



## Project Summary

# Characterization of Emissions from the Simulated Open Burning of Scrap Tires

Jeffrey V. Ryan

Discarded automobile tires have become a serious health concern, largely because the growing number of stockpile fires has focused attention on the potentially harmful products of incomplete combustion (PICs) emitted into the atmosphere from burning scrap tires. This small-scale combustion study was designed to collect, identify, and quantify products emitted during the simulated open combustion of scrap tires. Fixed combustion gas, volatile and semi-volatile organic, particulate, and airborne metals data were collected under two burn conditions that varied by the size of tire material. Burn rates, varied by material size, were used to estimate potential emissions of identified products. Total estimated emissions of semi-volatile organics ranged from 10 to 50 g/kg of tire material burned. Mono and poly aromatic hydrocarbons were the main emission products identified. Benzo(a)pyrene (BAP) in particulate extracts is of particular concern because it is a known carcinogen. The presence of zinc in gaseous particulate collection was also verified and quantified. Several trends were evaluated relating emission products with burn rates.

*This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).*

### Introduction

Approximately 240 million vehicle tires are discarded annually. Although viable methods for reclamation exist, less than 25% are re-used or re-processed. The remaining 170 million scrap tires are discarded in landfills, above-ground stockpiles, or illegal dumps.

Many landfills are refusing to accept tires because they present not only disposal but also health-related problems. After burial, tires often float to the surface and become partially filled with water. Cutting the tire in half or in pieces can reduce this tendency. It is very costly to cut or shred tires into a condition suitable for landfill; in any event, many sites lack the necessary equipment. Steel-belted radials which comprise the majority of the nation's discarded tires, are particularly difficult to cut and/or shred. Often, they are simply stockpiled or illegally dumped. These stockpiles and dumps can become a breeding ground for many insects, especially mosquitos, where water collects in the tires and creates an ideal breeding habitat. The introduction and spread of several mosquito species has been directly attributed to the presence of refuse tires.

The growing incidence of tire fires creates another potential health hazard. More tire stockpiles and illegal dumps are coming into existence, and with them the occurrence of tire fires. These fires, often started by arson, generate a huge amount of heat making them extremely difficult to extinguish. Some of these tire fires have continued for months. For example, the Rhinehart tire fire in Winchester, Virginia, burned for nearly 9

months, potentially exuding large quantities of harmful compounds.

The EPA's Control Technology Center (CTC) received numerous requests from state and local agencies nationwide for information pertaining to tire fires and their effects. Because very little information on the open burning of scrap tires was available, the steering committee felt a study investigating this potential problem was warranted. Guided by the Combustion Research Branch (CRB) of EPA's Air and Energy Engineering Research Laboratory (AEERL), Acurex conducted a study which identified and quantified organic and inorganic emission products produced during the simulated open combustion of scrap tires.

## Experimental Approach

The project consisted of a parametric study to collect organic and inorganic emissions from the simulated open combustion of scrap tires. Small quantities (10-20 lb, 4.5-9.0 kg) of scrap-tire material were burned under two controlled conditions determined by the size of the material. The conditions were evaluated in duplicate on successive days. An existing burn hut used for similar projects was modified to accommodate this task. A separate outbuilding housed the required organic and particulate sampling equipment. CRB's Hazardous Air Pollutants Mobile Laboratory (HAPML) was used to monitor fixed combustion gases. Organics were collected using the Volatile Organic Sampling Train (VOST) and a semi-volatile collection system using XAD-2 and particulate filters. Particulate was also collected to assess airborne metals. The organic constituents were analyzed both qualitatively and quantitatively by GC/MS, GC/FID, HPLC, and gravimetric methodologies.

Representative scrap truck and passenger car bias ply tires were obtained from local tire dealers. Bias ply tires were chosen due to difficulties encountered attempting to cut steel belted radial tires. The tires were cut into two sizes in order to vary initial surface area and therefore combustion rate. The "CHUNK" condition represented a quarter to a sixth of an entire tire, while tire material cut into 5.08 cm (2 in.) squares represented the "SHRED" condition. Tire material approximating the equivalent weight of two passenger car tires (30 lbs, 13.6 kg) was placed in a small burn pit and combusted. A platform scale under the burn pit monitored the

weight of tire material combusted. An air system designed to deliver nominally 1,200 cfm (34.0 m<sup>3</sup>/min) was used to simulate rapid dilution and cooling of combustion products.

An insulated duct transported the gaseous sample to an adjacent sampling shed for collection of volatile and semi-volatile organics, particulate, and fixed combustion gases. Common combustion gases, O<sub>2</sub>, CO, CO<sub>2</sub>, SO<sub>2</sub>, and total hydrocarbons (THC) were monitored continuously throughout the burn period. Volatile organics were collected using the Volatile Organic Sampling Train (VOST). Semi-volatile organics and particulate were collected using applicable modified sampling systems. During the sampling, tire material weight differentials were recorded to determine burn rates.

The VOST samples collected were analyzed by gas chromatography/mass spectrometry (GC/MS). Compounds were identified through spectral library searches and matching, along with investigator interpretation. The identified compounds were quantitated using the system response to toluene. Individual compound responses were not determined. Semi-volatile organics were collected on both particulate filters as well as the XAD-2 organic sorbent material. The organics were retrieved from the collection media by soxhlet extraction with dichloromethane. Both the particulate extracts and the XAD-2 extracts were analyzed for total chromatographable organics (TCO) and GRAV—organic compounds with boiling points of 100-300°C, and > 300°C, respectively. The XAD-2 extracts were analyzed by GC/MS to identify compounds found in the TCO range. Again, compounds were identified using library spectral matching and investigator interpretation. Identified compounds were quantitated using the same response used for TCO quantitation. Individual identified compound responses were not determined. The organic extracts were also analyzed for polycyclic aromatic hydrocarbons (PAHs). Separately collected particulate matter was also quantitated for specific metals common in tire ash residues.

## Data and Results

The size of tire material was varied to change combustion conditions and gain insight into the mechanisms governing burn rate. Burn rates were calculated by dividing the amount of tire material burned over a given period by that time in minutes and normalizing to a mass per

hour basis. A higher burn rate was observed during CHUNK tests than in SHRED tests. Roughly double the amount of tire material was combusted during the same time. In both burn conditions, an initial high burn rate was observed and led to a gradual leveling off until the burn rate was steady.

Combustion gases were monitored continuously throughout the test. High emissions of CO, SO<sub>2</sub>, and THC were observed at high burn rates.

The identification of unknown volatile organics using the MS proved to be highly successful. More than 50 compounds were identified from the VOST samples collected. Most of these compounds are aliphatically, olefinically or acetylenically substituted aromatics. Cyclic and chained alkanes, alkenes and dienes were also identified. Several sulfonated and nitrogenated compounds were also identified in samples. Thiophene, substituted thiophenes, isocyanobenzene and benzodiazine were isolated in multiple samples. Following quantitation of identified compounds, average gaseous concentration and emissions were estimated. Of particular interest are the emission rate estimations. The estimated emissions are based on several variables and were obtained by relating the amount of tire material combusted during the sampling period with the average gaseous concentration. It was assumed that the dilution air added to the burn hut was constant.

It is difficult to isolate consistent trends in the types and amounts of specific volatile organic compounds formed during the combustion of scrap tires under varied burn rates. A trend appears that, as burn rate decreases, the amount of organics potentially emitted tends to increase with respect to the amount of tire material combusted.

As with the volatile organic analyses, the MS analysis of the XAD-2 extracts identified the same types of compounds. Table 1 lists the 60 compounds identified and indicates that substituted mono and poly aromatics were the predominant products of incomplete combustion. Table 2 presents the average gaseous concentration and estimated emissions of the quantitated identified compounds from the four test conditions. The estimated emissions of many compounds increase with decreased burn rate. Table 3 summarizes the semi-volatile organic emission data from the four test conditions. The total organics from respective boiling-point-based analyses are presented for each component of the sampling media. The estimated emis-

**Table 1.** Compounds Identified by GC/MS from XAD-2 Extracts

Compound Identified	Formula	Compound Identified	Formula	Compound Identified	Formula
Methyl Benzene	C <sub>7</sub> H <sub>8</sub>	Limonene	C <sub>10</sub> H <sub>16</sub>	Dihydro, Methyl Naphthalene	C <sub>11</sub> H <sub>12</sub>
Cyclopentanone	C <sub>5</sub> H <sub>8</sub>	Dihydro Indene	C <sub>9</sub> H <sub>10</sub>	Butyl, Trimethyl Benzene	C <sub>13</sub> H <sub>20</sub>
Dimethyl Cyclohexene	C <sub>8</sub> H <sub>12</sub>	Hydroxy Benzaldehyde	C <sub>7</sub> H <sub>6</sub> O <sub>2</sub>	Methyl Naphthalene	C <sub>11</sub> H <sub>10</sub>
Ethenyl Cyclohexene	C <sub>8</sub> H <sub>12</sub>	Indene	C <sub>9</sub> H <sub>8</sub>	Biphenyl	C <sub>12</sub> H <sub>10</sub>
Ethyl Benzene	C <sub>8</sub> H <sub>10</sub>	Tetramethyl Benzene	C <sub>10</sub> H <sub>14</sub>	Dimethyl Naphthalene	C <sub>12</sub> H <sub>12</sub>
Dimethyl Benzene	C <sub>8</sub> H <sub>10</sub>	Ethyl, Dimethyl Benzene	C <sub>10</sub> H <sub>14</sub>	Dihydro Acenaphthalene	C <sub>12</sub> H <sub>10</sub>
Hexanenitrile	C <sub>6</sub> H <sub>11</sub> N	Methyl Phenol	C <sub>7</sub> H <sub>8</sub> O	Acenaphthalene	C <sub>12</sub> H <sub>8</sub>
Ethynyl Benzene	C <sub>8</sub> H <sub>6</sub>	Methyl Benzaldehyde	C <sub>8</sub> H <sub>8</sub> O	(Dimethyl, Hexenyl), Methyl Benzene	C <sub>14</sub> H <sub>20</sub>
Styrene	C <sub>8</sub> H <sub>8</sub>	Methyl, (Methylethyl) Benzene	C <sub>10</sub> H <sub>14</sub>	Pentadecane	C <sub>15</sub> H <sub>32</sub>
Nonane	C <sub>9</sub> H <sub>20</sub>	Propenyl, Methyl Benzene	C <sub>10</sub> H <sub>12</sub>	1,1' Biphenyl, Methyl	C <sub>13</sub> H <sub>12</sub>
Propenyl Cyclohexane	C <sub>9</sub> H <sub>16</sub>	Undecane	C <sub>11</sub> H <sub>24</sub>	Isocyano Naphthalene	C <sub>11</sub> H <sub>7</sub> N
Methylethyl Benzene	C <sub>9</sub> H <sub>12</sub>	(Dimethylpropyl) Benzene	C <sub>11</sub> H <sub>16</sub>	Naphthalenecarboxaldehyde	C <sub>11</sub> H <sub>8</sub> O
Propyl Benzene	C <sub>9</sub> H <sub>12</sub>	Dimethyl, (Methylethyl) Benzene	C <sub>11</sub> H <sub>16</sub>	Propenyl Naphthalene	C <sub>13</sub> H <sub>12</sub>
Benzaldehyde	C <sub>7</sub> H <sub>6</sub> O	Butynyl Benzene	C <sub>10</sub> H <sub>12</sub>	Trimethyl Naphthalene	C <sub>13</sub> H <sub>14</sub>
Trimethyl Benzene	C <sub>9</sub> H <sub>12</sub>	Methyl Indene	C <sub>10</sub> H <sub>10</sub>	1H Fluorene	C <sub>13</sub> H <sub>10</sub>
Phenol	C <sub>6</sub> H <sub>6</sub> O	Azulene	C <sub>10</sub> H <sub>8</sub>	Dimethyl Biphenyl	C <sub>14</sub> H <sub>14</sub>
Cyanobenzene	C <sub>7</sub> H <sub>5</sub> N	Naphthalene	C <sub>10</sub> H <sub>8</sub>	Dibenzothiophene	C <sub>12</sub> H <sub>10</sub> S
Propenyl Benzene	C <sub>9</sub> H <sub>10</sub>	Benzo[b]thiophene	C <sub>8</sub> H <sub>6</sub> S	Phenanthrene	C <sub>14</sub> H <sub>10</sub>
Methyl, Ethenyl Benzene	C <sub>9</sub> H <sub>10</sub>	Benzisothiazole	C <sub>7</sub> H <sub>6</sub> NS	9H Fluorene, Methylene	C <sub>14</sub> H <sub>10</sub>
Methyl, Methylethyl Benzene	C <sub>10</sub> H <sub>14</sub>	Hexahydro Azepinone	C <sub>6</sub> H <sub>11</sub> NO	Phenyl naphthalene	C <sub>16</sub> H <sub>12</sub>

sions data presented show that 12-50 g of semi-volatile organics can be emitted for every kilogram of tire burned. A trend does seem evident when relating the amount of organics emitted to burn rates. It appears that, as burn rate decreases, the amount of organics emitted, particularly in the TCO range, increases. There did not seem to be any significant variation in GRAV range organic emissions when related to burn rate. A PAH analysis was performed on the XAD-2 and particulate filter extractions. Of particular importance is the presence of benzo(a)pyrene (BAP) in all particulate portions. BAP is a reported carcinogen and a highly scrutinized compound when evaluating combustion processes.

A separate particulate collection system was operated to verify and quantitate the presence of metals collected from ambient emissions. The results of the analyses were marginal for many of the targeted metals. Many of the results were at or near instrument detection levels. It did seem evident that lead and particularly zinc were found to be collected from gaseous emissions.

## Conclusions

The primary goal of this project was to characterize potentially harmful emissions from the simulated open

burning of scrap tires. The simulation was necessarily crude, because it would be extremely difficult to match the burning of the equivalent of two tires with a 6 million tire, full-scale, stockpile fire. Nevertheless, the study allowed the investigators to identify and measure gaseous emissions and directly relate this information to a mass burn rate. This task was accomplished by accurately measuring dilution volumes, sample volumes, and weights of tire material combusted.

It is not known how well the concentrations obtained from this study represent those at an actual tire fire. The dilution air added to the burn hut was used not only to control known volumes introduced, but also to simulate ambient conditions. The same types of compounds identified during this study are probably emitted during an actual fire, but whether the average gaseous concentrations and estimated emissions are comparable is uncertain. A comparison with limited data collected at the Winchester, Virginia, fire by NIOSH, indicates that reasonable agreement exists within several measurement areas. Many of the same compounds were identified in actual plume samples. Particularly good agreement exists in PAH plume measurements. NIOSH reported ambient concentrations of total PAHs are gener-

ally within the same order of magnitude as average gaseous concentrations obtained during testing. Measurements of CO and metals also indicate similar agreement. Both the lead and zinc measurements show similar values both in concentration and relative concentration between the two metals. It may be reasonable to assume that the estimates obtained during this study may be within an order of magnitude of emissions realized from actual stock-pile fires.

The results of this study pose a variety of pertinent topics and questions regarding tire fires. How far does the particulate from a stockpile fire carry? Are evacuation procedures for populations near stockpile fires sufficient? Is it good policy to continue to let tire fires burn themselves out? A greater potential for harmful organic emissions seems to exist at lower burn rates; thus a smoldering tire fire may be more harmful than one that is burning out of control. The identification of significant quantities of benzo(a)pyrene in the particulate extracts warrants serious concern. High emissions of other noxious compounds, particularly benzene, with concentrations often exceeding 1 ppm, suggest that uncontrolled scrap tire combustion poses significant health risks.

**Table 2. Quantitation and Emission Summary of Compounds Identified in XAD-2 Extracts<sup>1,2</sup>**

Compound Identified	Day 1 CHUNK Condition Vol Samp = 12.98 m <sup>3</sup> Burn Rate = 2.3 kg/h		Day 2 CHUNK Condition Vol Samp = 12.76 mg/m <sup>3</sup> Burn Rate = 1.7 kg/h		Day 1 SHRED Condition Vol Samp = 13.77 mg/m <sup>3</sup> Burn Rate = 1.1 kg/h		Day 2 SHRED Condition Vol Samp = 12.43 mg/m <sup>3</sup> Burn Rate = 1.3 kg/h	
	Average Gaseous Concentration (mg/m <sup>3</sup> )	Estimated Emissions (mg/kg TIRE)	Average Gaseous Concentration (mg/m <sup>3</sup> )	Estimated Emissions (mg/kg TIRE)	Average Gaseous Concentration (mg/m <sup>3</sup> )	Estimated Emissions (mg/kg TIRE)	Average Gaseous Concentration (mg/m <sup>3</sup> )	Estimated Emissions (mg/kg TIRE)
Methyl Benzene	0.716	634.8	1.500	1,799.5	0.731	1,354.9	0.911	1,429.0
Ethyl Benzene	0.074	65.8	0.289	347.1	0.192	355.0	0.203	318.3
Dimethyl Benzene	0.000	0.0	0.513	615.3	0.554	1,026.1	0.532	834.2
Ethynyl Benzene	0.185	163.6	0.325	390.0	0.078	144.2	0.150	235.2
Styrene	0.419	371.5	0.795	953.3	0.332	614.6	0.433	679.8
Methylethyl Benzene	0.000	0.0	0.081	97.4	0.142	263.5	0.122	191.0
Propyl Benzene	0.000	0.0	0.000	0.0	0.136	251.2	0.118	184.6
Benzaldehyde	0.111	98.6	0.327	392.1	0.343	635.3	0.000	0.0
Trimethyl Benzene	0.000	0.0	0.000	0.0	0.156	289.9	0.351	549.9
Phenol	0.190	168.3	0.473	566.9	0.360	667.2	0.470	736.8
Cyanobenzene	0.095	84.3	0.305	365.5	0.307	569.3	0.292	458.6
Trimethyl Benzene	0.127	112.8	0.256	307.6	0.195	361.5	0.199	312.2
Methyl, Methylethyl Benzene	0.000	0.0	0.215	258.1	0.926	1,716.1	0.704	1,104.9
Limonene	0.000	0.0	0.094	113.2	1.402	2,599.2	1.316	2,064.5
Indene	0.325	288.5	0.602	722.0	0.156	289.9	0.251	393.9
Tetramethyl Benzene	0.000	0.0	0.000	0.0	0.094	174.8	0.000	0.0
Ethyl, Dimethyl Benzene	0.000	0.0	0.000	0.0	0.000	0.0	0.154	241.8
Methyl Benzaldehyde	0.000	0.0	0.000	0.0	0.089	164.7	0.000	0.0
Ethyl, Dimethyl Benzene	0.000	0.0	0.000	0.0	0.162	300.0	0.000	0.0
Propenyl, Methyl Benzene	0.000	0.0	0.000	0.0	0.537	996.2	0.000	0.0
Methyl Indene	0.000	0.0	0.188	225.6	0.223	413.7	0.114	179.2
Methyl Indene	0.000	0.0	0.000	0.0	0.000	0.0	0.132	207.3
Naphthalene	1.230	1,090.4	1.931	2,315.9	0.516	957.2	0.843	1,322.8
Benzo[B]thiophene	0.099	87.6	0.000	0.0	0.000	0.0	0.000	0.0
Benzisothiazole	0.000	0.0	0.000	0.0	0.179	330.9	0.000	0.0
Hexahydro Azepinone	0.000	0.0	0.126	151.4	0.345	638.9	0.555	869.9
2-Methyl Naphthalene	0.164	145.6	0.466	559.4	0.202	373.9	0.313	490.5
1-Methyl Naphthalene	0.124	109.9	0.463	555.3	0.122	225.7	0.146	229.7
Biphenyl	0.083	73.5	0.290	347.8	0.180	333.6	0.208	326.3
Dimethyl Naphthalene	0.000	0.0	0.069	83.0	0.183	338.8	0.000	0.0
Acenaphthalene	0.390	345.6	0.773	927.0	0.217	402.2	0.430	673.8
1,1' Biphenyl, Methyl	0.025	22.1	0.000	0.0	0.000	0.0	0.000	0.0
Isocyano Naphthalene	0.021	18.7	0.000	0.0	0.000	0.0	0.000	0.0
Propenyl Naphthalene	0.053	46.6	0.000	0.0	0.000	0.0	0.000	0.0
Trimethyl Naphthalene	0.000	0.0	0.000	0.0	0.169	312.9	0.203	319.1
1H Fluorene	0.087	76.9	0.288	346.0	0.141	260.8	0.230	361.2
Phenanthrene	0.152	135.0	0.194	233.2	0.000	0.0	0.251	394.2
Totals	4.670	4,140.4	12,672.8	9,367	17,362.2	9,633	15,108.7	10,566

<sup>1</sup> Concentrations determined using system response to TCO calibration mix.<sup>2</sup> Average gaseous concentrations and estimated emissions are based on controlled dilution of pit emissions. It is not known how well this dilution represents ambient air exchange under actual conditions.

**Table 3. Organic Emission Summary**

Sample Portion	Sample Time (min)	Weight Change (kg)	Avg Burn Rate (kg/h)	Volume Samp (m <sup>3</sup> )	Average Gaseous Concentration		Estimated Emissions			
					TCO (mg/m <sup>3</sup> )	GRAV (mg/m <sup>3</sup> )	TCO (mg/kg TIRE)	GRAV		
<i>Day 1 CHUNK Condition</i>										
XAD-2										
Filter 1	140	5.4	2.3	12.98	6.067	0.698	5,379	619		
Filter 2	11	1.7	9.4	0.93	0.043	33.634	9	7,296		
Filter Total	129	3.7	1.7	12.05	0.066	4.823	79	5,785		
	140	5.4	2.3	12.98	0.065	6.888	58	6,106		
						Total	5,436	6,725	12,161	
<i>Day 2 CHUNK Condition</i>										
XAD-2										
Filter 1	152	4.3	1.7	12.76	11.398	0.749	13,671	898		
Filter 2	42	2.4	3.5	3.3	0.018	18.498	11	10,776		
Filter Total	110	1.8	1.0	9.45	0.53	10.219	1,081	20,837		
	152	4.3	1.7	12.76	0.398	12.359	477	14,824		
						Total	14,148	15,722	29,870	
<i>Day 1 SHRED Condition</i>										
XAD-2										
Filter	182	3.2	1.1	13.77	20.658	0.89	38,292	1,650		
	182	3.2	1.1	13.77	0.141	6.822	261	12,646		
						Total	38,554	14,295	52,849	
<i>Day 2 SHRED Condition</i>										
XAD-2										
Filter	183	4.0	1.3	12.43	15.65	1.099	24,546	1,724		
	183	4.0	1.3	12.43	0.173	8.771	271	13,757		
						Total	24,818	15,481	40,299	

Results from the airborne metals portion of the study were inconclusive. Maximum values were presented, often based on detection levels. Emissions of lead and zinc may reach significant quantities. Reported chemical analysis of tire ash residues reveals that zinc comprises nearly 50 percent of the total residue. Evidently, the other metals known to be contained in tires remain in the ash residue. Although no attempt was made to analyze ash residue, significant quantities of metals present in the ash could potentially be leached out into groundwater systems, posing another major problem.

The values obtained by the on-line analyzers for normal combustion gases

showed that as burn rate increased, the amount of CO, SO<sub>2</sub>, and unburned hydrocarbons also increased. High burn rate conditions were not fully evaluated, so greater quantities of these gases, particularly SO<sub>2</sub>, may be emitted during a stockpile fire. Tires contain a significant amount of sulfur, so high emissions of SO<sub>2</sub>, while likely only a minor contributor to the acid rain problem, could have significant local consequences.

This study was designed to identify the potential chemical hazards from tire fires on a small-scale, simulation basis. The study reveals the potential for the emission of great amounts of organic compounds, primarily aromatics, some of which may be extremely harmful.

Although the estimates of average gaseous concentrations and emissions are crude, the trends presented for burn rate may be helpful in directing further research and control efforts. That the "SHRED" condition resulted in a lower burn rate indicates that the gaps between the tire material provide the major avenue of oxygen transport. Oxygen transport appears to be a major if not *the* controlling mechanism for sustaining the combustion process. This fact could have advantageous implications for those attempting to combat tire fires. It may be possible to fill the gaps between tires with a foam inhibitor, potentially suffocating the fire from within.

---

*J. V. Ryan is with Acurex Corp., Research Triangle Park, NC 27709.  
Paul M. Lemieux is the EPA Project Officer (see below).  
The complete report, entitled "Characterization of Emissions from the Simulated  
Open Burning of Scrap Tires," (Order No. PB 90-126 004/AS; Cost: \$17.00,  
subject to change) will be available only from:  
National Technical Information Service  
5285 Port Royal Road  
Springfield, VA 22161  
Telephone: 703-487-4650  
The EPA Project Officer can be contacted at:  
Air and Energy Engineering Research Laboratory  
U.S. Environmental Protection Agency  
Research Triangle Park, NC 27711*

United States  
Environmental Protection  
Agency

Center for Environmental Research  
Information  
Cincinnati OH 45268

---

Official Business  
Penalty for Private Use \$300

EPA/600/S2-89/054