{-6} lb /MMBtu	% Change
Hexachlorobenzene	31.60	73.49	17.38	40.42	-45	22.99	53.46	-27
Naphthalene	146.20	340.00	76.944	178.94	-47	68.456	159.20	-53
2-Nitroanaline	2.01	4.67	ND	ND	-100	2.16	5.02	+7
N-Nitrosodiphenyl-amine	39.05	90.81	20.47	47.60	-48	21.47	49.92	-45
Pyrene	2.14	4.97	1.02	2.38	-52	0.959	2.23	-55
1,2,4-Tricholrobenzene	7.504	17.45	1.11	2.57	-85	ND	ND	-100
4,6-Dinitro-2-methylphenol	2.38	5.53	ND	ND	-100	ND	ND	-100
4-Methyl Phenol	8.407	19.55	3.93	9.13	-53	6.570	15.28	-22
2-Nitrophenol	83.846	194.99	72.747	169.18	-13	74.012	172.12	-12
4-Nitrophenol	ND	ND	21.34	49.62	NA	12.80	29.77	NA
Pentachlorophenol	ND	ND	ND	ND	NA	ND	ND	NA
Phenol	140	32	69.247	161.04	-50	131.89	306.71	-4
2,4,5-Trichlorophenol	ND	ND	ND	ND	NA	ND	ND	NA

NA = Not applicable.
ND = Not detected.

Table A-11a. Facility K - Lime Kiln

Source Description

Facility Name, Location:	Boise Cascade Wallula, WA
Source Type:	Pulp and Paper Mill - Rotary Lime Kiln
Test Dates:	May 20-21, 1986
Other fuel(s):	Natural Gas
Air pollution control device(s) used:	Air Pol variable throat venturi scrubber (27 - 29 inches H_2O, 1100 gallons water/hour).
Test Conditions:	Approximately 15% TDF by heat input
Test Methods:	Washington DOE Methods 3 and 5
Fuel Handling/Feeding:	Unknown
Testing Company:	Washington DOE
Environmental Agency:	Washington DOE
Reference:	Clark, et al (1991), State of Washington (1986a, 1986b)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form	X		
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates			X
Multiple Baseline Fuels		X	
Test Witnessed by or Prepared for Governmental Agency	X		

Table A-11b. Facility K - Lime Kiln

Pollutant	100% Gas Fired		85% Gas, 15% TDF		% Change
	10^{-6}g /MJ	10^{-6} lb/MMBtu	10^{-6}g /MJ	10^{-6} lb/MMBtu	
Organics[a]					
Anthracene	1.6	3.7	0.77	1.8	-51
Phenanthrene	22.3	51.9	12.5	29.1	-44
Fluoranthene	3.7	8.6	3.8	8.8	+2
Pyrene	2.8	6.6	2.7	6.2	-6
Benzo(a)anthracene	0.47	1.1	0.47	1.1	0
Chrysene	0.47	1.1	0.47	1.1	0
Benzo(b)fluoranthene	0.3	0.8	0.3	0.8	0
Benzo(k)fluoranthene	0.1	0.3	0.2	0.4	+33
Metals					
Arsenic	0.82	1.9	1.5	3.5	+84
Copper	1.4	3.2	1.3	2.9	-9
Zinc	98.5	28.8	183.9	427.7	+1,385
Iron	99.63	231.7	72.37	168.3	-27
Nickel	2.4	5.6	1.5	3.5	-38
Chromium	35.8	83.3	137.0	318.6	+282

(Continued)

Table A-11b. Facility K - Lime Kiln (Cont.)

Pollutant	100% Gas Fired		85% Gas, 15% TDF		% Change
	10^{-6}g /MJ	10^{-6} lb/MMBtu	10^{-6}g /MJ	10^{-6} lb/MMBtu	
Cadmium	0.60	1.4	0.56	1.3	-7
Lead	1.8	4.1	0.56	1.3	-31
Vanadium	2.5	5.7	1.6	3.8	-33
Barium	10.7	24.9	22.4	52.1	+109

[a] Also measured, but not detected with or without (TDF) were naphthalene, acenaphthalene, benzo(a)pyrene, dibenzo(a,h)anthracene, benzo(g,h,i)perylene, and indeno(1,2,3-cd)pyrene.

Table A-12a. Facility L - Pulp Mill

Source Description

Facility Name, Location:	Port Townsend Paper Company Port Townsend, WA
Facility Type:	Kraft Pulp Mill
Source Type:	Power Boiler, No. 10. 200,000 lb/hr steam
Test Dates:	February 25 and March 5, 1986
Other fuel(s):	Hogged fuel, oil
Air pollution control device(s) used:	600 tube multiclone followed by venturi scrubber. Multiclone operated at 3.5 - 4 inch H_2O pressure differential. Venturi operated at 15 inches H_2O when tires burned and 13 inches when tires were not burned. Venturi water rate 2,500 - 2,900 gpm.
Test Conditions:	Approximately 7% TDF by heat input
Test Methods:	Washington DOE Methods 3 and 5
Fuel Handling/Feeding:	Shredded tires
Testing Company:	Washington DOE
Environmental Agency:	Washington DOE
Reference:	State of Washington (1986e)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form	X		
Baseline Fuel Test Data Available		X	
Accurate Fuel Feed Rates		X	
Multiple Baseline Fuels	X		
Test Witnessed by or Prepared for Governmental Agency	X		

Table A-12b. Facility L - Pulp Mill - PNA and Metal Emissions

Pollutant	Port Townsend Paper (2/25/86)							
	Waste Wood + 5% Oil				Waste Wood + 7% TDF			
	kg/hr	lb/hr	g/MJ	10^{-6}lb/ MMBTu	kg/hr	lb/hr	g/MJ	10^{-6}lb/ MMBtu
Particulate	21.0	46.2	NT	NT	29.0	63.8	NT	NT
Metals								
Arsenic	NT	NT	NA	NA	NT	NT	NA	NA
Barium	NT	NT	110.7	257.4	NT	NT	150.7	350.5
Cadmium	0.004	0.009	18.4	42.8	0.003	0.007	12.5	31.3
Chromium	0.005	0.01	23.6	54.9	0.05	0.01	15.0	34.9
Copper	NT	NT	1,038.7	2,415.6	NT	NT	987.62	2,296.8
Iron	NT	NT	859.91	1,999.8	NT	NT	1,106.8	2,574.0
Lead	0.05	0.1	259.7	603.9	0.01	0.03	56.89	132.3
Nickel	0.05	0.1	296.3	689.0	0.05	0.01	25.4	59.0
Vanadium	0.09	0.2	388.2	902.9	0.0005	0.001	3.8	8.9
Zinc	1.4	3.1	6,359.96	14,790.6	22.2	48.8	107,276.4	249,480.0
PNA's								
Anthracene	0.01	0.03	4.3	9.9	0.05	0.01	11.5	26.7
Phenanthrene	0.05	0.1	180.5	419.8	0.09	0.2	332.0	772.2

(Continued)

Table A-12b. Facility L - Pulp Mill - PNA and Metal Emissions (Cont.)

Pollutant	Port Townsend Paper (2/25/86)							
	Waste Wood + 5% Oil				Waste Wood + 7% TDF			
	kg/hr	lb/hr	g/MJ	10^{-6}lb/ MMBTu	kg/hr	lb/hr	g/MJ	10^{-6}lb/ MMBtu
Fluoranthene	NT	NT	197.6	459.4	NT	NT	101.3	235.6
Pyrene	NT	NT	107.3	249.5	NT	NT	163.5	380.2
Benzo(b)fluoranthene	NT	NT	0.3	0.6	NT	NT	0.52	1.2
Benzo(k)fluoranthene	NT	NT	0.3	0.6	NT	NT	0.3	0.6
Benzo(a)fluoranthene	NT	NT	0.7	1.6	NT	NT	0.95	2.2
Chrysene	NT	NT	1.4	3.2	NT	NT	1.0	2.4
TOTAL PNA's	**NT**	**NT**	**NT**	**NT**	**0.1**	**0.3**	**NT**	**NT**

NT = Not tested or data not available.

Table A-13a. Facility M - Pulp and Paper Mill

Source Description

Facility Name, Location:	Crown Zellerbach Port Angeles, WA
Facility Type:	Pulp and Paper Mill
Source Type:	Wood-fired Boiler
Test Dates:	June 10 -11, 1986
Other fuel(s):	Hogged fuel, oil
Air pollution control device(s) used:	Multi-clone followed by venturi scrubber (scrubber uses single pass fresh water and operated at 11 - 12 inches H_2O pressure drop during test.).
Test Conditions:	Approx. 2% TDF heat input on June 11 (oil = 11% of heat input; balance was wood).
Test Methods:	Washington DOE Methods 3 and 5
Fuel Handling/Feeding:	Unknown
Testing Company:	Washington DOE
Environmental Agency:	Washington DOE
Reference:	Clark, et al (1991), State of Washington (1986c, 1986d)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form	X		
Baseline Fuel Test Data Available		X	
Accurate Fuel Feed Rates		X	
Multiple Baseline Fuels	X		
Test Witnessed by or Prepared for Governmental Agency	X		

Table A-13b. Facility M - Pulp and Paper Mill - PNA and Metal Emissions

Pollutant	Crown Zellerbach Corp. (6/10/86)							
	Waste Wood + 12% Oil				Waste Wood + 2% TDF + 11% Oil			
	kg/hr	lb/hr	10^{-6}g /MJ	10^{-6}lb /MMBtu	kg/hr	lb/hr	10^{-6}g /MJ	10^{-6}lb /MMBtu
Particulate	5.00	11.0	NT	NT	7.00	15.4	NT	NT
Metals								
Arsenic	NT	NT	1.4	3.3	NT	NT	2.70	6.28
Barium	NT	NT	4.86	11.3	NT	NT	12.5	29.1
Cadmium	NT	NT	1.3	2.9	NT	NT	2.49	5.8
Chromium	NT	NT	0.2	0.5	NT	NT	1.51	3.5
Copper	NT	NT	13.2	30.7	NT	NT	17.2	40.0
Iron	NT	NT	113.1	263.1	NT	NT	163	377.8
Lead	NT	NT	27.5	64.0	NT	NT	31.1	72.4
Nickel	NT	NT	1.5	3.5	NT	NT	1.55	3.6
Vanadium	NT	NT	1.3	3.0	NT	NT	3.23	7.5
Zinc	NT	NT	1,055.7	2,455.0	1.41	3.1	7,044	16,381.4
PNA's								
Anthracene	NT	NT	0.43	1.0	NT	NT	0.3	0.6
Phenanthrene	NT	NT	19.5	45.3	NT	NT	7.18	16.7

(Continued)

Table A-13b. Facility M - Pulp and Paper Mill - PNA and Metal Emissions (Cont.)

Pollutant	Crown Zellerbach Corp. (6/10/86)							
	Waste Wood + 12% Oil				Waste Wood + 2% TDF + 11% Oil			
	kg/hr	lb/hr	10^{-6}g /MJ	10^{-6}lb /MMBtu	kg/hr	lb/hr	10^{-6}g /MJ	10^{-6}lb /MMBtu
Fluoranthene	NT	NT	16.1	37.4	NT	NT	6.11	14.2
Pyrene	NT	NT	20.6	47.8	NT	NT	9.33	21.7
Benzo(b)fluoranthene	NT	NT	0.99	2.3	NT	NT	ND	ND
Benzo(k)fluoranthene	NT	NT	0.3	0.7	NT	NT	ND	ND
Benzo(a)fluoranthene	NT	NT	ND	ND	NT	NT	ND	ND
Chrysene	NT	NT	ND	ND	NT	NT	ND	ND
TOTAL PNA's	**NT**	**NT**	**NT**	**NT**	**0.009**	**0.02**	**NT**	**NT**

NT = Not tested or data not available.

Table A-14a. Facility N - Pulp and Paper Mill

Source Description

Facility Name, Location:	Smurfit Newsprint Newburg, OR
Facility Type:	Pulp and Paper Mill
Source Type:	Wood-fired boiler
Test Dates:	May 28, June 3, July 16, 1987
Other fuel(s):	Wood
Air pollution control device(s) used:	Venturi scrubber
Test Conditions:	May 28 - wood only June 3 - 1% TDF July 16 - 1.5%
Test Methods:	Unknown
Fuel Handling/Feeding:	Tire chips
Testing Company:	Horizon Engineering
Environmental Agency:	Oregon DEQ
Reference:	Clark, et al (1991)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form		X	
Baseline Fuel Test Data Available	some		
Accurate Fuel Feed Rates	X		
Multiple Baseline Fuels		X	
Test Witnessed by or Prepared for Governmental Agency			X

Table A-14b. Facility N - Pulp and Paper Mill - PM

Date	% TDF	PM Emissions			
		kg/hr	lb/hr	Mg/yr[a]	tons/yr[a]
5/28/87	0	12.2	26.8	106	117
5/28/87	1	20.7	45.6	182	200
5/28/87	1.5	26.0	57.2	228	251
11/14/89	1	13.9	30.5	122	134
8/14/90	1	11.8	26.0	103	114

[a] Assumes 8,760 h/yr.

Table A-14c. Facility N - Pulp and Paper Mill - Non-particulate Testing

Pollutant	Date	%TDF	kg/hr	lb/hr	Mg/yr	tons/yr
Criteria						
VOC[a]	5/28/87	0	11.4	25.1	99.9	110
	5/28/87	1	3.6	8.0	31.9	35.1
	5/28/87	1.5	31.8	69.9	278	306
	11/14/89	1.0	0.55	1.2	4.8	5.3
	8/14/90	1.0	0.46	1.0	4.0	4.4
NO_x[b]	11/14/89	1.0	37.6	82.8	33.0	36.3
	8/14/90	1.0	15.2	33.4	133	146
SO_2[c]	11/14/89	1.0	2.2	4.8	19	21
	8/14/90	1.0	NT	NT	NT	NT
CO[d]	11/14/89	1.0	43.1	94.9	379	417
	8/14/87	1.0	66.4	146	580	639
Barium	11/14/89	1.0	ND	ND	NT	NT
Cadmium	11/14/89	1.0	0.0077	0.017	NT	NT
Chromium	11/14/89	1.0	0.003	0.006	NT	NT
Copper	11/14/89	1.0	0.0091	0.020	NT	NT
Iron	11/14/89	1.0	0.118	0.260	NT	NT

(Continued)

Table A-14c. Facility N - Pulp and Paper Mill - Non-particulate Testing (Cont.)

Pollutant	Date	%TDF	kg/hr	lb/hr	Mg/yr	tons/yr
Lead	11/14/89	1.0	0.017	0.037	NT	NT
Zinc	11/14/89	1.0	1.74	3.82	NT	NT
Titanium	11/14/89	1.0	ND	ND	NT	NT

[a] VOC limit is 189 TPY.
[b] NO_x limit is 2,850 TPY.
[c] SO_2 limit is 250 TPY.
[d] CO limit is 570 TPY.
ND = Not detected.
NT = Not tested or data not available.

Table A-15a. Facility O - Paper Mill

Source Description

Facility Name, Location:	Packaging Corp. of America (Formerly Nekoosa Packaging) Tomahawk, WI
Facility Type:	Paper Mill (Corrugated paper products)
Source Type:	Traveling grate spreader/stoker boilers (3)
Test Dates:	August 4 - 11, 1989
Other fuel(s):	Coal, bark
Air pollution control device(s) used:	ESP
Test Conditions:	Tested on overall facility basis; all three boilers ducted to common duct, then to two ESPs.
Test Sampling Procedures:	EPA Methods 1, 2, 3, 4, 5, MM5, 6, 7E, 10, 12, 13B, 18, 25A, and 101A.
Fuel Handling/Feeding:	Unknown
Testing Company:	Clean Air Engineering (Report Date November 7, 1989)
Environmental Agency:	Wisconsin DNR
Reference:	CAE (1989), Clark, et al (1991)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form		X	
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates		X	
Multiple Baseline Fuels		X	
Test Witnessed by or Prepared for Governmental Agency	X		

Table A-15b. Facility O - Paper Mill

Pollutant	0% TDF		1-2%TDF		% Change
	kg/hr	lb/hr	kg/hr	lb/hr	
Particulate	8.64	19.0	9.41	20.7	+9
NO_x	51.977	114.36	48.659	107.06	-6
CO	50.490	111.09	66.916	147.23	+33
SO_2	82.3	180.67	121.81	268.00	+48
Chromium VI	0.00586	0.0129	0.016	0.036	+179
<u>Metals</u>					
Arsenic	0.001	0.003	0.001	0.003	0.0
Cadmium	<0.0010	<0.0023	<0.0010	<0.0023	ND
Lead	0.0086	0.019	0.0082	0.018	-5
Nickel	<0.004	<0.008	<0.004	<0.008	ND
Zinc	0.325	0.715	0.367	0.851	+19
Mercury	0.0002	0.0005	0.0003	0.0006	+20
Chloride	0.44	0.96	0.827	1.82	+90
Benzene	<0.0253	<0.0557	0.0303	0.0665	+20

NOTE: All three boilers are ducted to common duct and then to two ESP's.

ND = Not detected.

Table A-16a. Facility P - Pulp and Paper Mill

Source Description

Facility Name, Location:	Champion International, Inc. Sartell, MN
Facility Type:	Pulp and Paper Mill
Source Type:	Stoker boiler with traveling grate.
Test Dates:	October 28 - 30, 1987
Other fuel(s):	Coal, wood, sludge
Air pollution control device(s) used:	Zuran multi-clone as a pre-separator followed by a Neptune AirPol venturi scrubber.
Test Conditions:	Baseline: Approximately 55% coal, 25% tree bark, 20% sludge, 0% TDF Unknown fuel mix, 15% TDF Unknown fuel mix, 30% TDF
Test Methods:	EPA Methods 1- 5, MM5, 7, 8, 25A
Fuel Handling/Feeding:	Unknown
Testing Company:	Pace Laboratories, Inc.
Environmental Agency:	Minnesota Pollution Control Agency (MPCA)
Reference:	Pace (1988), Malcolm Pirnie (1991)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form	X		
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates			X
Multiple Baseline Fuels	X		
Test Witnessed by or Prepared for Governmental Agency	X		

Table A-16b. Facility P - Pulp and Paper Mill

Test Type		Test 1, 0% TDF	Test 2, 15% TDF	Test 3, 30% TDF
Particulate	g/dscm	0.05	0.09	0.2
	gr/dscf	0.02	0.04	0.09
	kg/hr	8.04	13.5	33.7
	lb/hr	17.7	29.8	74.1
	g/MJ	0.02	0.04	0.095
	lb/MMBtu	0.05	0.09	0.22
Sulfur Oxides				
SO_2	g/dscm	0.23	0.32	0.46
	gr/dscf	0.10	0.14	0.20
	kg/hr	35.5	47.54	75.40
	lb/hr	78.2	104.6	165.9
	g/MJ	0.11	0.14	0.19
	lb/MMBtu	0.25	0.33	0.45
H_2SO_4	g/dscm	0.02	0.02	0.02
	gr/dscf	0.01	0.01	0.01
	kg/hr	4.64	4.55	4.59
	lb/hr	10.2	10.0	10.1

(Continued)

Table A-16b. Facility P - Pulp and Paper Mill (Cont.)

Test Type		Test 1, 0% TDF	Test 2, 15% TDF	Test 3, 30% TDF
	g/MJ	0.01	0.01	0.01
	lb/MMBtu	0.03	0.03	0.03
Nitrogen Oxides	g/dscm	0.589	0.631	0.484
	gr/dscf	0.257	0.276	0.212
	kg/hr	91.4	98.2	75.9
	lb/hr	201	216	167
	g/MJ	0.28	0.29	0.20
	lb/MMBtu	0.64	0.67	0.47
Metals				
Cd	mg/dscm	0.004	0.014	0.028
	gr/dscf	1	6.1	12
	kg/hr	0.001	0.002	0.004
	lb/hr	0.001	0.005	0.009
	10^{-2}g/MJ	0.0002	0.00065	0.0011
	10^{-2}lb/MMBtu	0.0005	0.0015	0.0026
Cr (total)	mg/dscm	0.022	0.010	0.25
	gr/dscf	9.61	4.37	109

(Continued)

Table A-16b. Facility P - Pulp and Paper Mill (Cont.)

Test Type		Test 1, 0% TDF	Test 2, 15% TDF	Test 3, 30% TDF
	kg/hr	0.004	0.5	0.039
	lb/hr	0.008	0.003	0.085
	10^{-2}g/MJ	0.0099	0.0004	0.010
	10^{-2}lb/MMBtu	0.0023	0.0009	0.024
Pb	mg/dscm	0.066	0.21	0.34
	gr/dscf	28.8	91.8	149
	kg/hr	0.011	0.035	0.055
	lb/hr	0.023	0.076	0.12
	10^{-2}g/MJ	0.0031	0.095	0.014
	10^{-2}lb/MMBtu	0.0071	0.022	0.032
Zn	mg/dscm	0.231	36.4	90.0
	gr/dscf	101	15,900	39,300
	kg/hr	0.036	5.59	14.1
	lb/hr	0.080	12.3	31.0
	10^{-2}g/MJ	0.011	1.7	3.7
	10^{-2}lb/MMBtu	0.025	3.9	8.6
<u>PAH</u>		ND	ND	ND
Total Hydrocarbons	ppm	959	16	3
	kg/hr	75.0	1.2	0.3
	lb/hr	165	2.7	0.6

ND = Not detected.

Table A-17a. Facility Q - Pulp and Paper Mill

Source Description

Facility Name, Location:	Champion International, Inc. Sartell, MN
Facility Type:	Pulp and Paper Mill
Source Type:	Stoker boiler with traveling grate
Test Dates:	March 12 - 16, 1990
Other fuel(s):	Coal, wood, sludge
Air pollution control device(s) used:	Zuran multi-clone as a pre-separator followed by a Neptune AirPol venturi scrubber.
Test Conditions:	Baseline: 82% coal, 13% bark, 5% sludge, 0% TDF TDF: 80 % coal, 12% bark, 4% sludge, 4% TDF [Clark, et al (1991)]
Test Methods:	Method 5, with both front and back-half catch included.
Fuel Handling/Feeding:	Unknown
Testing Company:	Pace Laboratories
Environmental Agency:	Minnesota Pollution Control Agency (MPCA)
Reference:	Pace (1990), Clark, et al (1991)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form		X	
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates			X
Multiple Baseline Fuels	X		
Test Witnessed by or Prepared for Governmental Agency	X		

Table A-17b. Facility Q - Pulp and Paper Mill

	0% TDF[a]		4% TDF[b]		% Change
	kg/hr	lb/hr	kg/hr	lb/hr	
Particulate	8.95	19.7	11.0	24.3	+23
SO_x	121	266	126	277	+4
Cadmium	0.0011	0.0025	0.00082	0.0018	-28
Chromium (total)	0.022	0.048	0.0020	0.0046	-90
Lead	0.023	0.050	0.016	0.036	-28
Mercury	1.7×10^{-4}	3.8×10^{-4}	3.6×10^{-5}	8.0×10^{-5}	+111
Zinc	0.11	0.23	1.56	3.43	+1,391

[a] Baseline = 82% coal, 13% bark, 5% sludge, 0% TDF.
[b] TDF = 80% coal, 12% bark, 4% sludge, 4% TDF.

Table A-18a. Facility R - Cogeneration

Source Description

Facility Name, Location:	Monsanto - K.G. Krummrich Plant Sauget, IL
Facility Type:	Industrial (Cogeneration)
Source Type:	Boiler - four-drum chain grate stoker
Test Dates:	December 18-19, 1990
Other fuel(s):	Low-sulfur coal
Air pollution control device(s) used:	ESP
Test Conditions:	80% coal, 20% TDF
Test Methods:	Unknown
Fuel Handling/Feeding:	Tire chips blended with coal. Delivered to plant pre-blended and handled as a single fuel.
Testing Company:	The Almega Corp.
Environmental Agency:	Test not conducted for environmental compliance. Test commissioned by Illinois Department of Commerce and Community Affairs to study feasibility of use of TDF.
Reference:	Dennis (1991)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form		X	
Baseline Fuel Test Data Available		X	
Accurate Fuel Feed Rates	X		
Multiple Baseline Fuels		X	
Test Witnessed by or Prepared for Governmental Agency		X	

Table A-18b. Facility R - Cogeneration

	100% Coal		80% Coal, 20%TDF		% Change
	kg/hr	lb/hr	kg/hr	lb/hr	
Particulate	1.64	3.60	0.814	1.79	-50
CO	0.17	0.38	0.24	0.53	+40
VOC	0.473	1.04	0.33	0.73	-30
SO_2	37.7	83.0	49.54	109.0	+31
NO_x	15.8	34.7	11.0	24.3	-30
HCl	6.14	13.5	4.36	9.59	-29
HF	0.42	0.93	0.38	0.84	-10
<u>Metals</u>					
Chromium (total)	0.00217	0.00478	0.00207	0.00456	-4
Mercury	7.95×10^{-5}	1.75×10^{-5}	7.27×10^{-5}	1.60×10^{-4}	-9
Zinc	0.27	0.59	0.20	0.44	-25
Cadmium	0.00165	0.00363	0.00120	0.00263	-28
Lead	0.045	0.099	0.002	0.005	-95
Beryllium	ND	ND	ND	ND	NT

ND = Not detected.
NT = Not tested or data not available.

Table A-19a. Facility S - Industrial Boiler

Source Description

Facility Name, Location:	University of Iowa Iowa City, Iowa
Facility Type:	Industrial/Commercial
Source Type:	Boiler (Riley - 1975) with stoker and economizer (170,000 lb steam/hr capacity).
Test Dates:	December 9 - 14, 1991
Other fuel(s):	Coal
Air pollution control device(s) used:	Seven-section coldside ESP (Buell)
Test Conditions:	100% Coal 96% Coal/4% TDF 92% Coal/8% TDF
Test Methods:	EPA Methods 1, 2, 3, 4, 5 (front and back half), 6, 7, 201A, 26, 13B, Multi-Metal Modified Method 5 (4M5), 23.
Fuel Handling/Feeding:	Unknown
Testing Company:	Interpoll Laboratories, Inc.
Environmental Agency:	Iowa DNR
Reference:	Interpoll (1992)

Source Test Data Evaluation

	Yes	**No**	**Unknown**
Data Expressed in Emission Factor Form		X	
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates			X
Multiple Baseline Fuels		X	
Test Witnessed by or Prepared for Governmental Agency	X		

Table A-19b. Facility S - Industrial Boiler

	100% Coal		96% Coal/4% TDF			92% Coal/8% TDF		
	kg/hr	lb/hr	kg/hr	lb/hr	Difference	kg/hr	lb/hr	Difference
Particulate[1]	14	31	9.5	21	-32.3%	13	29	-6.5%
PM_{10}[1]	4.2	9.3	4.1	9.0	-3.2%	8.6	19	104%
SO_2	265	582	246	542	-6.9%	244	537	-7.7%
NO_x	68.2	150	66.4	146	-2.7%	64.1	141	-6.0%
CO	3.9	8.5	6.8	15	76.5%	5.5	12	41.2%
Fluoride	0.00082	0.0018	0.00064	0.0014	-22.2%	0.00077	0.0017	-5.6%
HCl	5.0	11	6.8	15	36.4%	8.6	19	72.7%
THC	9.5	2.1	0.95	2.1	0.0%	0.68	1.5	-28.6%

[1] Dry catch only

Dioxins	ng/sec	10^{-12}lb/sec	ng/sec	10^{-12}lb/sec	Difference	ng/sec	10^{-12}lb/sec	Difference
PCDD/PCDF	18	40	10	22	-44.4%	6.0	6.9	-82.6%

Metals	g/hr	10^{-3}lb/hr	g/hr	10^{-3}lb/hr	Difference	g/hr	10^{-3}lb/hr	Difference
Arsenic	2.97	6.55	2.08	4.58	-30.1%	11.9	26.2	300%
Barium	1.25	2.75	0.93	2.05	-25.5%	3.13	6.90	151%
Beryllium	0.04	0.086	0.03	0.064	-25.6%	0.19	0.41	377%

(Continued)

Table A-19b. Facility S - Industrial Boiler (Cont.)

Metals	g/hr	10^{-3}lb/hr	g/hr	10^{-3}lb/hr	Difference	g/hr	10^{-3}lb/hr	Difference
Cadmium	<0.19	<0.419	<0.188	<0.414	NT	0.45	0.99	NT
Chromium	0.92	2.03	0.779	1.72	-15.3%	2.11	4.66	130%
Copper	2.13	4.69	2.47	5.44	16%	9.100	20.09	328%
Lead	2.02	4.45	2.26	4.99	12.1%	10.32	22.79	412%
Magnesium	9.730	21.48	7.506	16.57	-22.9%	15.57	34.38	60.1%
Mercury	1.42	3.13	1.21	2.67	-14.7%	1.15	2.53	-19.2%
Nickel	1.41	3.11	1.77	3.90	25.4%	4.34	9.56	207%
Zinc	36.40	80.35	163.56	361.07	349%	1,575.5	3,478.0	4,229%

NT = Not tested or data not available.

Table A-20a. Facility T - Industrial Boiler

Source Description

Facility Name, Location:	John Deere Works - Waterloo Waterloo, Iowa
Facility Type:	Industrial
Source Type:	Boiler
Test Dates:	November 6 - 16, 1995
Other fuel(s):	Coal, oil
Air pollution control device(s) used:	Unknown
Test Conditions:	100% coal 90% coal, 10% oil 84% coal, 7.4% oil, 8.9% TDF (by weight) 88% coal, 12% TDF
Test Methods:	EPA Reference Methods 1, 2, 3, 4, 201A, 202, 6C, 7E, 10
Fuel Handling/Feeding:	Unknown
Testing Company:	Compliance Services, Inc.
Environmental Agency:	Iowa DNR
Reference:	Compliance Services (1996)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form	some		
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates			X
Multiple Baseline Fuels	X		
Test Witnessed by or Prepared for Governmental Agency	X		

Table A-20b. Facility T - Industrial Boiler

Pollutant	100% Coal		90% Coal/10% Oil		Difference[a]	84% Coal/7.4% Oil/8.9% TDF		Difference[a]	88% Coal/12% TDF		Difference[a]
	kg/hr	lb/hr	kg/hr	lb/hr	%	kg/hr	lb/hr	%	kg/hr	lb/hr	%
PM_{10}	10.484	23.067	4.5814	10.080	-57.9	5.4940	12.088	-49.5	4.265	9.384	-60.8
SO_2	528.22	1,162.2	495.81	1,090.9	-5.60	449.3	988.6	-14.5	527.54	1,160.7	0.33
NO_x	49.90	109.8	48.54	106.8	-53.3	50.81	111.8	-51.3	56.40	124.1	-45.8
CO	3.0	6.5	5.18	11.4	81.3	6.09	13.4	109	6.14	13.5	114

[a] % Difference with respect to 100% coal emission rate.

Table A-21a. Facility U - Industrial Boiler

Source Description

Facility Name, Location:	Cargill Inc. Corn Milling Division Eddyville, Iowa
Facility Type:	Industrial (Food Processing)
Source Type:	Boiler
Test Dates:	June 30 - July 1, 1993
Other fuel(s):	Coal
Air pollution control device(s) used:	Ten section reverse baghouse (Joy Manufacturing).
Test Conditions:	100% Coal 95% Coal, 5% TDF
Test Methods:	EPA Methods 7, 10, 201A
Fuel Handling/Feeding:	Unknown
Testing Company:	Interpoll Laboratories
Environmental Agency:	Iowa DNR
Reference:	Interpoll (1993)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form	some		
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates			X
Multiple Baseline Fuels		X	
Test Witnessed by or Prepared for Governmental Agency	X		

Table A-21b. Facility U - Industrial Boiler

Parameter		100% Coal	5% TDF
Particulate	g/dscm	0.117	0.0670
	gr/dscf	0.0514	0.0293
	g/MJ	0.0424	0.024
	lb/MMBtu	0.0987	0.056
PM_{10}	g/dscm	0.1048	0.0558
	gr/dscf	0.0458	0.0244
	kg/hr	35	18
	lb/hr	77	40
Nitrogen Oxides	ppm,d	134	152
	g/MJ	0.0972	0.105
	lb/MMBtu	0.226	0.245
Carbon Monoxide	ppm,d	4,305	2,048
	kg/hr	1,663	789.9
	lb/hr	3,659	1,738

Table A-22a. Facility V - Industrial Boiler

Source Description

Facility Name, Location:	Dow Corning Midland, MI
Facility Type:	Manufacturing
Source Type:	Boiler
Test Dates:	March 9 - 29, 1989
Other fuel(s):	Wood
Air pollution control device(s) used:	ESP
Test Conditions:	100% Wood, 0% TDF 95% Wood, 5% TDF 90% Wood, 10% TDF 85% Wood, 15% TDF
Test Methods:	Unknown
Fuel Handling/Feeding:	Tire chips 2 - 3 inches in diameter, with wire.
Testing Company:	Unknown.
Environmental Agency:	Michigan DNR
Reference:	Clark, et al (1991) and Malcolm Pirnie (1991)

Source Test Data Evaluation

	Yes	No	Unknown
Data Expressed in Emission Factor Form	X		
Baseline Fuel Test Data Available	X		
Accurate Fuel Feed Rates			X
Multiple Baseline Fuels		X	
Test Witnessed by or Prepared for Governmental Agency			X

Table A-22b. Facility V - Industrial Boiler

Pollutant	0% TDF lb/hr	0% TDF lb/MMBtu	5% TDF lb/hr	5% TDF lb/MMBtu	5% TDF % Change	10% TDF lb/hr	10% TDF lb/MMBtu	10% TDF % Change	15% TDF lb/hr	15% TDF lb/MMBtu	15% TDF % Change
Particulate	4.29	0.012	7.53	0.0205	+68	11.22	0.0305[a]	+150	38.10	0.1130[a]	+826
Cadmium	4.9×10^{-4}	1.39×10^{-6}	NT		N/T	--	--	N/T	0.0028	8.21×10^{-6}	+491
Chromium (total)	1.28×10^{-4}	3.64×10^{-6}	NT	NT	--		--	N/T	0.0019	5.57×10^{-6}	+53
Zinc	0.0634	1.8×10^{-4}	--	NT	N/T	--	--	N/T	11.32	0.03	+16,567
Beryllium[c]	ND	ND	--	--	N/T	--	--	N/T	ND	ND	ND
NO_x[c]	NT	0.153	--	0.162	+6	--	0.133	-13	--	0.081	-47
SO_2[d]	NT	0.026	--	0.028	+8	--	0.037	+42	--	0.059	+127

Pollutant	0% TDF kg/hr	0% TDF $g \times 10^{-6}$/MJ	5% TDF kg/hr	5% TDF $g \times 10^{-6}$/MJ	5% TDF % Change	10% TDF kg/hr	10% TDF $g \times 10^{-6}$/MJ	10% TDF % Change	15% TDF kg/hr	15% TDF $g \times 10^{-6}$/MJ	15% TDF % Change
Particulate	1.95	0.00525	3.42	0.0088	+68	5.099	0.0131[a]	+150	17.32	0.0486[a]	+826
Cadmium	0.00022	5.98×10^{-7}	--	--	N/T	--	--	N/T	0.0013	3.53×10^{-6}	+491
Chromium (total)	0.000058	1.57×10^{-6}	--	--	N/T	--	--	N/T	0.00086	2.40×10^{-6}	+53
Zinc	0.0288	7.7×10^{-5}	--	--	N/T	--	--	N/T	5.144	0.01	+16,567

(Continued)

Table A-22b. Facility V - Industrial Boiler (Cont.)

Pollutant	0% TDF		5% TDF			10% TDF			15% TDF		
	kg/hr	$gx10^{-6}$ /MJ	kg/hr	$gx10^{-6}$ /MJ	% Change	kg/hr	$gx10^{-6}$ /MJ	% Change	kg/hr	$gx10^{-6}$/MJ	% Change
Beryllium[c]	ND	ND	--	--	N/T	--	--	N/T	ND	ND	ND
NO_x[c]	--	0.0695	--	0.0697	+6	--	0.0572	-13	--	0.035	-47
SO_2[d]	--	0.011	--	0.012	+8	--	0.016	+42	--	0.025	+127

[a] Emission limits of 0.035 lb/MMBtu at 12 percent CO_2.
[b] No limit for Beryllium was 7.3 $x10^{-5}$ lb/hr.
[c] NO_x limit is 0.7 lb/MMBtu.
[d] SO_2 limit is 0.8 lb/MMBtu.
N/T = Not tested.
ND = Not detected.

Ref.: Clark, et al (1991)

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

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16. ABSTRACT The report discusses air emissions from two types of scrap tire combustion: uncontrolled and controlled. Uncontrolled sources are open tire fires, which produce many unhealthful products of incomplete combustion and release them directly into the atmosphere. Controlled combustion sources (combustors) include boilers and kilns specifically designed for efficient combustion of solid fuel. Very little data exist for devices that are not well-designed and use scrap tires for fuel. These sources include fireplaces, wood stoves, small kilns, small incinerators, or any device with poor combustion characteristics. Air emissions from these types of devices are likely between that of open burning and a combustor. However, there is a serious concern that the emissions are much more similar to those of an open tire fire than a combustor. Open tire fires are discussed. Data from a laboratory test program on uncontrolled burning of tire pieces and ambient monitoring at open tire fires are presented and the emissions are characterized. Mutagenic emission data from open burning of scrap tires are compared to mutagenic data for other fuels from both controlled and uncontrolled combustion. A list of 34 target compounds representing the highest potential for health impacts from open tire fires is presented. The list can be used to design an air monitoring plan to evaluate health risk potential.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Fireplaces	Pollution Control	13B
Emission	Wood	Stationary Sources	14G 11L
Tires	Stoves	Scrap Tires	13F
Combustion	Incinerators	Wood Stoves	21B
Boilers	Monitors		13A
Kilns			

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