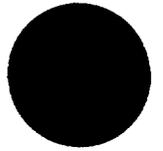


Note: This is a reference cited in AP 42, *Compilation of Air Pollutant Emission Factors, Volume I Stationary Point and Area Sources*. AP42 is located on the EPA web site at [www.epa.gov/ttn/chief/ap42/](http://www.epa.gov/ttn/chief/ap42/)

The file name refers to the reference number, the AP42 chapter and section. The file name "ref02\_c01s02.pdf" would mean the reference is from AP42 chapter 1 section 2. The reference may be from a previous version of the section and no longer cited. The primary source should always be checked.



# ncasi

# technical bulletin

NATIONAL COUNCIL OF THE PAPER INDUSTRY FOR AIR AND STREAM IMPROVEMENT, INC., 260 MADISON AVENUE, NEW YORK, N.Y. 10016

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## A POLYCYCLIC ORGANIC MATERIALS EMISSIONS STUDY FOR INDUSTRIAL WOOD-FIRED BOILERS

TECHNICAL BULLETIN NO. 400

MAY 1983



NATIONAL COUNCIL OF THE PAPER INDUSTRY FOR AIR AND STREAM IMPROVEMENT, INC.  
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May 23, 1983

TECHNICAL BULLETIN NO. 400

A POLYCYCLIC ORGANIC MATERIALS EMISSIONS STUDY FOR  
INDUSTRIAL WOOD-FIRED BOILERS

The attached material was printed from a report of the same title which was made available for distribution as a technical bulletin by the North Carolina Department of Natural Resources and Community Development, Division of Environmental Management Air Quality Section. The study which was sponsored by the North Carolina Energy Institute and U.S. Environmental Protection Agency was initiated to answer one of several questions regarding the soundness of promotion of wood as an energy source in the state.

The report deals with a measurement program carried out on small to medium sized wood fired boilers to fill an information gap on the level of polycyclic organic emissions under good everyday operating conditions from this source. A total of seven boilers were sampled ranging in rated heat input size from about 5 to 70  $10^6$ /Btu/hr. While most were horizontal return tube boilers, one each underfeed stoker, fluidized bed, and a 300 psi watertube boiler were sampled. Both wet and dry fuel was being burned during the tests and in one case, the boiler was fired on wet and then dry fuel.

No significant difference in emission rates were noted (a) between the different type boilers, (b) the condition of the boiler, (c) the condition of the wood (wet or dry), (d) boiler load as represented by percent of rated capacity, or (e) mode of operation. The authors concluded that the combustion of wood in commercial boilers is certainly no greater, and most likely less, a source of polycyclic organic materials than commercial boilers fired with coal. The authors do not cover the subject and compare the emission rates for this class of materials from commercial wood fired boilers to that from wood fired stoves which was the original cause for concern. The information available shows boiler emissions are only a small fraction of that from stoves.

Your questions and comments on the contents of this technical bulletin are solicited and should be directed to me.

Yours very truly,

A handwritten signature in black ink, appearing to read "Russell O. Blosser". The signature is written in a cursive style with a large initial "R".

Russell O. Blosser  
Technical Director

ROB:lb  
Attach.

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## PREFACE

North Carolina has historically been a tree growing State. Today, North Carolina is still heavily forested. Of its 30 million acres, approximately 20 million are in forests. Most of these forest lands have been harvested two and three times since the turn of the century. Today however, much of these forested lands are covered with low quality trees which are not usable for saw timber. Due to limited markets for reconstituted wood products such as paper, fiberboard, etc., much of this material has little or no market value in North Carolina.

Recognizing this potential and the need to develop alternative energy sources, Governor James B. Hunt, Jr. of North Carolina authorized the formation of a wood energy coordinating group in late 1977. The purpose of this group is to coordinate programs of participating agencies so as to effectively promote and develop wood for energy. The coordinating group is composed of five members from State agencies involved with wood energy and the State University system. In December 1978 a plan to promote the use of wood for energy was adopted. This plan called for developing wood energy use in non-forest product related industries. At about this same time the group recognized the need for additional expertise in several areas, including the environment, and formed committees for each of the areas of concern. The Air Quality Technical Committee was given the responsibility to review the various activities of the coordinating group, assess the environmental concerns and offer recommendations and opinions.

One of the first items on the Air Quality Technical Committee agenda was to review the status and associated problems of wood fuel usage in N.C. Because of the tremendous consumer interest in residential wood stoves, as well as the unfavorable emissions reports for wood combustion from EPA, it was necessary that the committee assess these factors in light of the North Carolina wood energy program.

The first questions asked by Air Quality Technical Committee was:

Is the promotion of industrial wood energy a sound environmental policy? One aspect of this question was unanswerable at this time; i.e., what are the polycyclic organic material (POM) emissions from an industrial wood-fired boiler? Available industrial (POM) data was limited and conflicting. The Air Quality Technical Committee was concerned because of the highly carcinogenic properties of some of the POM compounds found in these emissions. In December 1980 the Committee recommended to the Wood Energy Coordinating Group that the State of North Carolina take the initiative and develop the missing POM data. The North Carolina Division of Environmental Management agreed to sample for POM emissions from selected industrial wood combustion sources. A program was established and funding obtained from the U.S. Environmental Protection Agency as well as from the North Carolina Energy Institute to sample 7 industrial wood-fired boilers for POM emissions. The objective is to determine the POM emission level in well designed and properly fired wood fuel boilers and to determine whether these emissions vary with a change in the fuel moisture content. The State was to sample three dry wood fuel boilers, three wet wood fuel boilers, and one boiler burning dry wood on one test and wet on the next test. Testing would be conducted using a modified Method 5 sampling train.

The following report is the results of this testing program.

#### ACKNOWLEDGEMENTS

The authors wish to acknowledge the excellent cooperation received from North Carolina industry for their support of this project. Special acknowledgement and recognition is due Frank Love Lumber Co., Ethan Allen Corporation, Burlington Industries, Huntersville Hardwoods Corp., Stanley Furniture Company, Evans Lumber Company and Wade Wood, Inc. for their excellent support for this project.

In addition, the authors wish to thank Michael C. Osborne of EPA and C. Leon Neal of the N.C. Energy Institute for their financial support; Ray Merrill and Ray Steiber of EPA for their technical support and supplies of clean XAD-2 resin; Acurex Corporation for their excellent cooperation with coordinating sampling efforts and the interchange of data; Lawrence B. McGee, N.C. Wood Energy Project Coordinator, for support and assistance and those staff members of the North Carolina Division of Environmental Management whose coordination and support facilitated the field activities necessary for securing the actual data. We would especially like to thank Judy Johnson and her staff in Word Processing who spent numerous hours typing this manuscript.

Our sincere thanks to each individual and company for their support.

## 1.0 INTRODUCTION

This study was undertaken to establish the polycyclic organic material (P.O.M.) emissions from industrial wood fired boilers. At first it was our intention to establish the lowest emissions rate possible, however, after some preliminary screening of the available sources and after careful consideration of how our results would serve the needs of the Wood Energy Coordinating group, this intention was changed and the goals were redefined. Our goal then was to record the POM emissions that were achievable under good every day operating conditions. Boilers were selected on the basis of their past history meeting the state's air quality regulations as well as boiler condition and steam load. It had been our hope to sample boilers under load with a substantial percentage of the total steam capacity, however, this wasn't possible and three test series EA, HH, & WW were conducted on boilers operating with substantially less than 50% capacity.

In each of our test series an attempt was made to make all our test runs on the same day and this was accomplished except for test series HH. It was our desire, in so doing, to limit as many variables as possible.

This test series was conducted using modified Method 5 equipment, and is described in Section 4.0, Sampling Methods and Analytical Procedures. Because much of the research data previously published by others was generated using the SASS train method, it was felt that simultaneous SASS testing would corroborate our testing results. Acurex Corporation, Mountain View, California was under contract with EPA to study industrial boiler organic and gaseous emissions for many fuels, including wood. We invited Acurex to simultaneously test with us on three test series, they used the SASS train and we used a modified Method 5 train. These tests were conducted on both EA tests and the BP test series. Results and discussions are covered in Section 6.0. Although the Acurex data is not fully developed and is preliminary at the time this report is written, there is correlation between the two test methods.

Because North Carolina has 400 (5) or more industrial wood fired energy systems it was felt that any emissions examination should be representative of those types of boilers found in this state. Since the majority are Horizontal Return Tube (HRT) boilers, it was felt these should be in the majority of the units tested, and four HRT installations were chosen. Additionally three other sites were picked for water tube, fluidized bed and underfed units as representative of other boiler types found in North Carolina.

The testing effort of this study was applied to boilers of typical type but not to those of average condition with average firing practices. Characterizing average POM emissions from existing sources was not the purpose of this study.

Conversely the boilers selected were not state-of-the-art devices of unreasonable cost.

The goal of this study (as previously stated) was to characterize the POM emissions that are achievable with good (currently available) equipment, using good operating practices. The boilers chosen for this study were selected with this goal in mind.

## 2.0 SUMMARY

The North Carolina POM emission results are based on 21 separate test runs. Collaborative field testing was done on three of the tests. Collaborative analysis was done on two test runs.

The results of this study when viewed together with the selection criteria for the boilers tested, lead to the conclusion that good, properly fired wood boilers can achieve POM emissions at least as low, and possibly lower, than commercial boilers fired with bituminous coal.

It is not within the scope of this study to design boilers. Furthermore, operating practices that produced good results may vary from one boiler to another. The authors do believe, however, that good practices are those which result in a well developed fire bed. By well developed we mean a good distribution of hot fire and visible flames, but not necessarily a large amount of fuel. This situation should reduce visible emissions as well as POM emissions.

Introducing fresh fuel in such a way that the fire bed is blanketed and the flames are temporarily extinguished will cause volatile material in the fuel to be driven off without necessarily reaching combustion temperature. After the material is driven out of the wood, it can partially burn. POMs result from this partial combustion and from recombination of some of the resulting compounds. This situation appears to be more typical of hand fired, batch fed, boilers but can occur even with mechanized feed systems. This blanketed fire bed situation appears to be the principal cause of high POM emissions and is also usually characterized by high visible emissions.

It appears that visible emissions may be used as an indicator of POM emissions, but it should be understood that one is not the cause of the other. They both result from the condition of the fire bed. The condition of the fire bed in turn is the result of boiler design and firing practice, and of these two parameters, firing practice appears to have the greater effect.

It should be noted that this summary contains a good deal of opinion. These opinions, however, are the result of experience and observations made during the course of this study.

The authors hope that these subjective opinions will complement the scientific data contained in this report and help to bridge the gap between the laboratory analyst and the boiler operator.

### 3.0 SOURCE DESCRIPTION

#### Site Selection Criteria

The boilers chosen for this test series were selected on the basis of their past history of compliance with the state's air quality regulations together with good operating practices. Historically the state's 400 (4) or so wood fired boilers have been located at forest product related industries and were used primarily as incinerators for mill residue and secondarily for steam generation. Therefore there has been little concern on the part of industry for installation of any more than the very basic instrumentation necessary for combustion. As part of our criteria for good operating practices we wanted boilers with controls for modulating fuel to air ratios and steam demand recording equipment and hopefully air preheaters, oxygen analyzers, etc. Upon closer examination of the eligible boilers we found very little control sophistication except in one case and several of these instruments were not working or were out of calibration.

The selection criteria then became a good history of compliance with air quality regulations, visible emissions of less than number one ringleman, some automatic control instrumentation, and a steam load greater than 50% of capacity. This latter criteria didn't hold up in every case and the EA, HH and WW tests were conducted on boilers operating at considerably less than 50% capacity.

Most all of the 400 or so wood waste boilers in North Carolina are Horizontal Return Tube (HRT) boilers. Therefore the majority of those boilers in the test series are HRT, however, we did sample one underfeed stoker, one fluidized bed unit, and a 300 psi watertube boiler.

Additionally, the testing criteria called for testing an equal number of dry and wet wood fired boilers, with one of the boilers burning dry fuel for one test series and wet for another. This was achieved on test EA 1, 2, 3, 4.

Test "K"

This unit is a 100 hp HRT boiler approximately 40 years old, and although the cast iron doors were warped and would not close properly, the fire box was in good condition. In recent years automatic draft and wood feed controls had been installed. This boiler has no emissions controls yet has an excellent history of compliance with air quality regulations. Visible emissions during the test were undetectable.

The wood feed is pneumatic using a plow spreader for fuel dispersion in the fire box. During the tests, green ash sawdust (moisture content 45 to 50%) was being burned and there was a fuel bed accumulation of 3 to 6 inches in the fire box.

The steam produced is used for wood kilns and during test #1 the boiler was at maximum firing capacity and steam pressure dropped to 85 psi. During test 2 steam demand dropped off slightly (approximately 10%) and the boiler was able to recover and maintain 100 psi pressure throughout tests #2 and #3.

Test "EA"

This unit is a recently installed, used, 45,000 pound per hour water tube steam boiler having been converted from a coal spreader stoker to wood. The fire box was completely redesigned and rebuilt. It had the best boiler firing controls of all the units sampled in the POM test series, monitoring; steam pressure, steam demand, underfired and overfired air, flue gas temperatures, bridge wall temperature, smoke density, and % oxygen in the flue gas. However, the oxygen analyses, smoke density recorder and bridge wall temperature were not working and there was some concern regarding the accuracy of the steam flow measuring equipment. Even with the deficiencies in instrumentation it was better than what was encountered in the rest of the test series. Emission control was achieved using a multi-cyclone.

The wood feed system is a chute feed using a pneumatic spreader for dispersion in the fire box. This plant did not generate sufficient mill residue to fire this boiler and therefore purchased additional residue from saw mills in the area. Because the plant residue was kiln dried material and the saw mill residue green material, it was decided to conduct two test series at this plant. One series burning kiln dried wood (Test EA 1 & 2) and the other burning the green saw mill residue (EA 3 & 4)

The dry wood test (EA1 & 2) were conducted burning oak sawdust and hogged waste, and a small steam load of 15, 000 to 17,000 pounds per hour. The dry waste was burning pretty much in suspension with a light fuel cover on the grates. Steam pressure was maintained at between 165-170 psi through the tests.

Tests EA3 & 4 were conducted burning green saw mill residue of mixed species. The steam load during this test series varied between 8,000 and 10,000 pounds per hour at 175 psi and the boiler fireman had difficulty maintaining his fire. At one point, during the last few minutes of test EA4, the fire actually went out, and steam pressure dropped to 150 psi before reignition using dry wood residue. Fuel cover on the grates was quite deep running 12 to 15" in the corners.

#### Test BP

The boiler tested is a conventional HRT woodwaste boiler rated at  $37.2 \times 10^6$  BTU/hr input. It was pneumatically dual feed, burning kiln dried mill residue of mixed species which for the most part burned in suspension. The hogged wood particles settled in the fire box and there was a fuel bed of several inches to a foot deep in the corners. This boiler is equipped with a multi-cyclone emission control device with reinjection of the collected particulates.

The combustion controls were not sophisticated and monitored the following: draft at the furnace, outlet from the furnace and at the multi clone collector; steam pressure and steam flow.

This boiler is rated at 150 psi working pressure but is normally operated at approximately 125 psi. During the test series, pressure fluctuated between 120 and 125 psi. Steam demand during the first test was 12,000 lbs/hr while during the second test it ran about 15,000 lbs/hr. During the last 20 minutes of the second test steam demand dropped due to plant shift change, to 13,500 lbs/hr.

Visible emission during both tests were maintained at less than #1 Ringelmann.

### Test HH

This boiler is very different than the majority of the boilers tested and was included because they appear to be rapidly increasing in number within the state. It is a 300 hp boiler with a double pass fire tube pressure vessel. It is fired by a completely automatic underfeed stoker and has an operating cycle as follows; when the steam pressure is satisfied the boiler goes into a dormant stage with the induced draft fans off and dampers closed. Upon a call for steam the fans start up and the dampers open. Because there is no auxiliary ignition there is a several minute delay in obtaining high temperatures in the fire box. Due to the fact this unit regulates air flow rather than fuel supply to control the steam supplied we were very interested in testing its emissions.

The tests were conducted over a two day period with HH1 being performed on day one and HH2 and HH3 on day two.

This boiler operates in cycles to satisfy steam demand. On a low steam demand period there are long shut-down periods where the fans are shut off and the dampers closed. On day one, test HH1, the boiler was operating in this mode so sampling was conducted only during the operating periods. Due to the long dormant periods the fire box cooled down. When the unit started up there was a continual increase in the stack temperature and the volume of stack gasses, causing the sampling team to constantly make corrections for these increases until it shut down for the next dormant period.

On day two (samples HH2 & HH3) the boiler had a substantial load on it, thereby limiting the dormant periods. The operating periods were long enough for a complete sampling traverse of 48 minutes to be made, and the dormant periods were approximately 40 minutes. A typical temperature rise during a traverse is about 100° F.

This boiler used a multi-cyclone collector for emissions control without reinjection.

Visible emissions from this unit were less than #1 Ringelmann except for a very short time (1 minute or less) on start-up after a dormant period.

#### Test SF

This test was conducted on a well maintained 40-year old 13.5 MBTU HRT boiler fired on kiln dried oak wood waste using a pneumatic feed system. The boiler had a working pressure rating of 100 psi. This boiler has no emissions control equipment.

Three test runs were conducted on the same day. During the first run steam loads fluctuated between 14,000 and 17,000 lbs/hour at 90 psi and during the second run they started at 16,000 and dropped to 12000 lbs/hr at 84 psi. The steam was being used for wood drying kilns and production heat, and demand varied rapidly.

Visible emission during the test series stayed below #1 Ringelmann.

It should be noted here, that although the boiler was equipped with automatic feed and draft controls, a fireman constantly fine-tuned these adjustments throughout the tests due to the rapid swing in steam demand being experienced.

Test EL

This boiler was another of the HRT boilers we tested, this one being 150 hp and burning green pine sawdust, bark and shavings. The steam demand was constant, by comparison, being used in wood drying kilns only. This boiler was not equipped with steam flow measuring equipment so no actual values are known. Again, this unit is pneumatically fed, however there was no fuel bed on the grates. All the fuel was burning in suspension or passing over the bridge wall. There was some difficulty during the tests with the stack damper not operating when commanded by the combustion controls. The controls on this boiler are unsophisticated, controlling fuel, and draft control dampers, against steam pressure.

Emissions are uncontrolled.

Visible emissions were not recorded during this test.

Test WW

This plant uses a fluidized bed combustion chamber that exhausts to a separate boiler. The boiler and burner system is rated at  $70.8 \times 10^6$  BTU/hr input. This system is equipped with a multicyclone for particulate emissions control, with the induced draft fan placed downstream of the collector.

In this test the sampling ports were located between the induced draft fan and the collector, a location that was easily accessible.

No formal visible emissions readings were taken during testing, however, the exhaust appeared to be quite clean with no emissions exceeding No. 2 ringelmann being noticed.

There were no upsets in the combustion system during the sampling period.

Steam output was being used exclusively for a wood drying kiln which has a fairly constant steam demand. No steam flow data is available.

Summary of the Boilers Tested

Of the seven boilers tested there were four HRT Boilers, one water tube, one underfeed stoker, and one fluidized bed. Four used multi-cyclone emission controls, three were uncontrolled. Tests were conducted at points downstream of the emissions collector.

As part of the testing objectives 4 tests were conducted on boilers burning kiln dried mill residue and 4 on the green bark and/or sawdust.

The water tube boiler was used for two test series, one burning dry wood waste and a second burning green saw mill residue.

Table 3-1 summarizes these boilers and the operating conditions during testing.

Table 3-1  
Boiler Summary and Operating Characteristics  
During Testing

Test	Boiler Fuel Type	Boiler Rating Input MBTU	Testing Heat Input 10 <sup>6</sup> BTU	Excess Air %	Stack Temp. °F	Particulate Emission Control	Particulate Specific Emissions Rate Lbs/10 <sup>6</sup> BTU	Chromatographical Organics Collected g/kg of Fuel
K1			6.35	187	550		0.363	0.141695*
K2	Green Ash	5.2	4.9	249	538	No	0.3092	0.263798
K3			4.6	294	519		0.2614	0.102669
EA1	Kiln Dry		18.7	354	317		0.306	0.018667
EA2	Oak	55	14.7	464	309	Yes	0.496	0.120120
EA3	Green Saw		28.8	145	298		0.452	0.030042
EA4	Dust		26.3	215	307		0.638	0.057522
BP1	Kiln Dried		28.4	175	529	Yes	0.358	0.319840
BP2	Hardwood	37.2	26.0	196	519		0.354	0.078120
HH1			5.7	129	298		0.292	0.127561
HH2	Kiln Dried	13	4.3	212	299	Yes	0.344	0.102885
HH3			6.5	109	297		0.221	0.081576
SF1			14.3	350	389		0.445	0.111
SF2	Kiln Dried	13.5	12.7	412	393	No	0.349	0.114
SF3			10.7	493	373		0.518	0.388
EL1			13.6	69	376		1.045	0.0313
EL2	Green Pine	16	13.5	67	408	No	1.177	0.0526
EL3	Sawdust & Bark		12.6	84	400		0.937	**
WW1	Green Bark		18.6	357	316		0.376	0.06405
WW2		70.8	16.8	397	335	Yes	0.395	0.10250
WW3			18.0	381	332		0.590	0.088165

\* Composite Peak Area Used  
\*\* XAD Sample Lost

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#### 4.0 SAMPLING METHODS AND ANALYTICAL PROCEDURES

##### Sample Train Construction and Preparation

In order to collect samples of polycyclic organic materials (POM) a standard EPA Method 5 sampling train was modified with additional components.

The modified train can best be described by tracing the path of the sample gas through it. The gas passes through the various components of the train in the following order:

1. Nozzle (standard Method 5);
2. Probe (standard Method 5);
3. Filter Assembly (standard Method 5);
4. A water cooled condenser with a tubing length of approximately 48 inches;
5. A water-cooled glass cartridge of approximately 30 ml volume. The cartridge was filled with porous polymer resin XAD-2. Glass wool was used to pack the ends of the cartridge to hold the resin in place;
6. A knock-out trap. The trap was used because the arrangement of the equipment required an upward turn in the gas path following the XAD-2 cartridge. The trap removed the flow restriction that would have resulted from having condensate percolating in the upward "riser";
7. Impinger train (standard Method 5); and
8. Metering apparatus (standard Method 5).

A description of the unmodified Method 5 sampling apparatus may be found in Federal Register, Volume 42, Number 247 dated August 18, 1977, (Reference 1).

The modification to the sampling train did not remove its particulate sampling capability. Particulate samples were taken together with the POM samples, and particulate emission results are reported.

Prior to assembly, the sampling glassware was cleaned according to the following procedure:

1. Wash with water and laboratory soap (Alconox);
2. Rinse with tap water;
3. Rinse with deionized water;
4. Rinse with a 50-50 mixture of sulfuric acid and nitric acid;
5. Rinse with tap water a minimum of five times;
6. Rinse with deionized water a minimum of five times;
7. Rinse with methanol (pesticide grade); and
8. Rinse with methylene chloride (pesticide grade).

Clean XAD-2 resin was supplied by Ray Merrill and Ray Steiber of EPA. Their protocol for preparing the resin consisted of extracting it in a Soxhlet extractor with methylene chloride followed by drying it in such a way as to prevent recontamination.

After it was cleaned and dried, a small portion of the resin was reextracted and the extract analyzed to assure the quality of the cleaning procedure.

### Sampling

Sampling port locations and number of test points to be used were determined according to EPA Method 1 (Reference 1).

Actual operation of the sampling apparatus (once it was assembled) was essentially the same as for EPA Method 5 (Reference 1) except that the temperature limits for the filter oven were 250°F to 400°F. Also, cooling water had to be supplied to the condenser and to the XAD-2 cartridge.

Flue gas composition was determined by EPA Method 3 (Reference 1). A continuous gas sample was drawn from a point near the sampling nozzle into a Tedlar bag during each test run. The bag sampler was then analyzed with an Orsat analyzer.

The heat input to the boiler was determined by the "F-factor" method as outlined in Federal Register Volume 40, Number 194, dated October 6, 1975, (Reference 2) and also in a paper by Shigehara, Neulicht, Smith, and Peeler (Reference 3).

#### Sample Recovery

Sample recovery was conducted by collecting the XAD-2 Resin, the filter, and the washings from various parts of the train in glass containers. The numbers on the accompanying diagram (Figure 4-1) identify the different containers and identify, by reference to the sample train, the various parts of the sample they were to contain. Containers 1, 3, 4, and 5 were amber glass jars with teflon liners. Container 2 was a petri dish. Containers 5 and 7 were clear glass jars with plastic liners. Prior to sample recovery, containers 1, 2, 3, 4, and 5 were taken through the same clean-up procedure as the sample train glassware itself. Containers 6 and 7 were simply washed with soap and water.

Pesticide grade methylene chloride was used as a sample recovery (clean-up) solvent. The usual practice for cleaning a probe calls for using a brush on a long rod to scrub out any solid material that may adhere to the bore of the probe liner. This was not possible using methylene chloride because no brushes were available that would withstand this solvent. Several methylene chloride rinses, however, should have removed all the organic material and most of the particulate matter, leaving only a slight bias to the final particulate results. For most of the tests done during the course of the POM study an attempt was made to remove this bias. The attempt consisted of a final brushing with acetone collected in a separate jar. Analysis of the contents of this jar by our own laboratory revealed a small amount of residue. Examination of the lab sheets labeled "Analytical Data", (Appendix D), will reveal whether or not his extra acetone brushing was done for this particular test.

## Analysis

Analytical work was done by Research Triangle Institute (RTI) under the direction of Robert S. Truesdale. The analysis protocol prepared by RTI is included as written.

### PNA ANALYSIS OF THE GAS EFFLUENT FROM INDUSTRIAL WOOD BURNING BOILERS USING GC GLASS CAPILLARY COLUMN

## Preparation

Each set of samples was prepared for analysis by the Battelle Trial Protocol for Sampling and Analysis of Emissions from Residential Wood Combustion.

## Identification and Quantitation

Compound identification for each sample was based on comparing the retention times of the peaks in each sample spiked 50/50 with a known concentration of triphenyl ethylene (TPE) with the retention times (RTs) in that sample spiked 50/50 with TPE + 22 PNAs at known concentrations. TPE was used as an internal standard because it was not present in any of the samples. The TPE served as a marker; thus, when matched, the PNA peaks subsequently would match if present. The matching was based both on the visual inspection of the curves and the list of retention times and areas of peaks automatically integrated and reported after each run. Slight variations in the RT of TPE were observed, which meant that slight variation in PNA RTs would also be present. These variations were cancelled by matching TPE peaks as described above. Two samples were analyzed by GC/MS (GC<sup>2</sup>) to confirm our results. Overall, their results compared favorably to those obtained by us.

Compound quantitation was accomplished using the known concentration of TPE in the samples spiked with TPE only. Once a PNA peak was identified, the area of that peak was used with the area of TPE at known concentration to calculate the concentration of the PNA. The equation used is as follows:

$$\frac{\text{Area PNA}}{\text{Area TPE}} \times \text{conc. TPE} \times \text{dilution factor (2)} = \text{Conc. PNA}$$

Then the concentration of the PNA was multiplied by the amount of sample, thusly:

$$\text{PNA} \frac{\text{ug}}{\text{ml}} \times \text{ml sample} = \text{ug PNA present}$$

The concentration of hydrocarbons in each sample was calculated by adding the areas of all the peaks in the XAD, particulate, and Part 5 GC curves. The total amount of hydrocarbons present then was calculated in the same manner as were the PNA's.

#### RTI WOOD COMBUSTION SAMPLE PREPARATION

##### Part 1: Probe Wash

- (1) Pour into weighed beakers and let dry, desiccate.
- (2) Re-weigh beakers for probe wash particulate.
- (3) Add to Part 2, Step 3.

##### Part 2: Filter

- (1) Desiccate for 24 hours.
- (2) Weigh and record particulate weight.
- (3) Put in Soxhlet extractor for 24 hours in 250 ml  $\text{CH}_2 \text{Cl}_2$  along with probe wash particulate.
- (4) Put extract into K-D evaporator and concentrate to about 1.0 ml (record volume).
- (5) Make 50/50 mixture with 173 ppm triphenyl ethylene (standardized).
- (6) Make 50/50 mixture with 22 PNA standards (25-50 ppm final conc. each).
- (7) Store in freezer until GC is run.

##### Part 3: XAD Absorbent

- (1) Put into Soxhlet with 250 ml of  $\text{CH}_2 \text{Cl}_2$ .

- (2) Add part 4 then extract for 24 hours with  $\text{CH}_2 \text{Cl}_2$ .
- (3) Put into K-D evaporate and concentrate to 1-2 ml (record volume).
- (4) Make 50/50 mixture with 173 ppm triphenyl ethylene (standardized).
- (5) Make 50/50 mixture with 22 PNA standard (25-50 ppm conc. each).
- (6) Store in freezer until GC is run.

#### Part 4: Condenser Wash

Part 4 is added to Part 3 before extraction.

#### Part 5: Condensate

- (1) Separate  $\text{H}_2\text{O}$  and  $\text{CH}_2 \text{Cl}_2$  fractions with a separatory funnel. Wash  $\text{H}_2\text{O}$  fraction three times with 25 ml  $\text{CH}_2 \text{Cl}_2$ .
- (2) Put  $\text{CH}_2 \text{Cl}_2$  into K-D evaporator and concentrate.
- (3) Make 50/50 mixture with 173 ppm triphenyl ethylene (standardized).
- (4) Make 50/50 mixture with 22 PNA standard (25-50 ppm conc. each).
- (5) Store in freezer until GC is run.

#### REFERENCES

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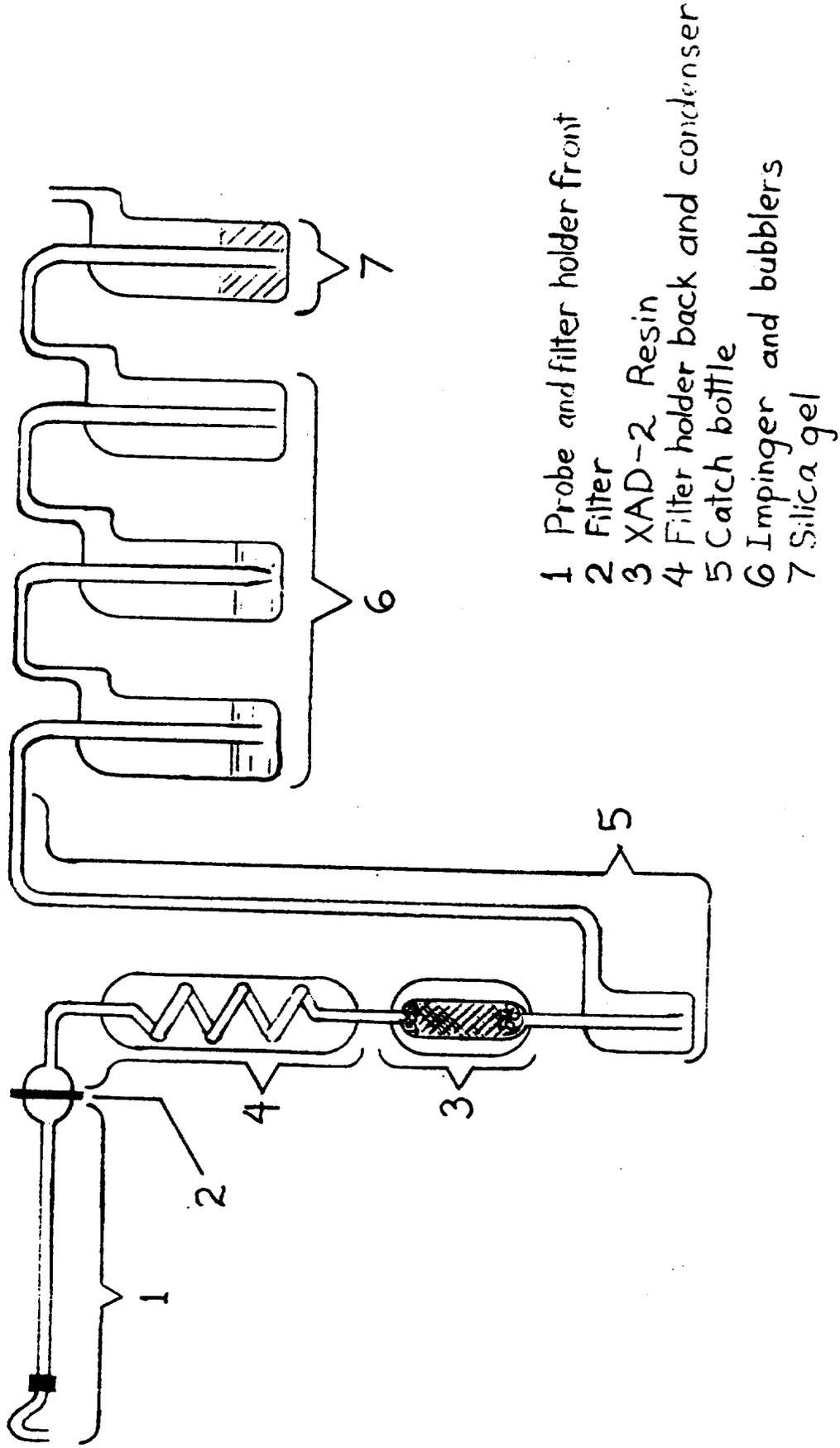


Figure 4-1 POM SAMPLING TRAIN

## 5.0 LABORATORY SEPARATION AND ANALYSIS PROCEDURES

### Sample Preparation - RTI

Six sample fractions were delivered to RTI for each modified method 5 sampling run. These were (1) methylene chloride wash of the probe and filter housing (probe wash), (2) filter with particulate catch, (3) a methylene chloride wash of the condenser preceding the XAD module, (4) the XAD polymer absorbent plus a methylene chloride wash of the XAD module, (5) aqueous condensate from the XAD condenser, and (6) impinger water.

Figure 5-1 is a flowchart of sample preparation and analysis of these samples. This preparation and analysis scheme was adapted from the Trial Protocol for Sampling and Analysis of Emissions from Residential Wood Combustion,<sup>1</sup> with several changes approved by the EPA Project Officer in charge of this project.

After receiving samples, the probe wash was filtered and the particulates thus obtained were weighed. This weight was then combined with the weight of particulate collected on the filter to give the total amount of particulate sampled during the run. Probe wash filtrate and filter were then placed in a Soxhlet extractor with enough clean methylene chloride to bring the volume of the solvent to about 250 ml. The filter was then extracted for 24 hours. (At the recommendation of EPA, the solvent used for this and all subsequent extractions and sample preparation steps was Burdick-Jackson, distilled-in-glass methylene chloride.)

Similarly, the XAD, XAD wash, and condenser wash were also placed in a Soxhlet apparatus and extracted for 24 hours. The aqueous condensate was extracted in a separatory funnel with three successive 25 ml aliquots of methylene chloride. Impinger water was not analyzed because of the lack of odor or color in all such samples, and because only very low levels of organics were found in the condensate collected before the impingers.

Each extract was concentrated separately using a Kuderna-Danish (K-D) evaporator with a 3 ball Snyder column to 1-3 ml final volume, depending on how colored the extract became during concentration. After concentration, extracts were chromatographed separately for a measurement of chromatographyable organics, providing a measure of how the hydrocarbons partitioned into the various sample fractions. Finally, the separate extracts were combined for each run and analyzed for PAHs.

#### Analytical - RTI

RTI has amassed considerable experience in the analysis of PAH in various process streams, including the aqueous condensate and tar effluents from coal gasification.<sup>2,3,4</sup> During these studies, RTI encountered difficulty in characterizing these highly complex mixtures by gas chromatography-mass spectroscopy (GC/MS) in a time and cost-effective manner. Time consuming sample separation procedures were necessary for good GC/MS quantitation of PAHs in these samples. Fractionation of the PAH's by these methods was not complete,<sup>4</sup> and the complexity of the fractionation techniques gave rise to some sample loss. These considerations motivated the development of a direct technique for the analysis of PAH's in complex mixtures utilizing glass capillary gas chromatography (GC<sup>2</sup>). This technique has been presented in detail in two papers.<sup>2,3</sup>

Gas chromatographs of the previously described sample extracts indicated that the samples obtained from wood combustors were indeed very complex, being dominated by what appeared to be a large number of straight chain aliphatic compounds. This complexity, in conjunction with project time and cost constraints, led to the selection of GC<sup>2</sup> as the analytical method for determining PAH concentrations in the industrial wood combustion samples. A Varian 3700 GC<sup>2</sup> system with a flame ionization detector (FID) was used for these analyses.

The system was all-glass from the injector to the detector. A wall-coated OV-101 capillary column was used in the system. All sample-wetted parts were made of glass. Helium was used as the carrier gas as well as

makeup gas. Chromatographic conditions were listed in Table 1. Samples were injected using the Grob "splitless" technique<sup>5</sup> and sample volumes ranging from 3 to 4 ul were used. The splitless technique consists of injecting the sample and then 30 seconds later, opening the splitter to remove the excess solvent. This prevents a long solvent tail. The advantages of using this technique for polycyclic materials are well documented.<sup>6</sup>

Prior to GC<sup>2</sup> injection, concentrated sample extracts were internally standardized. A problem was to find a suitable internal standard for GC analysis since the extracts were substantially complex. Triphenyl ethylene (TPE) was found to be the most suitable among the many tested since it was present at negligible concentrations in the extracts, was similar in nature to other aromatic compounds, and was well separated from peaks of interest.

PAH analysis was performed on a composite of the three sample extracts previously described. PAH compound identification for each composite sample was based on comparing the retention times (RTs) of the peaks in each TPE spiked sample with the PAH RTs in a duplicate sample spiked 50/50 with TPE + 22 PAHs at known concentrations. The TPE served as a marker in both samples. Matching of peaks in the PAH spiked sample with peaks in the unspiked sample was based both on the visual inspection of the curves and on the list of retention times reported after each run. Small differences in the RT of TPE between the spiked and unspiked samples were observed, which meant that small differences in PAH RTs were also present. These variations were cancelled by comparing TPE peaks in the two samples.

Compound quantitation was accomplished using the known concentration of TPE in the samples spiked with TPE only. Once a PAH peak was identified, the area of that peak was compared with the area of TPE peak at known concentration, in order to calculate the concentration of the PAH. The equation used is as follows:

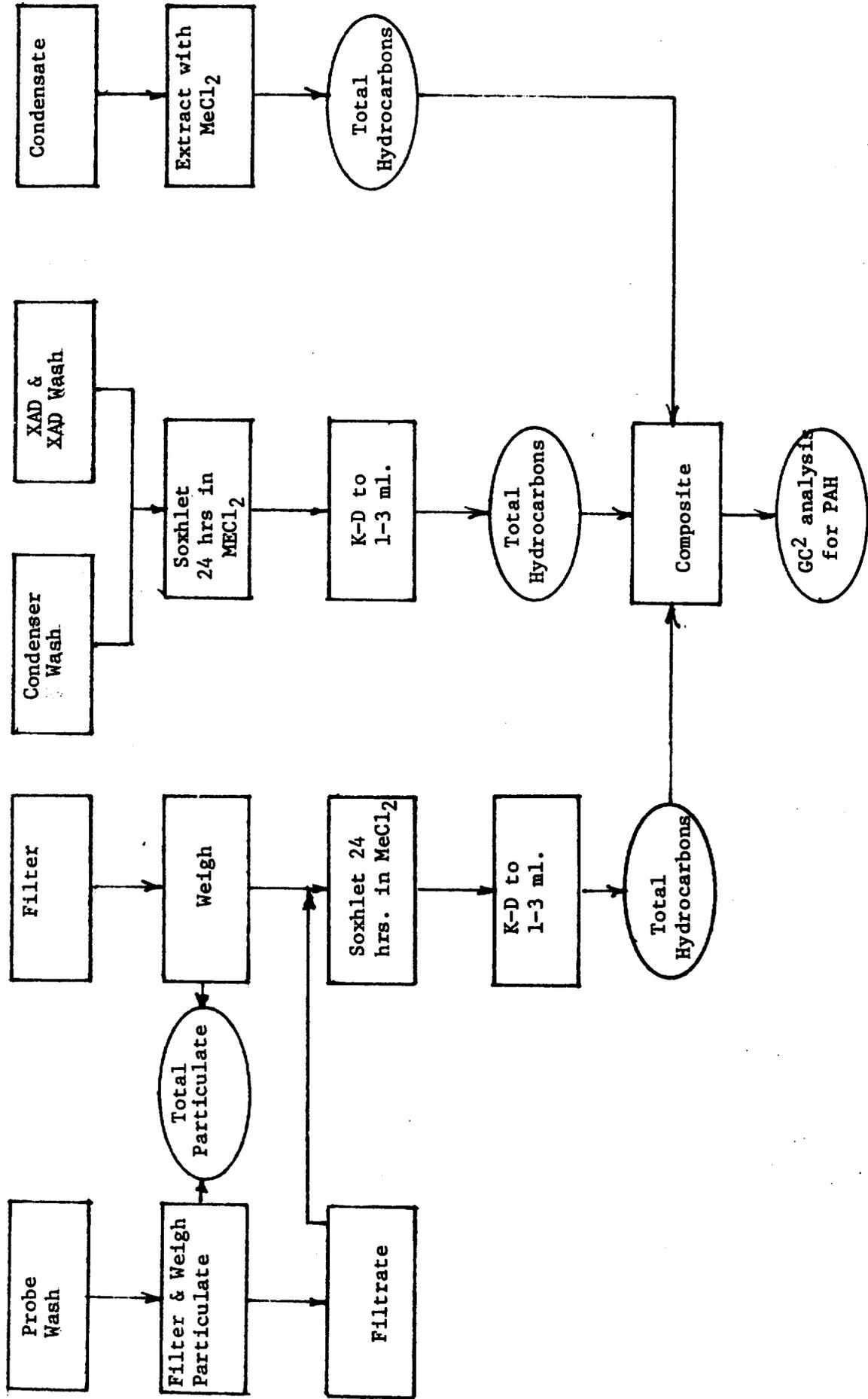


Figure 5-1 Sample flowchart for preparation and analysis of Method 5 samples of industrial wood combustors.

$$\frac{\text{Area PAH}}{\text{Area TPE}} \times \text{conc. TPE} \times \text{Dilution factor (2)} = \text{Conc. PNA}$$

The concentration of the PNA was then multiplied by the amount of sample,

$$\frac{\text{PNA ug} \times \text{ml sample}}{\text{ml}} = \text{ug PNA present}$$

In addition, two samples were analyzed for PAH compounds by GC<sup>2</sup>/MS for verification of the GC<sup>2</sup> results. Overall, these results compared favorably (see Results and Discussion).

To determine how organics were partitioned in the different parts of the sampling train, a measure of chromatographable organics in each of the three extracts was made for each sample. The concentration of organics in each sample was calculated by adding the areas of all of the peaks in the XAD, particulate, and condensate chromatograms. The total amount of hydrocarbons of chromatographable organic compounds should not be confused or directly compared with data from the total chromatographable organics (TCO) procedure as described in the Trial Protocol.<sup>1</sup>

#### Results and Discussion - RTI

Table 5-2 lists the results of RTI analyses of Method 5 sample extracts for 22 PAHs. Results are given in total ug of each compound for each sample run. Examination of this table will show that several compounds were not detected in any samples and those that were detected were found in low concentrations. These low concentrations, in combination with the high level of aliphatic and other straight chain hydrocarbons in the samples, made analyses fairly tedious. Sample cleanup, using column chromatography and consisting of successive elutions with increasingly polar solvents, may result in improved peak resolution. However, this technique is time consuming and could not be carried out under the present scope of work. Also, the low levels of PNA's detected in all samples make this a questionable approach from a cost/benefit perspective.

Table 5-3 is a listing of chromatographable organics in the industrial wood combustion samples. It should be noted that, for most samples, most of the organic material was trapped in the XAD resin. Total particulate for each sample run is listed in Table 5-4. Probe wash particulate is not included in the Kinston runs because the samples were lost.

Table 5.5 is a comparison of RTI PAH results using GC<sup>2</sup> with those obtained by an independent testing laboratory using computerized GC<sup>2</sup>/MS on two samples from two separate combustors. Considering the low levels of PAHs in the sample and the high level of interference from other compounds, these results show good correlation with most of the GC/MS results falling within an order of magnitude of the RTI GC<sup>2</sup> results. Major disagreements (e.g., anthracene and B(a)P for HH1 and benzo (g,h,i) perylene for EL2) occurred for compounds for which the computer library match of the spectra was poor or nonexistent for the GC<sup>2</sup>/MS analysis. Reexamination of the RTI GC<sup>2</sup> spectra for the presence or absence of compounds which showed up on GC<sup>2</sup>/MS, but not on GC<sup>2</sup>, did not identify any peaks which could be attributed to these compounds. Full GC<sup>2</sup>/MS results and a description of the analytical techniques used to obtain these results may be found in Appendix A.

TABLE 5-2 PNA's DETECTED (total ug)

Compound	Test Run Number						
	SF1	SF2	SF3	EA1	EA2	EA3	EA4
naphthalene	2.1	30.7	17.9	77.5	90.59	29.2	67.2
biphenyl	+	+	+	+	+	59.8	+
fluorene	ND	ND	7.5	ND	ND	ND	ND
phenanthrene	3.3	ND	ND	ND	ND	+	ND
anthracene	ND	ND	ND	ND	ND	0.69	ND
carbazole	ND	ND	ND	ND	ND	ND	ND
1-methyl phenanthrene	ND	ND	ND	ND	ND	ND	1.6
9-methyl anthracene	ND	ND	ND	1.2	ND	ND	0.87
fluoranthene	ND	ND	ND	ND	ND	+	0.53
pyrene	ND	1.4	ND	ND	ND	5.0	7.2
benzo(a)anthracene	2.8	ND	ND	0.22	ND	0.16	0.98
chrysene	ND	ND	ND	ND	ND	0.26	ND
benzo(b)fluoranthene	ND	ND	ND	} 0.44	ND	ND	ND
benzo(k)fluoranthene	ND	ND	ND		ND	ND	ND
7,12 dimethyl benz(a) anthracene	ND	ND	ND	ND	ND	ND	ND
benzo(e)pyrene	ND	ND	ND	ND	ND	ND	ND
benzo(a)pyrene	ND	ND	ND	0.32	ND	0.14	ND
perylene	ND	ND	ND	ND	ND	ND	ND
3-methyl cholanthene	ND	ND	ND	ND	ND	0.23?	ND
indeno (1,2,3-cd)pyrene	ND	ND	ND	ND	ND	0.68?	ND
dibenz(a,h)anthracene	ND	ND	ND	ND	ND	ND	ND
benzo(g,h,i)perylene	ND	ND	ND	ND	ND	ND	ND
detection limit	0.37	0.35	1.2	0.07	0.32	0.03	0.24

+ Compound peak obscured by aliphatic peak.  
 \* NBS library match not possible for peak identification due to low level of compound or interference.  
 ? Compound identification in question due to low concentration.  
 ND Not Detected  
 Peak resolution not sufficient to differentiate these two compounds.  
 Value reported is amount of both species combined.

Table 5-2 (con't)

Compound	Test Run Number				
	HH1	HH2	HH3	K1	K2
naphthalene	398.1	311.1	323.1	193.5	186.2
biphenyl	+	14.0	+	+	+
fluorene	4.2	6.6	2.1	ND	ND
Phenanthrene	} 6.3	1.5	} 7.0	5.8	ND
anthracene		ND		9.0	8.8
carbazole	ND	ND	ND	ND	ND
1-methyl phenanthrene	ND	ND	ND	ND	ND
9-methyl anthracene	ND	1.4	ND	+	+
fluoranthene	+	+	+	+	ND
pyrene	+	3.7	22.2	ND	6.4
benzo(a)anthracene	2.1	0.94	ND	ND	3.3
chrysene	14.3	1.1	ND	ND	ND
benzo(b)fluoranthene	} 2.4	} 2.0	5.2	} 5.0	} 4.6
benzo(k)fluoranthene			0.94		
7,12 dimethyl benz(a)anthracene	ND	ND	ND	ND	ND
benzo(e)pyrene	} 0.51	} 0.90	1.1	1.7	3.0
benzo(a)pyrene			1.5	3.4	1.8
perylene	ND	ND	ND	ND	ND
3-methyl cholanthene	ND	ND	ND	ND	ND
indeno (1,2,3-cd)pyrene	1.0	2.7	ND	ND	ND
dibenz(a,h)anthracene	ND	ND	ND	ND	ND
benzo(g,h,i)perylene	4.2	ND	ND	3.3	ND
detection limit	0.24	0.26	0.26	0.25	0.13

+ Compound peak obscured by aliphatic peak.

\* NBS library match not possible for peak identification due to low level of compound or interference.

ND Not Detected

Peak resolution not sufficient to differentiate these two compounds.  
Value reported is amount of both species combined.

Table 5-2 (con't)

Compound	Test Run Number				
	K3	BP1	BP2	ELI	EL2
naphthalene	221.6	10.6	1.4	76.1	384.4
biphenyl	+	+	+	+	+
fluorene	ND	ND	ND	ND	ND
phenanthrene	21.7	ND	0.4	10.6	1.2
anthracene	29.5	ND	ND	4.7	29.1
carbazole	ND	ND	ND	ND	ND
1-methyl phenanthrene	ND	4.9	ND	ND	ND
9-methyl anthracene	+	+	ND	4.3	+
fluoranthene	+	ND	ND	ND	13.4
pyrene	ND	ND	0.5	6.4	ND
benzo(a)anthracene	26.1	ND	ND	2.7	ND
chrysene	2.5	ND	ND	ND	ND
benzo(b)fluoranthene	} 1.32	ND	ND	ND	ND
benzo(k)fluoranthene		ND	ND	ND	ND
7,12 dimethyl benz(a)anthracene	ND	ND	ND	ND	ND
benzo(e)pyrene	3.3	ND	ND	ND	ND
benzo(a)pyrene	1.7	ND	ND	ND	ND
perylene	ND	ND	ND	ND	ND
3-methyl cholanthene	ND	ND	ND	ND	ND
indeno(1,2,3-cd)pyrene	ND	ND	ND	ND	ND
dibenz(a,h)anthracene	3.6	ND	ND	ND	ND
benzo(g,h,i)perylene	6.3	ND	ND	ND	ND
detection limit	0.28	0.20	0.14	0.11	0.51

+ Compound peak obscured by aliphatic peak.

\* NBS library match not possible for peak identification due to low level of compound or interference

ND Not Detected

Peak resolutions not sufficient to differentiate these two compounds. Value reported is amount of both species combined.

Table 5-2 (con't)

Compound	Test Run Number		
	WW1	WW2	WW3
naphthalene	49.03	23.08	5.19
biphenyl	+	+	ND
fluorene	9.30	12.71	14.82
phenanthrene	27.22	34.80	32.65
anthracene	7.82	12.11	13.13
carbazole	ND	ND	0.50
1-methylphenanthrene	ND	ND	ND
9-methylanthracene	ND	ND	+
fluoranthene	+	ND	0.52
pyrene	4.30	ND	+
benzo(a)anthracene	4.73	0.62	0.46
chrysene	ND	0.28	ND
benzo(b)fluoranthene	ND	ND	1.17
benzo(k)fluoranthene	ND	ND	ND
7,12-dimethylbenz(a) anthracene	ND	ND	ND
benzo(e)pyrene	0.98	1.55	2.13
benzo(a)pyrene	0.93	1.11	1.44
perylene	ND	ND	ND
3-methylcholanthene	ND	ND	ND
indeno(1,2,3-cd)pyrene	ND	ND	ND
dibenz(2h)anthracene	*	ND	ND
benzo(g,h,i)perylene	ND	ND	ND
detection limit	0.24	0.22	0.12

+ Compound peak obscured by aliphatic peak.

\* NBS library match not possible for peak identification due to low level of compound or interference

ND Not Detected

Peak resolution not sufficient to differentiate these two compounds. Value reported is amount of both species combined.

TABLE 5-3 CHROMATOGRAPHABLE ORGANICS (ug)

	<u>XAD</u>	<u>Particulates</u>	<u>Condensate</u>	<u>Total</u>
HH1	6,857.56	1,348.90	5,330.54	15,937.14
HH2	9,727.84	876.60	65.60	10,670.04
HH3	7,868.16	594.30	4,525.72	12,988.18
BP1	19,600.22	12,226.51	8,906.88	40,733.62
BP2	8,016.82	721.08	279.58	9,017.48
EA1	792.74	399.37	114.76	1,306.87
EA2	5,134.58	91.79	1,318.11	6,544.48
EA3	3,120.65	173.57	78.30	3,372.52
EA4	+	+	+	5,735.68
EL1	1,767.79	594.85	215.87	2,578.51
EL2	1,812.68	762.18	88.85	2,663.71
EL3 (XAD lost)		728.08	75.14	803.22*
SF1	2,305.45	991.82	889.18	4,186.45
SF2	1,919.01	960.83	946.50	3,826.34
SF3	9,023.07	907.77	720.58	10,651.42
K1	+	+	+	18,878.55
K2	1,411.20	963.90	368.22	2,743.32
K3	9,254.68	1,199.71	21.17	10,475.56
WW1	683.3	2,629.3	607.1	3,919.7
WW2	545.8	4,420.9	747.3	5,714.0
WW3	1,197.3	3,584.3	467.9	5,249.5

\*XAD GC was done.

+Composite peak areas used.

TABLE 5-4 PARTICULATE MATTER FROM INDUSTRIAL WOOD BURNING SOURCES

	<u>Run 1</u>	<u>Run 2</u>	<u>Run 3</u>	<u>Run 4</u>
K	0.3869	0.2572	0.2134	
EA				
	(on filter)	0.1302	0.1572	0.2413
	(probe wash)	0.0331	0.0400	0.1560
	Total	0.1633	0.1972	0.3973
BP				0.4969
	(on filter)	0.2278	0.2063	
	(probe wash)	0.0850	0.0447	
	Total	0.3128	0.2510	
HH				
	(on filter)	0.2158	0.2173	0.2124
	(probe wash)	0.0543	0.0543	0.0489
	Total	0.2701	0.2716	0.2613
EL				
	(on filter)	0.3109	0.1534	0.2438
	(probe wash)	1.0425	0.7827	0.4434
	Total	1.3534	0.9361	0.6872
SF				
	(on filter)	0.0742	0.0542	0.0784
	(probe wash)	0.0548	0.0388	0.0349
	Total	0.1290	0.0930	0.1133
WW				
	(on filter)	0.1462	0.1271	0.1832
	(probe wash)	0.0072	0.0356	0.0747
	Total	0.1534	0.1627	0.2579

TABLE 5-5 GC/MS CHECK OF GC<sup>2</sup> RESULTS FOR PAH ANALYSES.

Compound	GC/MS			GC/MS
	H1	HH1	EL2	EL2
naphthalene	398.1	363.0	384.4	202.0
biphenyl	+	11.0	+	1.7*
fluorene	4.2	3.2*	ND	0.9*
phenanthrene	} 6.3	ND	1.2	ND
anthracene		117.0*	29.1	17.6
carbazole	ND	ND	ND	ND
1-methyl phenanthrene	ND	ND	ND	ND
9-methyl anthracene	ND	3.2*	+	7.2
fluoranthene	+	53.7	13.4	10.4
pyrene	+	46.4	ND	ND
benzo(a)anthracene	2.1	ND	ND	ND
chrysene	14.3	18.9	ND	ND
benzo(b)fluoranthene	} 2.4	} 11.6	ND	ND
benzo(k)fluoranthene			ND	ND
7,12 dimethyl benz(a)anthracene	ND	ND	ND	ND
benzo(e)pyrene	} 0.51	} 12.9*	ND	ND
benzo(a)pyrene			ND	ND
perylene	ND	ND	ND	ND
3-methyl cholanthene	ND	ND	ND	ND
indene(1,2,3-cd)pyrene	1.0	2.2*	ND	ND
dibenz(a,h)anthracene	ND	ND	ND	ND
benzo(g,h,i)perylene	4.2	7.0	ND	3.8*
detection limit	0.24	-	0.51	-

+ Compound peak obscured by aliphatic peak.  
 \* NBS library match not possible for peak identification due to low level of compound or interference.

ND Not Detected

Peak resolution not sufficient to differentiate these two compounds.  
 Value reported is amount of both species combined.

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## 6.0 REVIEW AND DISCUSSION

All of the data collected from the sampling of flue gases from a number of wood fired combustion sources in North Carolina are presented in Table 6-1, normalized to show the results as micrograms of the various compounds emitted per kilogram of dry wood burned. A detailed description of the boilers and the conditions under which they were operating when the samples were collected is given in an earlier section of this report. The study included seven different types of boilers, operating under a wide variety of conditions and burning both wet and dry wood. The uniformity of the data presented is very impressive.

With few exceptions, no significant differences are noted between the different boiler types, the condition of the boiler, the kind of wood burned (wet or dry), the load on the boiler (percentage of rated capacity), or the mode of operation of the boiler.

Figure 6-1 shows a graph of the total emission of all compounds shown in Table 6-1 except naphthalene and biphenyl. Naphthalene is omitted because the large values would tend to mask the relatively more important, high molecular weight POM compounds, and biphenyl because one of the two values reported is suspected of a large error. This visual representation shows some indication that the fluidized bed combustor (WW1, WW2, WW3) gave somewhat higher emission of poly-aromatic hydrocarbons than the other types, however, more testing is certainly required before any firm conclusions are made with regard to this single type of combustor. In addition, there is some slight indication that the control of boiler load response by the control of combustion air (HH1, HH2, HH3), gives rise to higher emissions of poly-aromatic compounds.

As had already been mentioned, the North Carolina study included a number of different types of boilers operated under a wide variety of conditions. In addition, great care was taken to make sure that sampling methods and sample analyses were both free of error and representative of the gas streams sampled.

The analyses leading to the results shown in Table 6-1, were carried out by the Research Triangle Institute, Research Triangle Park, North Carolina, and were done by glass capillary, gas chromatography. In addition, to verify compound identification and analysis, two samples were also analyzed by an independent laboratory by GC/MS. These results are also listed in Table 6-3. The generally good agreement between the two methods is confirmation of both the compound identification and the quantitative results shown.

Since the North Carolina Test Series used a Modifier Method 5 sample train (described in detail elsewhere in this report) and many other emission studies have used the SASS train, three of the tests were duplicated using both sample trains. The SASS train sampling and analysis were done by the Acurex Corporation of Mountain View, California. Table 6-2 gives a summary of the results of the duplicate sampling and analysis of three tests from two test sites. It should also be noted that the Acurex analyses were done by GC/MS, while the North Carolina analyses were done by glass capillary GC. The table shows all compounds that were analyzed for by both testing laboratories.

With the possible exception of the results for naphthalene, the agreement between the two test methods, and the two testing laboratories is excellent, and indicates that there is essentially no difference between the results obtained from the two different sample trains. The good agreement also adds substantial weight to the general validity of the North Carolina data.

Table 6-3 presents all of the mean emission factors for the North Carolina test series. These emission factors were computed from the data presented in Table 1, by using a value of zero where "not detected" was listed in the table. The other alternative for the computation of mean emission factors would be to use the value of the detection limit for all compounds not detected. The difference between these two methods is not great as can be seen from the value of the mean emission factor calculated by averaging the detection limits. It is our belief that the mean emission factors shown represent a useful mean value for the test series.

Also shown in Table 6-3 are mean emission factors for bituminous combustion sources and for wood fired combustion sources as presented in reference (\*). The mean emission factors were computed from the data presented in the report by the same method as for the North Carolina test series. For most of the compounds which were analyzed for in both series of tests, the differences are significant, with the values reported in reference (\*) substantially higher for a number of important compounds. Since the North Carolina values are based on 20 separate tests, with several different methods of analysis used, it is believed that the North Carolina data should be more representative of emissions from wood fired combustion sources.

A review of the experimental program described in this report, and of the care taken to insure valid sampling and analytical results, leads to the conclusion that the emissions reported for wood fired combustion sources are valid. In addition, it can also be concluded that the combustion of wood in commercial boilers is certainly no greater, and most likely much less, a source of pollution than commercial boilers fired with coal.

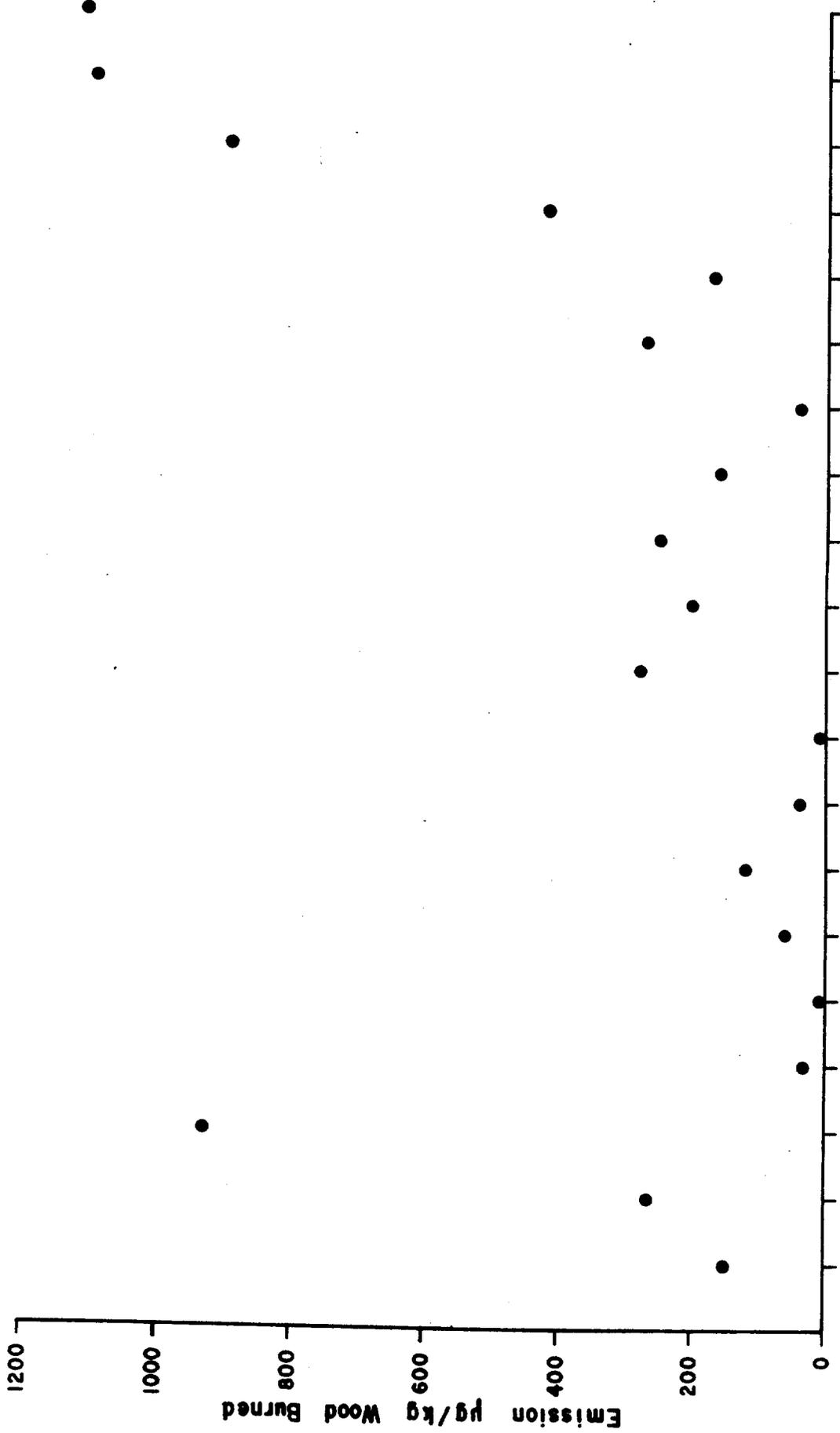


Figure 1  
Total Emission of all POM Compounds  
Except Naphthalene and Biphenyl

TABLE 6-1  
POLYCYCLIC ORGANIC MATERIALS (POM'S)  
Expressed in ug/kg of wood burned (dry weight)

Test Site/ Compound	K1	K2	K3	EA1	EA2	EA3	EA4	BP1	BP2	HH1	HH2	HH3	SF1	SF2	SF3	EL1	EL2	WM1	WM2	WM3	Mean Emission Factor X <sup>††</sup>
Naphthalene	1450	1790	2172	1107	3322	260.1	673.9	83.2	12.1	3185.5	2999.8	2030	56.0	915	650	462	3800	801	414	87	1313.5
Biphenyl	+	+	+	+	+	532.7	+	+	+	+	135	+	+	+	+	+	+	+	+	+	+
Fluorene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	33.5	13	ND	ND	274	ND	ND	152	228.0	248.9	50.72
Phenanthrene	43.5	ND	212.5	ND	ND	+	ND	ND	3.46	50	14.5	44	88.0	ND	ND	64.5	11.9	444.75	624.0	548.5	107.5
Anthracene	6.75	85	289	ND	ND	6.15	ND	ND	ND	ND	ND	ND	ND	ND	ND	28.5	288	128	217.2	220.5	63.5
Carbazole	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.4
1-Methylphenanthrene	ND	ND	ND	ND	ND	ND	16.0	38	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.7
9-Methylanthracene	+	+	+	17.1	ND	+	8.72	+	ND	ND	13.5	+	+	+	+	26.1	+	+	+	+	2.7
Fluoranthene	+	+	+	ND	ND	+	5.31	+	ND	+	+	+	+	+	+	+	+	+	+	+	3.3
Pyrene	ND	60	ND	ND	ND	44.5	72.2	ND	4.3	+	35.5	139.5	ND	41.8	ND	38.8	ND	70.5	ND	+	7.3
Benzo(a)Anthracene	ND	31.5	256	3.14	ND	1.42	9.83	ND	ND	16.8	9.0	ND	74.5	ND	ND	16.4	ND	77.5	11	7.5	25.4
Chrysene	ND	ND	24.6	ND	ND	2.32	ND	ND	ND	114.5	10.5	ND	ND	ND	ND	ND	ND	ND	5.0	ND	25.7
Benzo(b)Fluoranthene	37.5	44	12.95	6.28	ND	ND	ND	ND	ND	19.2	19.5	32.5	ND	ND	ND	ND	ND	ND	ND	ND	7.9
Benzo(k)Fluoranthene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.0	ND	ND	ND	ND	ND	ND	ND	ND	9.9
7,12-dimethylbenz(a)-anthracene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	9.9
Benzo(e)pyrene	12.75	29	32.5	ND	ND	ND	ND	ND	ND	2.1	4.5	7.0	ND	ND	ND	ND	ND	16	27.8	33.75	8.3
Benzo(a)pyrene	25.5	17.5	16.5	4.57	ND	1.25	ND	ND	ND	2	4	9.5	ND	ND	ND	ND	ND	15	19.9	24.2	7.0
Perylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
3-Methylcholanthrene	ND	ND	ND	ND	ND	2.05?	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Indo(1,2,3-cd)pyrene	ND	ND	ND	ND	ND	6.06?	ND	ND	ND	8.0	26	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.0
Dibenz(a,h)anthracene	ND	ND	35.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.8
Benzo(g,h,i)perylene	24.75	ND	60	ND	ND	ND	ND	ND	ND	33.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	5.9
Detection Limits	1.9	1.25	2.7	0.999	5.87	0.267	0.241	1.57	1.21	1.9	2.5	1.6	9.8	10.4	43.7	0.667	5.03	3.9	3.9	2.0	5.07
Total (ug/kg)	1600	2057	3111	1138	3322	856.5	785.9	121.2	19.86	3465.1	3336.8	2281	218.5	956.8	924	636.3	4232.9	704.75	1546.9	1207	2059.2
Total less Naphthalene & Biphenyl	150.7	267	939.5	31.09	0	64	112.06	38	7.76	279.6	202	251	162.5	41.8	274	174.3	432.9	903.75	1132.9	1120	745.7

\*\*Using ND = 0  
 + Compound peak obscured by aliphatic peak  
 \* NBS Library Match Not Possible For Peak Identification Due to Low Level of Compound Or Interference  
 ND Not Detected  
 Peak Resolution Not Sufficient to Differentiate these Two Compounds. Value is Amount of Both Species Combined.

TABLE 6-2  
COMPARISON OF TESTS RESULTS FROM SASS TRAIN AND  
MODIFIED METHOD 5

Compound	North Carolina Test Series Using Modified Method 5 Microgram/DSCM						Acurex Test Series Using SASS Train Microgram/DSCM		
	Dry		Wet		BP1	BP2	Dry	Wet	BP
	EA1	EA2	EA3	EA4			EA	EA	
Naphthalene	51.7	63.9	21.9	44.8	6.34	0.85	4.50	0.04	3.30
Fluorene	ND	ND	ND	ND	ND	ND	0.65	0.04	0.04
Phenanthrene	ND	ND	ND	ND	ND	ND	7.0	2.0	0.30
Anthracene	ND	ND	0.52	ND	ND	ND	ND	0.20	ND
Fluoranthene	ND	ND	ND	0.53	ND	ND	0.05	0.3	0.08
Pyrene	ND	ND	3.7	4.8	ND	0.30	0.3	0.2	0.2
Benzo(a)- anthracene	0.15	ND	0.12	0.65	ND	ND	ND	ND	ND
Chrysene	ND	ND	0.2	ND	ND	ND	0.05	0.04	0.04
Benzo(b)- fluoranthene	0.29	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(k)- fluoranthene	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(a)- pyrene	0.21	ND	0.10	ND	ND	ND	ND	ND	ND
Indo(1,2,3-cd)- pyrene	ND	ND	0.51?	ND	ND	ND	ND	ND	ND
Dibenzo(a,h)- anthracene	ND	ND	ND	ND	ND	ND	ND	ND	ND
Benzo(g,h,i)- perylene	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND - Not Detected

TABLE 6-3  
MEAN EMISSION FACTORS  
Microgram/kg of fuel burned (dry weight)

Compound	North Carolina Test Series	From Draft Report GCA-TR-79-62-G*	
	Wood Fired Combustion Sources	Wood Fired Combustion Sources	Bituminous Combustion Sources
Naphthalene	1313	5061	380
Biphenyl	----	354	ND
Fluorene	50.7	11	ND
Phenanthrene	107.5	5043	1014
Anthracene	63.5		
Carbazole	0.4		
1-Methylphenanthrene	2.7		
9-Methylanthracene	3.3		
Fluoranthene	7.3		
Pyrene	25.4	884	328
Benzo(a)anthracene	25.7	642	962
Chrysene	7.9		
Benzo(b)fluoranthene plus Benzo(k)fluoranthene	9.9	216	547
1,12-dimethylbenz(a)anthracene	0.0	413	ND
Benzo(e)pyrene	8.3		
Benzo(a)pyrene	7.0		
Perylene	0.0	323	78
3-Methylcholanthene	0.0		
Indo(1,2,3-cd)pyrene	2.0		
Dibenz(a,h)anthracene	1.8		
Benzo(g,h,i)perylene	5.9	0	11
Detection Limit Value	5.1		

\*Reference:

Surprenant, Battye, Roeck and Sandberg, 1981. Emissions Assessment of Conventional Stationary Combustion Systems: Volumn V: Industrial Combustion Sources. Prepared for: Industrial Environmental Research Laboratory, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. Contract No. 62-02-2197.

TABLE 6-4 GC/MS CHECK OF GC<sup>2</sup> RESULTS FOR PAH ANALYSES

Micrograms/Kilogram of Woodburned

Compound	GC/MS <i>1/1/80</i>			GC/MS <i>1/1/80</i>	
	HH1	HH1	EL2	EL2	
naphthalene	3185.5	2910. <i>5.85-2</i>	3800	1990	<i>4.05-3</i>
biphenyl	+	88. <i>1.50-4</i>	+	17*	
fluorene	33.5	25.6*	ND	8.9*	
phenanthrene	} 50	ND	11.9	ND	
anthracene		936.*	288.	174	<i>3.11-4</i>
carbazole	ND	ND	ND	ND	
1-methyl phenanthrene	ND	ND	ND	ND	
9-methyl anthracene	ND	25.6*	+	71	
fluoranthene	+	430 <i>5.55-4</i>	133	103	
pyrene	+	371 <i>5.55-4</i>	ND	ND	
benzo(a)anthracene	16.8	ND	ND	ND	
chrysene	114.5	151 <i>5.55-4</i>	ND	ND	
benzo(b)fluoranthene	} 19.2	} 92.8 <i>5.55-4</i>	ND	ND	
benzo(k)fluoranthene			ND	ND	
7,12 dimethyl benz(a)anthracene	ND	ND	ND	ND	
benzo(e)pyrene	2.1	} 103*	ND	ND	
benzo(a)pyrene	2		ND	ND	
perylene	ND	ND	ND	ND	
3-methyl cholanthene	ND	ND	ND	ND	
indene(1,2,3-cd)pyrene	8.0	17.6*	ND	ND	
dibenz(a,h)anthracene	ND	ND	ND	ND	
benzo(g,h,i)perylene	33.5	56 <i>5.55-4</i>	ND	37.5*	
detection limit	1.9	-	5.03	-	

+ Compound peak obscured by aliphatic peak.

\* NBS library match not possible for peak identification due to low level of compound or interference.

ND Not Detected

Peak resolution not sufficient to differentiate these two compounds. Value reported is amount of both species combined.

APPENDIX A  
GC/MS COMPARISON



TO: Robert S. Truesdale  
Research Triangle Institute  
P.O. Box 12194  
Research Triangle Park, NC 27709

FROM: Stewart Laboratories, Inc.  
5815 Middlebrook Pike  
Knoxville, TN 37921

PROJECT: RTI 13455

PO NO: 22868

DATE: September 16, 1981

ANALYSIS OF METHYLENE CHLORIDE EXTRACTS  
FOR POLYNUCLEAR AROMATIC HYDROCARBONS USING  
COMPUTERIZED GAS CHROMATOGRAPHY/MASS SPECTROMETRY

The extracts, after being concentrated by a factor of five under a gentle stream of helium, were analyzed by capillary gas chromatography using a 30m long fused silica capillary coated with SE-54. The results of the analyses of the two methylene chloride extracts are summarized in Tables 1 and 2.

Identification:

Positive identifications were based upon comparison of the gas chromatographic retention times and spectra with those of standards. Computerized searches of the 31,000 entry EPA/NIH/Battelle library were used to confirm the identifications.

Tentative identifications were made, in the absence of standards, by computer matching of spectra with the EPA/NIH/Battelle spectra library or by visual evaluation or interpretation of the spectra.

The Riber-Nermag/SADR data package uses a factor called the Dissimilarity Index (D.I.) to indicate the quality of a fit between spectra of an unknown and a library entry. D.I. values of 0.35 or less indicate good fit between spectra. When spectra are poorly matched, the D.I. factor approaches the number one. At times, when the signal to noise level is low or background

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contamination is high, the D.I. factors indicate a poor match despite the fact visual comparison of the unknown and standard spectra along with similar retention times confirm the identifications.

Quantitation:

The concentrations of the PAH's detected in the extracts are reported in Tables 1 and 2 (ng/ $\mu$ l of extract) with the following qualification:

- 1) When a standard was not available, quantitation was performed using the weighted response factor of the closest available analog standard;
- 2) Weighted response factors for available standards were calculated from the results of three standard runs.

Other Observations:

The specific isomers of the two detected PAH's, benzofluoranthene and benzopyrene, could not be positively identified for the two extracts. The retention times for the respective isomers differed by no more than two to three scans. During the running of the sample extracts, a difference of two to three scans was within the range of permissible variation in retention times of a chromatographic run, particularly at such a late stage of the run.

Table 1. Results from Analysis of Sample H8 Composite

Compound	Concentration in Original Extract (ng/ul)	Means of Quantitation	Scan No.	Base M/E	Library Identification	Computer D.I. Factor	Interpretations of Identifi- cation and Quantitation Results
Napthalene	214.	weighted RF	170	128	Napthalene	0.174	Quantitated against standard
Biphenyl	6.5	weighted RF	261	154	Biphenyl	0.457	Quantitated against standard
Fluorene	1.9	weighted RF	341	166	NI		Quantitated against standard
Anthracene	69.	weighted RF	412	178	Anthracene	0.236	Quantitated against standard
Methyl Anthracene*	1.0	nearest analog	451	192	Methyl Anthracene	0.650	Quantitated versus anthracene (best guess identification)
Methyl Anthracene*	0.9	nearest analog	458	192	NI		Quantitated versus anthracene (best guess identification)
Phenyl Napthalene	1.5	nearest analog	470	204	Phenyl Napthalene	0.682	Quantitated against standard
Fluoranthene	31.6	weighted RF	498	202	Pyrene	0.206	Quantitated against standard
Pyrene	27.3	weighted RF	514	202	Fluoranthene	0.396	Quantitated against standard
Chrysene	11.1	weighted RF	618	228	Chrysene	0.453	Quantitated against standard
Unknown PAH	8.7	nearest analog	599	226			Quantitated versus chrysene
Benzo(ghi)fluoranthene	8.6	nearest analog	614	226	Benzo(ghi) fluoranthene	0.596	Quantitated versus chrysene
Benzo(b or k)fluoranthene	6.8	weighted RF	700	252	Perylene	0.492	Library match poor
Benzo(a or e)pyrene	7.6	weighted RF	720	252	Benzo(e)pyrene	0.712	Quantitated versus standard
Unknown PAH	1.5	nearest analog	837	276	NI		Library match poor
Indeno(1,2,3-cd)pyrene	3.1	weighted RF	847	276	NI		Quantitated versus standard
Benzo(ghi)perylene	4.1	weighted RF	874	276	Benzo(ghi)perylene	0.761	Quantitated versus standard
Coronene	3.1	weighted RF	1180	300	NI		Quantitated versus standard (best guess identification)

\*Isomers  
NI = No library match possible due to low level of compound or interference.

Table 2. Results from Analysis of Sample EL Composite

<u>Compound</u>	<u>Concentration in Original Extract (ug/ul)</u>	<u>Means of Quantitation</u>	<u>Scan No.</u>	<u>Base M/E</u>	<u>Library Identification</u>	<u>Computer D.I. Factor</u>	<u>Interpretations of Identifi- cation and Quantitation Results</u>
Napthalene	58.7	weighted RF	162	128	Napthalene	0.179	Quantitated against standard
Biphenyl	0.5	weighted RF	256	154	NI		Quantitated against standard Identified by retention time of standard
Fluorene	0.27	weighted RF	337	166	NI		Quantitated against standard Identified by retention time of standard
Anthracene	5.1	weighted RF	407	178	Anthracene	0.154	Quantitated against standard
Fluoranthene	2.1	weighted RF	497	202	Fluoranthene	0.424	Quantitated against standard
Pyrene	3.0	weighted RF	517	202	Fluoranthene	0.352	Quantitated against standard
Benzo(ghi)fluoranthene	0.6	nearest analog	645	226	NI		Quantitated versus chrysene (best guess identification)
Benzo(ghi)perylene	1.1	weighted RF	927	276	NI		Quantitated against standard (best guess identification)

NI = Library match not possible due to low level of compound or interference.

**APPENDIX B**

**METHOD OF CALCULATING  
SPECIFIC POM EMISSIONS**

Method of Calculating Specific

POM Emissions on a per-compound Basis

The nomenclature for an existing TI-59 program (based on EPA Methods 2 thru 5) for calculating particulate emissions was modified as follows:

a. The value "1" was substituted for the sample weight,  $w_t$  making the specific emission rate figure  $pmr_u$  become a factor " $f_p$ ".

$f_p$  has units of:  $\frac{lb \text{ of a given compound-emitted}/10^6 \text{ BTU}}{\text{gram of sample}}$

b. " $m_p$ " represents the weight of a given compound detected in  $\mu\text{g}$ .

c. BTU's are converted to tons of fuel (8000 BTU/lb x 2000 lb/ton) and  $\mu\text{g}$  converted to gm ( $10^6 \mu\text{g} = 1 \text{ gm}$ ) with a proportionality factor,  $K_p = 16 \times 10^{-6}$ .

d. The specific mass rate of a given compound " $pmr_p$ " is obtained by multiplying these three values together as indicated in equation 19:

$$pmr_p = m_p \times f_p \times k_p$$

e. The answer in pounds/ton can be converted to metric units (g/kg) by dividing by 2.

$$\frac{2 \text{ lb}}{\text{Ton}} = \frac{2 \text{ lb}}{2000 \text{ lb}} = \frac{1 \text{ gm}}{1000 \text{ gm}} = \frac{1 \text{ gm}}{\text{Kg}}$$

EQUATIONS

1. Absolute Pressure in Dry Gas Meter -  $P_m$  (in. Hg.)

$$P_m = P_{atm} + \frac{\Delta H}{13.6}$$

2. Absolute Stack Pressure -  $P_s$  (in. Hg.)

$$P_s = P_{atm} + \frac{P_{s(gage)}}{13.6}$$

3. Sample Volume at Standard Conditions -  $V_{mstd}$  (ft<sup>3</sup>)

$$V_{mstd} = V_m \frac{T_{std}}{T_m} \frac{P_m}{P_{std}}$$

4. Volume of Water Vapor Collected, Corrected to Standard Conditions -  $V_{vstd}$  (ft<sup>3</sup>)

$$V_{vstd} = K_2 V_{lq} \frac{T_{std}}{P_{std}} \quad K_2 = 0.00267 \text{ (units conversion)}$$

5. Total Sample Volume at Standard Conditions -  $V_{std}$  (ft<sup>3</sup>)

$$V_{std} = V_{mstd} + V_{vstd}$$

6. Percent Moisture in Stack Gas - %M

$$\%M = \frac{V_{vstd}}{V_{std}} \times 100$$

7. Mole Fraction of Dry Gas -  $M_d$

$$M_d = \frac{100 - \%M}{100}$$

8. Molecular Weight of Wet Gas -  $M$  (lb/lb mole)

$$M = (MW_d \times M_d) + 18(1 - M_d)$$

9. Stack Velocity -  $v_s$  (ft/sec)

$$v_s = K_p C_p \sqrt{\frac{T_s}{P_s M}} \frac{\Sigma \sqrt{\Delta p}}{n \Delta p}$$

$$K_p = 85.48 \text{ (units conversion factor)}$$

10. Stack Volume Flow Rate -  $Q_s$  (ft<sup>3</sup>/min)

$$Q_s = K_1 v_s A'_s \quad K_1 = 60 \text{ (units conversion)}$$

11. Stack Volume Flow Rate at Standard Conditions -  $Q_{std}$  (ft<sup>3</sup>/min)

$$Q_{std} = \frac{T_{std}}{P_{std}} \frac{P_s}{T_s} Q_s$$

12. Pollutant Mass Rate Based on Particulate Concentration -  $pmr_c$  (lb/hr)

$$pmr_c = K_3 \frac{W_t Q_{std}}{V_{std}} \quad K_3 = 0.1323 \text{ (units conversion)}$$

13. Pollutant Mass Rate Based on the Ratio of the Cross Sectional Area of the Stack and the Sampling Nozzle -  $pmr_a$  (lb/hr)

$$pmr_a = K_3 \frac{W_t A_s}{\theta A_n} \quad K_3 = 0.1323 \text{ (units conversion)}$$

14. Percent Isokineticity - %I

$$\%I = \frac{pmr_a}{pmr_c} \times 100$$

15. Average Pollutant Mass Rate -  $pmr_{avg}$  (lb/hr)

$$pmr_{avg} = \frac{pmr_a + pmr_c}{2}$$

16. Percent Excess Air - %EA

$$\%EA = \frac{\%O_2 - .5(\%CO)}{.264(\%N_2) - \%O_2 + .5(\%CO)} \quad (100)$$

17. Heat Input Rate - HI (10<sup>6</sup> BTU/hr)

$$HI = \frac{60 Q_{std} M_d}{F(100 + \%EA)} \quad (100)$$

18. Specific Emission Rate -  $pmr_u$  (lb/10<sup>6</sup> BTU)

$$pmr_u = \frac{pmr_{avg}}{HI}$$

19. Mass rate of a specific POM (or PNA) -  $pmr_p$  (lb/Ton)

$$pmr_p = m_p \times f_p \times k_p$$

Where:

$m_p$  = mass of specific chemical (POM)  
detected ( $\mu\text{g}$ )

$f_p$  = factor (or multiplier) for a given  
run, obtained by substituting 1  
for  $W_t$  in Equations 12 & 13  
(  $\text{lb/g} \cdot 10^6 \text{BTU}$  )

$k_p$  = proportionality and units correction  
factor (  $16 \times 10^{-6} \text{BTU} \cdot \text{g}/\mu\text{g} \cdot \text{Ton}$  )

**APPENDIX C**  
**NOMENCLATURE**

NOMENCLATURE

$A_n$	(in <sup>2</sup> ), Cross sectional area of nozzle
$A_s$	(in <sup>2</sup> ), Cross sectional area of stack
$A'_s$	(ft <sup>2</sup> ), Cross sectional area of stack
$C_p$	Pitot tube calibration coefficient
%EA	Percent Excess Air
F	(scfd/10 <sup>6</sup> BTU), F factor
$\Delta H$	(in H <sub>2</sub> O), Average orifice meter reading
HI	(10 <sup>6</sup> BTU/hr), Heat Input Rate
%I	Percent Isokineticity
M	(lb/lb mole), Molecular Weight of wet gas
%M	Percent Moisture
$M_d$	Mole fraction of dry gas
MW <sub>d</sub>	(lb/lb mole) Molecular weight of dry gas
$n_{\Delta p}$	Number of $\Delta p$ readings
$P_{atm}$	(in Hg), Local atmospheric pressure
$P_m$	(in Hg), Absolute pressure in dry gas meter
$P_s$	(in Hg), Absolute stack pressure
$P_{s(gage)}$	(in H <sub>2</sub> O), Measured static stack pressure
$P_{std}$	(29.92 in Hg), Standard pressure
$pmr_a$	(lb/hr), Pollutant mass rate based on ratio of areas
$pmr_{avq}$	(lb/hr), Average pollutant mass rate
$pmr_c$	(lb/hr), Pollutant mass rate based on concentration
$pmr_u$	(lb/10 <sup>6</sup> BTU), Specific emission rate
$\Delta p$	(in H <sub>2</sub> O), Velocity pressure
$Q_s$	(ft <sup>3</sup> /min), Actual stack volume flow rate
$Q_{std}$	(ft <sup>3</sup> /min), Stack volume flow rate at standard conditions

- $T_m$  ( $^{\circ}R$ ), Average dry gas meter temperature
- $T_s$  ( $^{\circ}R$ ), Average stack temperature
- $T_{std}$  ( $530^{\circ}R$ ), Standard temperature
- $V_{lq}$  (ml), Liquid volume
- $V_m$  ( $ft^3$ ), Sample volume measured by dry gas meter
- $V_{mstd}$  ( $ft^3$ ), Sample volume at standard conditions
- $V'_{std}$  ( $ft^3$ ), Total sample volume at standard conditions
- $V_{vstd}$  ( $ft^3$ ), Volume of water vapor collected, corrected to standard conditions
- $v_s$  (ft/sec), Stack velocity
- $W_t$  (gm), Total weight of particulate collected
- $\theta$  (min), Duration of test

**APPENDIX D**

**TEST K**

Calculation Summary  
Polycyclic Organic Materials

SOURCE K Date 4-8-81  
LOCATION \_\_\_\_\_ Test Point Boiler Stack

ENTRY	RUN <u>1</u>	RUN <u>2</u>	RUN <u>3</u>	ANSWER
Ave. ΔH (in H <sub>2</sub> O)	2.1900	1.9700	2.3700	
Patm (in Hg)	30.4800	30.3900	30.3400	P <sub>m</sub> (in Hg)
	30.6410	30.5349	30.5143	
P <sub>s</sub> (gage)(in H <sub>2</sub> O)	-0.0200	-0.0200	-0.0200	P <sub>s</sub> (in Hg)
	30.4785	30.3885	30.3385	
T <sub>m</sub> (°R)	551.0000	547.0000	543.0000	
V <sub>m</sub> (ft <sup>3</sup> )	63.8940	60.8100	67.1750	V <sub>mstd</sub> (ft <sup>3</sup> )
	62.9260	60.1177	66.8543	
V <sub>lq</sub> (ml)	124.0000	108.5000	111.7000	
	5.8652	5.1321	5.2834	V <sub>vstd</sub> (ft <sup>3</sup> )
	68.7912	65.2497	72.1377	V <sub>std</sub> (ft <sup>3</sup> )
	8.5261	7.8652	7.3241	Z <sub>M</sub>
	0.9147	0.9213	0.9268	M <sub>d</sub>
MW <sub>d</sub>	29.5700	29.5300	29.4600	
	28.5835	28.6231	28.6207	M
T <sub>s</sub> (°R)	1010.0000	998.0000	979.0000	
Σ√Δp	10.4778	9.7355	10.2681	
nΔp	40.0000	40.0000	40.0000	Ave √Δp
	0.2619	0.2434	0.2567	
C <sub>p</sub>	0.8400	0.8400	0.8400	v <sub>s</sub> (ft/sec)
	20.2516	18.7195	19.5717	
D <sub>s</sub> (in)	29.5000	29.5000	29.5000	
	4.7465	4.7465	4.7465	A <sub>s</sub> (ft <sup>2</sup> )
	5767.	5331.	5574.	Q <sub>s</sub> (ft <sup>3</sup> /min)
	3082.	2875.	3059.	Q <sub>std</sub> (ft <sup>3</sup> /min)
Unity substitution	1.0000	1.0000	1.0000	
	5.9279	5.8290	5.6102	pmr <sub>c</sub> (lb/hr)
D <sub>n</sub> (in)	0.4900	0.4910	0.4990	
	0.1886	0.1893	0.1956	A <sub>n</sub> (in <sup>2</sup> )
θ (min)	80.0000	80.0000	80.0000	
	5.9941	5.9697	5.7798	pmr <sub>a</sub> (lb/hr)
	101.1164	102.4131	103.0230	Z <sub>I</sub>
	5.9610	5.8993	5.6950	pmr <sub>avg</sub> Multiplier
ZCO	0.0000	0.0000	0.0000	
ZO <sub>2</sub>	13.7300	14.9300	15.6000	
ZN <sub>2</sub>	79.8300	79.2700	79.1700	
	186.9268	248.9462	294.2908	Z <sub>EA</sub>
F Factor	9280.0000	9280.0000	9280.0000	
	6.3534	4.9078	4.6487	HI (10 <sup>6</sup> BTU/hr.)
	0.9382	1.2020	1.2251	f <sub>p</sub> (lb/g·10 <sup>6</sup> RTU)

Calculation Summary

SOURCE     K     Date     4-8-81    

LOCATION \_\_\_\_\_

ENTRY	RUN 1	RUN 2	RUN 3	ANSWER
Ave. $\Delta H$ (in H <sub>2</sub> O)	2.1900	1.9700	2.3700	
$P_{atm}$ (in Hg)	30.4800	30.3900	30.3400	
$P_g$ (gage) (in H <sub>2</sub> O)	30.6410	30.5349	30.5143	$P_m$ (in Hg)
	-0.0200	-0.0200	-0.0200	
$T_m$ (°R)	30.4785	30.3885	30.3385	$P_g$ (in Hg)
$V_m$ (ft <sup>3</sup> )	551.0000	547.0000	543.0000	
	63.8940	60.8100	67.1750	
$V_{1q}$ (ml)	62.9260	60.1177	66.8543	$V_{mstd}$ (ft <sup>3</sup> )
	124.0000	108.5000	111.7000	
	5.8652	5.1321	5.2834	$V_{vstd}$ (ft <sup>3</sup> )
	68.7912	65.2497	72.1377	$V_{std}$ (ft <sup>3</sup> )
	8.5261	7.8652	7.3241	$\Sigma M$
	0.9147	0.9213	0.9268	$M_d$
$MW_d$	29.5700	29.5300	29.4600	
	28.5835	28.6231	28.6207	$M$
$T_g$ (°R)	1010.0000	998.0000	979.0000	
$\Sigma \sqrt{\Delta p}$	10.4778	9.7355	10.2681	
$n_{\Delta p}$	40.0000	40.0000	40.0000	
$C_p$	0.2619	0.2434	0.2567	Ave $\sqrt{\Delta p}$
	0.8400	0.8400	0.8400	
$D_g$ (in)	20.2516	18.7195	19.5717	$v_s$ (ft/sec)
	29.5000	29.5000	29.5000	
	4.7465	4.7465	4.7465	$A_s$ (ft <sup>2</sup> )
	5767.	5331.	5574.	$Q_g$ (ft <sup>3</sup> /min)
$W_t$ (gm)	3082.	2875.	3059.	$Q_{std}$ (ft <sup>3</sup> /min)
	0.3869	0.2572	0.2134	
	2.2935	1.4992	1.1972	$pmr_c$ (lb/hr)
$D_n$ (in)	0.4900	0.4910	0.4990	
	0.1886	0.1893	0.1956	$A_n$ (in <sup>2</sup> )
$\theta$ (min)	80.0000	80.0000	80.0000	
	2.3191	1.5354	1.2334	$pmr_a$ (lb/hr)
	101.1164	102.4131	103.0230	$\Sigma I$
	2.3063	1.5173	1.2153	$pmr_{avg}$ (lb/hr)
$\Sigma CO$	0.0000	0.0000	0.0000	
$\Sigma O_2$	13.7300	14.9300	15.6000	
$\Sigma N_2$	79.8300	79.2700	79.1700	
	186.9268	248.9462	294.2908	$\Sigma EA$
F Factor	9280.0000	9280.0000	9280.0000	
	6.3534	4.9078	4.6487	HI (10 <sup>6</sup> BTU/hr.)
	0.3630	0.3092	0.2614	$pmr_u$ (lbs/10 <sup>6</sup> BTU)

SUMMARY OF ANALYTICAL VALUES FOR  
PARTICULATE DETERMINATION

	RUN <u>K1</u>	RUN <u>K2</u>	RUN <u>K3</u>
A. Particulate			
(1) CH <sub>2</sub> Cl <sub>2</sub> Wash, Parts 1 & 2 (RTI)	<u>.3869g</u>	<u>.2572g</u>	<u>.2134g</u>
(2) Acetone Scrub, Part 1 (Cary Lab)	<u>—</u>	<u>—</u>	<u>—</u>
TOTAL	<u>.3869g</u>	<u>.2572g</u>	<u>.2134g</u>
B. Moisture Collected			
(1) Part 5 (Catch Bottle)	<u>76 ml</u>	<u>69 ml</u>	<u>76 ml</u>
(2) Part 6 (Impingers)	<u>30 ml</u>	<u>20 ml</u>	<u>15 ml</u>
(3) Part 7 (Silica Gel)	<u>18 g</u>	<u>19.5g</u>	<u>20.7 ml</u>
TOTAL	<u>124 ml</u>	<u>108.5 ml</u>	<u>111.7 ml</u>

APPENDIX E

TEST EA

Calculation Summary  
Polycyclic Organic Materials

SOURCE EA Date 4/15/81  
LOCATION \_\_\_\_\_ Test Point Stack

ENTRY	RUN <u>EA1</u>	RUN <u>EA2</u>	RUN _____	ANSWER
Ave. $\Delta H$ (in $H_2O$ )	1.2880	1.1100		
$P_{atm}$ (in Hg)	28.9500	28.8500		
$P_g$ (gage) (in $H_2O$ )	29.0447	28.9316		$P_m$ (in Hg)
	0.0200	0.0200		
	28.9515	28.8515		$P_g$ (in Hg)
$T_m$ ( $^{\circ}R$ )	553.0000	561.0000		
$V_m$ (ft <sup>3</sup> )	56.8990	54.8320		
	52.9255	50.0798		$V_{mstd}$ (ft <sup>3</sup> )
$V_{lq}$ (ml)	57.5000	53.3000		
	2.7198	2.5211		$V_{vstd}$ (ft <sup>3</sup> )
	55.6453	52.6009		$V_{std}$ (ft <sup>3</sup> )
	4.8877	4.7929		$\Sigma M$
	0.9511	0.9521		$M_d$
$MW_d$	29.3700	29.2600		
	28.8143	28.7203		$M$
$T_g$ ( $^{\circ}R$ )	777.0000	769.0000		
$\Sigma \sqrt{\Delta p}$	19.9164	19.3124		
$n_{\Delta p}$	48.0000	48.0000		Ave $\sqrt{\Delta p}$
$C_p$	0.4149	0.4023		
	0.8400	0.8400		$v_s$ (ft/sec)
$D_g$ (in)	28.7531	27.8306		
	47.5000	47.5000		$A_s$ (ft <sup>2</sup> )
	12.3059	12.3059		$Q_s$ (ft <sup>3</sup> /min)
	21230.	20549.		$Q_{std}$ (ft <sup>3</sup> /min)
	14009.	13654.		
inity substitution	1.0000	1.0000	1.0000	
	33.3081	34.3413		$pmr_c$ (lb/hr)
$D_n$ (in)	0.3050	0.3070		
	0.0731	0.0740		$A_n$ (in <sup>2</sup> )
$\theta$ (min)	96.0000	96.0400		
	33.4254	32.9775		$pmr_a$ (lb/hr)
	100.3519	96.0289		%I
	33.3668	33.6594		$pmr_{avg}$ Multiplier
$\Sigma CO$	0.0000	0.0000		
$\Sigma O_2$	16.3000	17.2000		
$\Sigma N_2$	79.2000	79.2000		
	353.6712	463.7619		$\Sigma EA$
F Factor	9430.0000	9430.0000		
	18.6876	14.6711		HI (10 <sup>6</sup> BTU/hr.)
	<b>1.7855</b>	<b>2.2943</b>		$f_p$ (lb/g·10 <sup>6</sup> BTU)

Calculation Summary  
Polycyclic Organic Materials

SOURCE EA Date 4/16/81  
LOCATION \_\_\_\_\_ Test Point Stack

ENTRY	RUN <u>EA3</u>	RUN <u>EA4</u>	RUN _____	ANSWER
Ave. $\Delta H$ (in H <sub>2</sub> O)	0.9670	1.2000		
$P_{atm}$ (in Hg)	28.9500	28.8500		
$P_g$ (gage) (in H <sub>2</sub> O)	29.0211	28.9382		$P_m$ (in Hg)
$T_m$ (°R)	0.0200	0.0200		$P_s$ (in Hg)
$V_m$ (ft <sup>3</sup> )	28.9515	28.8515		
$V_{1q}$ (ml)	541.0000	543.0000		
	49.6260	56.0920		$V_{mstd}$ (ft <sup>3</sup> )
	47.1460	52.9409		$V_{vstd}$ (ft <sup>3</sup> )
	122.5000	93.5000		$V_{std}$ (ft <sup>3</sup> )
	5.7943	4.4226		$Z_M$
	52.9402	57.3635		$M_d$
	10.9449	7.7097		
	0.8906	0.9229		
$MW_d$	29.8200	29.5800		$M$
$T_s$ (°R)	28.5263	28.6872		
$\Sigma \sqrt{\Delta p}$	758.0000	767.0000		
$n \Delta p$	17.4231	19.8914		Ave $\sqrt{\Delta p}$
$C_p$	48.0000	48.0000		
$D_s$ (in)	0.3630	0.4144		$v_s$ (ft/sec)
	0.8400	0.8400		
	24.9692	28.6442		
	47.5000	47.5000		$A_s$ (ft <sup>2</sup> )
	12.3059	12.3059		$Q_s$ (ft <sup>3</sup> /min)
	18436.	21150.		$Q_{std}$ (ft <sup>3</sup> /min)
	12471.	14089.		
Unity substitution	1.0000	1.0000	1.0000	$pmr_c$ (lb/hr)
$D_n$ (in)	31.1648	32.4952		
	0.3070	0.3050		$A_n$ (in <sup>2</sup> )
$\theta$ (min)	0.0740	0.0731		
	96.0000	96.0000		$pmr_a$ (lb/hr)
	32.9913	33.4254		%I
	105.8607	102.8626		$pmr_{avg}$ Multiplie
	32.0780	32.9603		
ZCO	0.0000	0.0000		
ZO <sub>2</sub>	12.4000	14.3000		
ZN <sub>2</sub>	79.3000	79.4000		%EA
F Factor	145.2807	214.6631		
	9430.0000	9430.0000		HI (10 <sup>6</sup> BTU/hr.)
	28.8088	26.2932		$f_p$ (lb/g·10 <sup>6</sup> BTU)
	1.1135	1.2536		

Particulate Emission  
Calculation Summary

SOURCE EA Date 4/15/81

LOCATION \_\_\_\_\_

ENTRY	RUN EA1	RUN EA2	<del>RUN 9</del>	ANSWER
Ave. ΔH (in H <sub>2</sub> O)	1.2880	1.1100		
P <sub>atm</sub> (in Hg)	28.9500	28.8500		
	29.0447	28.9316		P <sub>m</sub> (in Hg)
P <sub>g</sub> (gage)(in H <sub>2</sub> O)	0.0200	0.0200		
	28.9515	28.8515		P <sub>s</sub> (in Hg)
T <sub>m</sub> (°R)	553.0000	561.0000		
V <sub>m</sub> (ft <sup>3</sup> )	56.8990	54.8320		
	52.9255	50.0798		V <sub>mstd</sub> (ft <sup>3</sup> )
V <sub>lq</sub> (ml)	57.5000	53.3000		
	2.7198	2.5211		V <sub>vstd</sub> (ft <sup>3</sup> )
	55.6453	52.6009		V <sub>std</sub> (ft <sup>3</sup> )
	4.8877	4.7929		%M
	0.9511	0.9521		M <sub>d</sub>
MW <sub>d</sub>	29.3700	29.2600		
	28.8143	28.7203		M
T <sub>s</sub> (°R)	777.0000	769.0000		
Σ√Δp	19.9164	19.3124		
nΔp	48.0000	48.0000		Ave √Δp
C <sub>p</sub>	0.4149	0.4023		
	0.8400	0.8400		v <sub>s</sub> (ft/sec)
D <sub>s</sub> (in)	28.7531	27.8306		
	47.5000	47.5000		A <sub>s</sub> (ft <sup>2</sup> )
	12.3059	12.3059		Q <sub>s</sub> (ft <sup>3</sup> /min)
	21230.	20549.		Q <sub>std</sub> (ft <sup>3</sup> /min)
W <sub>t</sub> (gm)	14009.	13654.		
	0.1715	0.2162		pmr <sub>c</sub> (lb/hr)
	5.7123	7.4246		
D <sub>n</sub> (in)	0.3050	0.3070		A <sub>n</sub> (in <sup>2</sup> )
	0.0731	0.0740		
θ (min)	96.0000	96.0400		pmr <sub>a</sub> (lb/hr)
	5.7325	7.1297		%I
	100.3519	96.0289		pmr <sub>avg</sub> (lb/hr)
	5.7224	7.2772		
XCO	0.0000	0.0000		%EA
XO <sub>2</sub>	16.3000	17.2000		
XN <sub>2</sub>	79.2000	79.2000		
	353.6712	463.7619		
F Factor	9430.0000	9430.0000		HI (10 <sup>6</sup> BTU/hr.)
	18.6876	14.6711		pmr <sub>u</sub> (lbs/10 <sup>6</sup> BTU)
	0.3062	0.4960		

0.4011  
TEST AVG.

- E4 -  
 Particulate Emission  
 Calculation Summary

Appendix E

SOURCE EA Date 4/16/81  
 LOCATION \_\_\_\_\_

ENTRY	RUN <del>EA3</del>	RUN <del>EA1</del>	<del>RUN 3</del>	ANSWER
Ave. ΔH (in H <sub>2</sub> O)	0.9670	1.2000		
P <sub>atm</sub> (in Hg)	28.9500	28.8500		
P <sub>s</sub> (gage) (in H <sub>2</sub> O)	0.0200	0.0200		P <sub>m</sub> (in Hg)
T <sub>m</sub> (°R)	541.0000	543.0000		P <sub>s</sub> (in Hg)
V <sub>m</sub> (ft <sup>3</sup> )	49.6260	56.0920		V <sub>mstd</sub> (ft <sup>3</sup> )
V <sub>lq</sub> (ml)	47.1460	52.9409		V <sub>vstd</sub> (ft <sup>3</sup> )
	122.5000	93.5000		V <sub>std</sub> (ft <sup>3</sup> )
	5.7943	4.4226		ZM
	52.9402	57.3635		M <sub>d</sub>
	10.9449	7.7097		
	0.8906	0.9229		
MW <sub>d</sub>	29.8200	29.5800		M
T <sub>s</sub> (°R)	28.5263	28.6872		
Σ√Δp	758.0000	767.0000		
nΔp	17.4231	19.8914		
C <sub>p</sub>	48.0000	48.0000		Ave √Δp
D <sub>s</sub> (in)	0.3630	0.4144		
	0.8400	0.8400		v <sub>s</sub> (ft/sec)
	24.9692	28.6442		
	47.5000	47.5000		A <sub>s</sub> (ft <sup>2</sup> )
	12.3059	12.3059		Q <sub>s</sub> (ft <sup>3</sup> /min)
	18436.	21150.		Q <sub>std</sub> (ft <sup>3</sup> /min)
W <sub>t</sub> (gm)	12471.	14089.		
	0.4055	0.5086		pmr <sub>c</sub> (lb/hr)
	12.6373	16.5270		
	0.3070	0.3050		A <sub>n</sub> (in <sup>2</sup> )
	0.0740	0.0731		
	96.0000	96.0000		pmr <sub>a</sub> (lb/hr)
	13.3780	17.0001		%I
	105.8607	102.8626		pmr <sub>avg</sub> (lb/hr)
	13.0076	16.7636		
ZCO	0.0000	0.0000		
ZO <sub>2</sub>	12.4000	14.3000		
ZN <sub>2</sub>	79.3000	79.4000		
	145.2807	214.6631		ZEA
F Factor	9430.0000	9430.0000		
	28.8088	26.2932		HI (10 <sup>6</sup> BTU/hr.)
	0.4515	0.6376		pmr <sub>u</sub> (lbs/10 <sup>6</sup> BTU)

0.5446  
 TEST AVG.

SUMMARY OF ANALYTICAL VALUES FOR  
PARTICULATE DETERMINATION

	RUN <u>EA1</u>	RUN <u>EA2</u>	RUN <u>EA3</u>	RUN <u>EA4</u>
A. Particulate				
(1) CH <sub>2</sub> Cl <sub>2</sub> Wash, Parts 1 & 2 (RTI)	<u>0.1633</u>	<u>0.1972</u>	<u>0.3973</u>	<u>0.4969</u>
(2) Acetone Scrub, Part 1 (Cary Lab)	<u>0.0082</u>	<u>0.0190</u>	<u>0.0082</u>	<u>0.0117</u>
TOTAL	<u>0.1715 gm.</u>	<u>0.2162 gm.</u>	<u>0.4055 gm.</u>	<u>0.5086 gm.</u>
B. Moisture Collected				
(1) Part 5 (Catch Bottle)	<u>31</u>	<u>30</u>	<u>90</u>	<u>70</u>
(2) Part 6 (Impingers)	<u>16</u>	<u>10</u>	<u>20</u>	<u>10</u>
(3) Part 7 (Silica Gel)	<u>15.5</u>	<u>13.3</u>	<u>12.5</u>	<u>13.5</u>
TOTAL	<u>57.5 ml</u>	<u>53.3 ml</u>	<u>122.5 ml</u>	<u>93.5 ml</u>

**APPENDIX F**

**TEST BP**

Calculation Summary  
Polycyclic Organic Materials

SOURCE BP (POM-3) Date 4/29/81  
LOCATION \_\_\_\_\_ Test Point Stack

ENTRY	RUN <u>BP1</u>	RUN <u>BP2</u>	RUN _____	ANSWER
Ave. ΔH (in H <sub>2</sub> O)	1.4600	1.4200		
P <sub>atm</sub> (in Hg)	29.0400	29.0100		
P <sub>s</sub> (gage)(in H <sub>2</sub> O)	29.1474	29.1144		P <sub>m</sub> (in Hg)
	-0.4500	-0.4500		
	29.0069	28.9769		P <sub>s</sub> (in Hg)
T <sub>m</sub> (°R)	567.0000	569.0000		
V <sub>m</sub> (ft <sup>3</sup> )	64.8090	64.5540		
V <sub>lq</sub> (ml)	59.0024	58.4975		V <sub>mstd</sub> (ft <sup>3</sup> )
	87.0000	89.0000		
	4.1151	4.2097		V <sub>vstd</sub> (ft <sup>3</sup> )
	63.1175	62.7072		V <sub>std</sub> (ft <sup>3</sup> )
	6.5197	6.7133		%M
	0.9348	0.9329		M <sub>d</sub>
MW <sub>d</sub>	29.7300	29.7000		
	28.9652	28.9145		M
T <sub>s</sub> (°R)	989.0000	979.0000		
Σ√Δp	37.1089	36.3657		
nΔp	48.0000	48.0000		Ave √Δp
C <sub>p</sub>	0.7731	0.7576		
	0.8400	0.8400		v <sub>s</sub> (ft/sec)
D <sub>s</sub> (in)	60.2268	58.8033		
	35.8200	35.8200		A <sub>s</sub> (ft <sup>2</sup> )
	6.9981	6.9981		Q <sub>s</sub> (ft <sup>3</sup> /min)
	25288.	24691.		Q <sub>std</sub> (ft <sup>3</sup> /min)
	13135.	12943.		
Unity substitution	1.0000	1.0000	1.0000	
	27.5330	27.3062		pmr <sub>c</sub> (lb/hr)
D <sub>n</sub> (in)	0.2500	0.2470		
	0.0491	0.0479		A <sub>n</sub> (in <sup>2</sup> )
θ (min)	96.0000	96.0000		
	28.2917	28.9832		pmr <sub>a</sub> (lb/hr)
	102.7559	106.1413		%I
	27.9124	28.1447		pmr <sub>avg</sub> Multiplier
XCO	0.0000	0.0000		
XO <sub>2</sub>	13.3000	13.8000		
XN <sub>2</sub>	79.2000	79.0000		
	174.7976	195.5782		%EA
F Factor	9430.0000	9430.0000		
	28.4308	25.9900		HI (10 <sup>6</sup> BTU/hr.)
	<b>0.9818</b>	<b>1.0829</b>		f <sub>p</sub> (lb/g·10 <sup>6</sup> BTU)
				see equation 19

Particulate Emission  
Calculation Summary

SOURCE BP POM-3 Date 4/29/81  
LOCATION \_\_\_\_\_

ENTRY	RUN 1	RUN 2	RUN 3	ANSWER
Ave. $\Delta H$ (in H <sub>2</sub> O)	1.4600	1.4200		
P <sub>atm</sub> (in Hg)	29.0400	29.0100		
P <sub>s</sub> (gage) (in H <sub>2</sub> O)	29.1474	29.1144		P <sub>m</sub> (in Hg)
	-0.4500	-0.4500		
T <sub>m</sub> (°R)	29.0069	28.9769		P <sub>s</sub> (in Hg)
V <sub>m</sub> (ft <sup>3</sup> )	567.0000	569.0000		
V <sub>lq</sub> (ml)	64.8090	64.5540		V <sub>mstd</sub> (ft <sup>3</sup> )
	59.0024	58.4975		
	87.0000	89.0000		V <sub>vstd</sub> (ft <sup>3</sup> )
	4.1151	4.2097		V <sub>std</sub> (ft <sup>3</sup> )
	63.1175	62.7072		%M
	6.5197	6.7133		M <sub>d</sub>
	0.9348	0.9329		
MW <sub>d</sub>	29.7300	29.7000		M
T <sub>s</sub> (°R)	28.9652	28.9145		
$\Sigma \sqrt{\Delta p}$	989.0000	979.0000		Ave $\sqrt{\Delta p}$
n $\Delta p$	37.1089	36.3657		
C <sub>p</sub>	48.0000	48.0000		v <sub>s</sub> (ft/sec)
D <sub>s</sub> (in)	0.7731	0.7576		
	0.8400	0.8400		A <sub>s</sub> (ft <sup>2</sup> )
	60.2268	58.8033		Q <sub>s</sub> (ft <sup>3</sup> /min)
	35.8200	35.8200		Q <sub>std</sub> (ft <sup>3</sup> /min)
	6.9981	6.9981		
W <sub>t</sub> (gm)	25288.	24691.		pmr <sub>c</sub> (lb/hr)
	13135.	12943.		
	0.3642	0.3267		A <sub>n</sub> (in <sup>2</sup> )
D <sub>n</sub> (in)	10.0275	8.9209		
	0.2500	0.2470		pmr <sub>a</sub> (lb/hr)
	0.0491	0.0479		%I
$\theta$ (min)	96.0000	96.0000		pmr <sub>avg</sub> (lb/hr)
	10.3039	9.4688		
	102.7559	106.1413		ZEA
ZCO	10.1657	9.1949		
ZO <sub>2</sub>	0.0000	0.0000		HI (10 <sup>6</sup> BTU/hr.)
ZN <sub>2</sub>	13.3000	13.8000		pmr <sub>u</sub> (lbs/10 <sup>6</sup> BTU)
	79.2000	79.0000		
F Factor	174.7976	195.5782		
	9430.0000	9430.0000		
	28.4308	25.9900		
	0.3576	0.3538		

0.3557

TEST AVG.

- F3 -

SUMMARY OF ANALYTICAL VALUES FOR  
PARTICULATE DETERMINATION

	RUN <u>BP1</u>	RUN <u>BP2</u>	RUN <u>    </u>
A. Particulate			
(1) CH <sub>2</sub> Cl <sub>2</sub> Wash, Parts 1 & 2 (RTI)	<u>0.3128</u>	<u>0.2510</u>	<u>    </u>
(2) Acetone Scrub, Part 1 (Cary Lab)	<u>0.0514</u>	<u>0.0757</u>	<u>    </u>
TOTAL	<u>0.3642 gm.</u>	<u>0.3267 gm.</u>	<u>    </u>
B. Moisture Collected			
(1) Part 5 (Catch Bottle)	<u>46</u>	<u>44</u>	<u>    </u>
(2) Part 6 (Impingers)	<u>23</u>	<u>29</u>	<u>    </u>
(3) Part 7 (Silica Gel)	<u>18</u>	<u>16</u>	<u>    </u>
TOTAL	<u>87 ml</u>	<u>89 ml</u>	<u>    </u>

APPENDIX G

TEST HH

Calculation Summary  
Polycyclic Organic Materials

SOURCE HH Date 5/13-14/81

LOCATION \_\_\_\_\_ Test Point Multifluore  
Outlet

ENTRY	RUN <u>HH1</u>	RUN <u>HH2</u>	RUN <u>HH3</u>	ANSWER
Ave. $\Delta H$ (in H <sub>2</sub> O)	2.3000	1.2030	1.2530	
$P_{atm}$ (in Hg)	29.2400	29.2000	29.0200	
$P_s$ (gage) (in H <sub>2</sub> O)	29.4091	29.2885	29.1121	$P_m$ (in Hg)
	-0.0700	-0.0700	-0.0700	
	29.2349	29.1949	29.0149	$P_s$ (in Hg)
$T_m$ (°R)	553.0000	551.0000	556.0000	
$V_m$ (ft <sup>3</sup> )	48.9500	56.4610	60.1800	
	46.1029	53.1511	55.8046	$V_{mstd}$ (ft <sup>3</sup> )
$V_{lq}$ (ml)	87.1000	99.9000	110.0000	
	4.1198	4.7253	5.2030	$V_{vstd}$ (ft <sup>3</sup> )
	50.2227	57.8763	61.0076	$V_{std}$ (ft <sup>3</sup> )
	8.2031	8.1644	8.5284	$ZM$
	0.9180	0.9184	0.9147	$M_d$
$MW_d$	29.8700	29.6300	29.9500	
	28.8963	28.6805	28.9309	$M$
$T_s$ (°R)	758.0000	759.0000	757.0000	
$\Sigma \sqrt{\Delta p}$	4.8298	9.9551	10.1151	
$n \Delta p$	12.0000	24.0000	24.0000	
$C_p$	0.4025	0.4148	0.4215	Ave $\sqrt{\Delta p}$
	0.8400	0.8400	0.8400	
$D_s$ (in)	27.3750	28.3565	28.7382	$v_s$ (ft/sec)
	19.0000	19.0000	19.0000	
	1.9689	1.9689	1.9689	$A_s$ (ft <sup>2</sup> )
	3234.	3350.	3395.	$Q_s$ (ft <sup>3</sup> /min)
	2209.	2282.	2305.	$Q_{std}$ (ft <sup>3</sup> /min)
inity substitution	1.0000	1.0000	1.0000	
	5.8190	5.2165	4.9976	$pmr_c$ (lb/hr)
$D_n$ (in)	0.3750	0.3080	0.3080	
	0.1104	0.0745	0.0745	$A_n$ (in <sup>2</sup> )
$\theta$ (min)	60.0000	96.0000	96.0000	
	5.6605	5.2444	5.2444	$pmr_a$ (lb/hr)
	97.2753	100.5342	104.9372	$ZI$
	5.7398	5.2304	5.1210	$pmr_{avg}$ Multiplier
$ZCO$	0.0000	0.0000	0.0000	
$ZO_2$	11.8000	14.2000	10.9500	
$ZN_2$	79.4700	79.1300	79.5500	
	128.5392	212.2469	108.9422	$ZEA$
F Factor	9280.0000	9280.0000	9280.0000	
	5.7367	4.3395	6.5231	$HI$ (10 <sup>6</sup> BTU/hr.)
	1.0005	1.2053	0.7851	$f_p$ (lb/g·10 <sup>6</sup> BTU)

Calculation Summary

SOURCE HH Date 5/13/14/81

LOCATION \_\_\_\_\_

ENTRY	RUN 1	RUN 2	RUN 3	ANSWER
Ave. $\Delta H$ (in H <sub>2</sub> O) <input type="checkbox"/>	2.3000	1.2030	1.2530	
$P_{atm}$ (in Hg) <input type="checkbox"/>	29.2400	29.2000	29.0200	
$P_s$ (gage) (in H <sub>2</sub> O) <input type="checkbox"/>	29.4091	29.2885	29.1121	$P_m$ (in Hg)
	-0.0700	-0.0700	-0.0700	
	29.2349	29.1949	29.0149	$P_s$ (in Hg)
$T_m$ (°R) <input type="checkbox"/>	553.0000	551.0000	556.0000	
$V_m$ (ft <sup>3</sup> ) <input type="checkbox"/>	48.9500	56.4610	60.1800	
	46.1029	53.1511	55.8046	$V_{mstd}$ (ft <sup>3</sup> )
$V_{lq}$ (ml) <input type="checkbox"/>	87.1000	99.9000	110.0000	
	4.1198	4.7253	5.2030	$V_{vstd}$ (ft <sup>3</sup> )
	50.2227	57.8763	61.0076	$V_{std}$ (ft <sup>3</sup> )
	8.2031	8.1644	8.5284	$ZM$
	0.9180	0.9184	0.9147	$M_d$
$MW_d$ <input type="checkbox"/>	29.8700	29.6300	29.9500	
	28.8963	28.6805	28.9309	$M$
$T_s$ (°R) <input type="checkbox"/>	758.0000	759.0000	757.0000	
$\Sigma \sqrt{\Delta p}$ <input type="checkbox"/>	4.8298	9.9551	10.1151	
$n_{\Delta p}$ <input type="checkbox"/>	12.0000	24.0000	24.0000	Ave $\sqrt{\Delta p}$
$C_p$ <input type="checkbox"/>	0.4025	0.4148	0.4215	
	0.8400	0.8400	0.8400	$v_s$ (ft/sec)
$D_s$ (in) <input type="checkbox"/>	27.3750	28.3565	28.7382	
	19.0000	19.0000	19.0000	
	1.9689	1.9689	1.9689	$A_s$ (ft <sup>2</sup> )
	3234.	3350.	3395.	$Q_s$ (ft <sup>3</sup> /min)
$W_t$ (gm) <input type="checkbox"/>	2209.	2282.	2305.	$Q_{std}$ (ft <sup>3</sup> /min)
	0.2915	0.2853	0.2812	
	1.6962	1.4883	1.4053	$pmr_c$ (lb/hr)
$D_n$ (in) <input type="checkbox"/>	0.3750	0.3080	0.3080	
	0.1104	0.0745	0.0745	$A_n$ (in <sup>2</sup> )
$\theta$ (min) <input type="checkbox"/>	60.0000	96.0000	96.0000	
	1.6500	1.4962	1.4747	$pmr_a$ (lb/hr)
	97.2753	100.5342	104.9372	$ZI$
	1.6731	1.4922	1.4400	$pmr_{avg}$ (lb/hr)
$Z_{CO}$ <input type="checkbox"/>	0.0000	0.0000	0.0000	
$Z_{O_2}$ <input type="checkbox"/>	11.8000	14.2000	10.9500	
$Z_{N_2}$ <input type="checkbox"/>	79.4700	79.1300	79.5500	
	128.5392	212.2469	108.9422	$ZEA$
F Factor <input type="checkbox"/>	9280.0000	9280.0000	9280.0000	
	5.7367	4.3395	6.5231	$HI$ (10 <sup>6</sup> BTU/hr)
	0.2917	0.3439	0.2208	$pmr_u$ (lbs/10 <sup>6</sup> BTU)

SUMMARY OF ANALYTICAL VALUES FOR  
PARTICULATE DETERMINATION

	RUN <u>HH1</u>	RUN <u>HH2</u>	RUN <u>HH3</u>
A. Particulate			
(1) CH <sub>2</sub> Cl <sub>2</sub> Wash, Parts 1 & 2 (RTI)	<u>.2701</u>	<u>.2716</u>	<u>.2613</u>
(2) Acetone Scrub, Part 1 (Cary Lab)	<u>.0214</u>	<u>.0137</u>	<u>.0199</u>
TOTAL	<u>.2915</u>	<u>.2853</u>	<u>.2812</u>
B. Moisture Collected			
(1) Part 5 (Catch Bottle)	<u>55 ml</u>	<u>69 ml</u>	<u>65 ml</u>
(2) Part 6 (Impingers)	<u>15 ml</u>	<u>16 ml</u>	<u>29 ml</u>
(3) Part 7 (Silica Gel)	<u>17.1 g</u>	<u>14.9 g</u>	<u>16.0 g</u>
TOTAL	<u>87.1 ml</u>	<u>99.9 ml</u>	<u>110 ml</u>

**APPENDIX H**

**TEST SF**

Calculation Summary  
Polycyclic Organic Materials

SOURCE SF Date 22 July 81  
LOCATION \_\_\_\_\_ Test Point Boiler #2

ENTRY	RUN <u>1</u>	RUN <u>2</u>	RUN <u>3</u>	ANSWER
Ave. $\Delta H$ (in H <sub>2</sub> O)	0.8400	0.8500	0.7700	
$P_{atm}$ (in Hg)	29.2200	29.2200	29.2300	
$P_g$ (gage) (in H <sub>2</sub> O)	29.2818	29.2825	29.2866	$P_m$ (in Hg)
	-0.1600	-0.1600	-0.1600	
$T_m$ (°R)	29.2082	29.2082	29.2182	$P_s$ (in Hg)
$V_m$ (ft <sup>3</sup> )	557.0000	557.0000	567.0000	
	30.0200	30.1430	29.8350	
$V_{1q}$ (ml)	27.9493	28.0645	27.2917	$V_{mstd}$ (ft <sup>3</sup> )
	38.7000	31.1000	30.7000	
	1.8305	1.4710	1.4521	$V_{vstd}$ (ft <sup>3</sup> )
	29.7798	29.5356	28.7438	$V_{std}$ (ft <sup>3</sup> )
	6.1468	4.9805	5.0519	$ZM$
	0.9385	0.9502	0.9495	$M_d$
$MW_d$	29.3400	29.3000	29.2300	
	28.6430	28.7372	28.6627	$M$
$T_g$ (°R)	849.0000	853.0000	833.0000	
$\Sigma \sqrt{\Delta p}$	3.0212	3.0389	2.9231	
$n \Delta p$	12.0000	12.0000	12.0000	
$C_p$	0.2518	0.2532	0.2436	Ave $\sqrt{\Delta p}$
	0.8400	0.8400	0.8400	
$D_g$ (in)	18.2110	18.3307	17.4439	$v_s$ (ft/sec)
	54.0000	54.0000	54.0000	
	15.9043	15.9043	15.9043	$A_s$ (ft <sup>2</sup> )
	17378.	17492.	16846.	$Q_g$ (ft <sup>3</sup> /min)
	10588.	10608.	10340.	$Q_{std}$ (ft <sup>3</sup> /min)
inity substitution	1.0000	1.0000	1.0000	*
	47.0386	47.5154	47.5940	$pmr_c$ (lb/hr)
$D_n$ (in)	0.3660	0.3660	0.3590	
	0.1052	0.1064	0.1012	$A_n$ (in <sup>2</sup> )
$\theta$ (min)	60.0000	60.0000	60.0000	
	47.9992	47.4789	49.8893	$pmr_a$ (lb/hr)
	102.0422	99.9232	104.8226	$ZI$
	47.5189	47.4971	48.7417	$pmr_{avg}$ Multiplier
$ZCO$	0.0000	0.0000	0.0000	
$ZO_2$	16.3000	16.8300	17.4000	
$ZN_2$	79.4000	79.2300	79.2700	
	349.6654	411.8217	493.2980	$ZEA$
F Factor	9280.0000	9280.0000	9280.0000	
	14.2883	12.7326	10.6993	HI (10 <sup>6</sup> BTU/hr.)
	3.3257	3.7304	4.5556	$f_p$ (lb/g · 10 <sup>6</sup> BTU)

Calculation Summary

SOURCE SF Boiler #2 Date 22 July 81  
 LOCATION \_\_\_\_\_

ENTRY	RUN 1	RUN 2	RUN 3	ANSWER
Ave. $\Delta H$ (in H <sub>2</sub> O) [	0.8400	0.8500	0.7700	
$P_{atm}$ (in Hg) [	29.2200	29.2200	29.2300	
$P_s$ (gage) (in H <sub>2</sub> O) [	29.2818	29.2825	29.2856	$P_m$ (in Hg)
	-0.1600	-0.1600	-0.1600	$P_s$ (in Hg)
	29.2032	29.2002	29.2132	
$T_m$ (°R) [	557.0000	557.0000	567.0000	
$V_m$ (ft <sup>3</sup> ) [	30.0200	30.1430	29.8350	$V_{mstd}$ (ft <sup>3</sup> )
	27.9493	28.0645	27.2917	
$V_{lq}$ (ml) [	33.7000	31.1000	30.7000	$V_{vstd}$ (ft <sup>3</sup> )
	1.8305	1.4710	1.4521	$V_{std}$ (ft <sup>3</sup> )
	29.7798	29.5356	28.7438	$ZM$
	6.1438	4.9805	5.0519	$M_d$
	0.9385	0.9502	0.9495	
$MW_d$ [	29.3400	29.3000	29.2300	
	28.6430	28.7372	28.6627	$M$
$T_s$ (°R) [	849.0000	853.0000	838.0000	
$\Sigma \sqrt{\Delta p}$ [	3.0212	3.0399	2.9231	
$n_{\Delta p}$ [	12.0000	12.0000	12.0000	Ave $\sqrt{\Delta p}$
$C_p$ [	0.2518	0.2532	0.2436	
	0.8400	0.8400	0.8400	$v_s$ (ft/sec)
$D_s$ (in) [	18.2110	18.3307	17.4439	
	54.0000	54.0000	54.0000	$A_s$ (ft <sup>2</sup> )
	15.9043	15.9013	15.9043	$Q_s$ (ft <sup>3</sup> /min)
	17378.	17492.	16646.	$Q_{std}$ (ft <sup>3</sup> /min)
$W_t$ (gm) [	10588.	10603.	10340.	
	0.1338	0.0936	0.1137	$pmr_c$ (lb/hr)
	6.2938	4.4474	5.4114	
$D_n$ (in) [	0.3660	0.3630	0.3590	$A_n$ (in <sup>2</sup> )
	0.1052	0.1054	0.1012	
$\theta$ (min) [	60.0000	60.0000	60.0000	$pmr_a$ (lb/hr)
	6.4223	4.4440	5.6724	$ZI$
	102.0422	99.9232	104.8226	$pmr_{avg}$ (lb/hr)
	5.3580	4.4437	5.5419	
$ZCO$ [	0.0000	0.0000	0.0000	
$ZO_2$ [	16.3000	16.8300	17.4000	
$ZN_2$ [	79.4000	79.2300	79.2700	
	349.6654	411.8217	493.2930	$ZEA$
F Factor [	9280.0000	9280.0000	9280.0000	
	14.2833	12.7326	10.6993	HI (10 <sup>6</sup> BTU/hr.)
	0.4450	0.3492	0.5160	$pmr_u$ (lbs/10 <sup>6</sup> BTU)

SUMMARY OF ANALYTICAL VALUES FOR  
PARTICULATE DETERMINATION

	RUN <u>SF1</u>	RUN <u>SF2</u>	RUN <u>SF3</u>
A. Particulate			
(1) CH <sub>2</sub> Cl <sub>2</sub> Wash, Parts 1 & 2 (RTI)	<u>0.1290</u>	<u>.0930</u>	<u>.1133</u>
(2) Acetone Scrub, Part 1 (Cary Lab)	<u>.0048</u>	<u>.0006</u>	<u>.0004</u>
TOTAL	<u>.1338</u>	<u>.0936</u>	<u>.1137</u>
B. Moisture Collected			
(1) Part 5 (Catch Bottle)	<u>22</u>	<u>12</u>	<u>16</u>
(2) Part 6 (Impingers)	<u>10.0</u>	<u>14</u>	<u>8</u>
(3) Part 7 (Silica Gel)	<u>6.7</u>	<u>5.1</u>	<u>6.7</u>
TOTAL	<u>38.7</u>	<u>31.1</u>	<u>30.7</u>

**APPENDIX I**

**TEST EL**

Calculation Summary  
Polycyclic Organic Materials

SOURCE EL Date 3 June 81  
LOCATION \_\_\_\_\_ Test Point Boiler #2

ENTRY	RUN <u>1</u>	RUN <u>2</u>	RUN <u>3</u>	ANSWER
Ave. $\Delta H$ (in $H_2O$ )	2.2600	0.9400	0.9000	
$P_{atm}$ (in Hg)	29.8700	29.8400	29.7900	
$P_g$ (gage) (in $H_2O$ )	30.0362	29.9091	29.8562	$P_m$ (in Hg)
	0.0400	0.0400	0.0400	
	29.8729	29.8429	29.7929	$P_s$ (in Hg)
$T_m$ ( $^{\circ}R$ )	565.0000	557.0000	557.0000	
$v_m$ (ft <sup>3</sup> )	47.7300	30.8800	30.8810	
	44.9372	29.3660	29.3149	$v_{mstd}$ (ft <sup>3</sup> )
$v_{lq}$ (ml)	176.6000	125.0000	88.1000	
	8.3532	5.9125	4.1671	$v_{vstd}$ (ft <sup>3</sup> )
	53.2904	35.2785	33.4821	$v_{std}$ (ft <sup>3</sup> )
	15.6748	16.7595	12.4459	$ZM$
	0.8433	0.8324	0.8755	$M_d$
$MW_d$	30.1600	30.2200	30.1000	
	28.2539	28.1720	28.5941	$M$
$T_s$ ( $^{\circ}R$ )	836.0000	868.0000	860.0000	
$L/\Delta p$	3.0311	3.0858	3.0111	
$n_{\Delta p}$	12.0000	12.0000	12.0000	
	0.2526	0.2572	0.2509	Ave $\sqrt{\Delta p}$
$C_p$	0.8400	0.8400	0.8400	
	18.0504	18.7612	18.1027	$v_s$ (ft/sec)
$D_s$ (in)	33.5000	33.5000	33.5000	
	6.1209	6.1209	6.1209	$A_s$ (ft <sup>2</sup> )
	6629.	6890.	6648.	$Q_s$ (ft <sup>3</sup> /min)
	4195.	4195.	4079.	$Q_{std}$ (ft <sup>3</sup> /min)
inity substitution	1.0000	1.0000	1.0000	
	10.4149	15.7333	16.1173	$pmr_c$ (lb/hr)
$D_n$ (in)	0.4940	0.3740	0.3730	
	0.1917	0.1099	0.1093	$A_n$ (in <sup>2</sup> )
$\theta$ (min)	60.0000	60.0000	60.0000	
	10.1401	17.6911	17.7861	$pmr_a$ (lb/hr)
	97.3615	112.4438	110.3542	$ZI$
	10.2775	16.7122	16.9517	$pmr_{avg}$ Multiplier
$ZCO$	0.0000	0.0000	0.0000	
$ZO_2$	8.6000	8.4300	9.6000	
$ZN_2$	80.0300	79.8000	79.6700	
	68.6467	66.7078	83.9683	$ZEA$
F Factor	9280.0000	9280.0000	9280.0000	
	13.5622	13.5441	12.5511	$HI$ ( $10^6$ BTU/hr.)
	0.7578	1.2339	1.3506	$f_p$ (lb/g $\cdot 10^6$ BTU)

Calculation Summary

SOURCE EL Date 3 June 81

LOCATION \_\_\_\_\_

ENTRY	RUN 1	RUN 2	RUN 3	ANSWER
Ave. $\Delta H$ (in H <sub>2</sub> O)	2.2600	0.9400	0.9000	
$P_{atm}$ (in Hg)	29.8770	29.8400	29.7900	
$P_s$ (gage) (in H <sub>2</sub> O)	30.0352	29.9091	29.8552	$P_m$ (in Hg)
	0.0400	0.0400	0.0400	
	29.8729	29.8429	29.7929	$P_s$ (in Hg)
$T_m$ (°R)	565.0000	557.0000	557.0000	
$V_m$ (ft <sup>3</sup> )	47.7300	30.8800	30.8810	
	44.9372	29.3660	29.3149	$V_{mstd}$ (ft <sup>3</sup> )
$V_{lq}$ (ml)	176.6000	125.0000	88.1000	
	8.3532	5.9125	4.1671	$V_{vstd}$ (ft <sup>3</sup> )
	53.2904	35.2735	33.4821	$V_{std}$ (ft <sup>3</sup> )
	15.6748	16.7595	12.4459	$ZM$
	0.8433	0.8324	0.8755	$M_d$
$MW_d$	30.1600	30.2200	30.1000	
	28.2539	28.1720	28.5941	$M$
$T_s$ (°R)	836.0000	868.0000	860.0000	
$\Sigma \sqrt{\Delta p}$	3.0311	3.0838	3.0111	
$n_{\Delta p}$	12.0000	12.0000	12.0000	
	0.2526	0.2572	0.2509	Ave $\sqrt{\Delta p}$
$C_p$	0.8400	0.8400	0.8400	
	18.0504	18.7612	18.1027	$v_s$ (ft/sec)
$D_s$ (in)	33.5000	33.5000	33.5000	
	6.1209	6.1209	6.1209	$A_s$ (ft <sup>2</sup> )
	6629.	6890.	6648.	$Q_s$ (ft <sup>3</sup> /min)
	4195.	4195.	4079.	$Q_{std}$ (ft <sup>3</sup> /min)
$W_t$ (gm)	1.3795	0.9541	0.6937	
	14.3674	15.0111	11.1806	$pmr_c$ (lb/hr)
$D_n$ (in)	0.4940	0.3740	0.3730	
	0.1917	0.1039	0.1038	$A_n$ (in <sup>2</sup> )
$\theta$ (min)	60.0000	60.0000	60.0000	
	13.9883	15.8791	13.3332	$pmr_a$ (lb/hr)
	97.3615	112.4438	110.3542	$ZI$
	14.1779	15.9451	11.7594	$pmr_{avg}$ (lb/hr)
$ZCO$	0.0000	0.0000	0.0000	
$ZO_2$	8.6000	8.4300	8.6000	
$ZN_2$	80.0300	79.8000	79.6700	
	68.6457	66.7078	83.9633	$ZEA$
F Factor	9280.0000	9280.0000	9280.0000	
	13.5622	13.5441	12.5511	HI (10 <sup>6</sup> BTU/hr.)
	1.0454	1.1773	0.9369	$pmr_u$ (lbs/10 <sup>6</sup> BTU)

APPENDIX J

TEST WW

Calculation Summary  
Polycyclic Organic Materials

SOURCE WW Date 9/16/81  
LOCATION \_\_\_\_\_ Test Point Multicenter  
Outlet.

ENTRY	RUN <u>WW1</u>	RUN <u>WW2</u>	RUN <u>WW3</u>	ANSWER
Ave. ΔH (in H <sub>2</sub> O)	1.2600	1.2100	1.3070	
P <sub>atm</sub> (in Hg)	29.8100	29.8000	29.8200	
P <sub>s</sub> (gage) (in H <sub>2</sub> O)	29.9026	29.8890	29.9161	P <sub>m</sub> (in Hg)
	-8.5000	-8.5000	-8.5000	
	29.1850	29.1750	29.1950	P <sub>s</sub> (in Hg)
T <sub>m</sub> (°R)	552.0000	550.0000	552.0000	
V <sub>m</sub> (ft <sup>3</sup> )	48.9280	48.9400	50.8070	
V <sub>1q</sub> (ml)	46.9404	47.1011	48.7650	V <sub>mstd</sub> (ft <sup>3</sup> )
	66.5000	62.0000	71.5000	
	3.1455	2.9326	3.3820	V <sub>vstd</sub> (ft <sup>3</sup> )
	50.0858	50.0337	52.1469	V <sub>std</sub> (ft <sup>3</sup> )
	6.2801	5.8613	6.4854	%M
	0.9372	0.9414	0.9351	M <sub>d</sub>
MW <sub>d</sub>	29.3400	29.3400	29.3300	
T <sub>s</sub> (°R)	28.6278	28.6753	28.5952	M
Σ/Δp	776.0000	795.0000	792.0000	
nΔp	26.5611	26.2640	27.3781	
C <sub>p</sub>	40.0000	40.0000	40.0000	Ave √Δp
	0.6640	0.6566	0.6845	
D <sub>s</sub> (in)	0.8400	0.8400	0.8400	v <sub>s</sub> (ft/sec)
	45.9501	45.9588	47.8684	
	37.4400	37.4400	37.4400	A <sub>s</sub> (ft <sup>2</sup> )
	7.6454	7.6454	7.6454	Q <sub>s</sub> (ft <sup>3</sup> /min)
	21078.	21082.	21958.	Q <sub>std</sub> (ft <sup>3</sup> /min)
inity substitution	14040.	13702.	14335.	
	1.0000	1.0000	1.0000	pmr <sub>c</sub> (lb/hr)
D <sub>n</sub> (in)	37.0850	36.2309	36.3691	
	0.2440	0.2440	0.2430	A <sub>n</sub> (in <sup>2</sup> )
θ (min)	0.0468	0.0468	0.0464	
	80.0000	80.0000	80.0000	pmr <sub>a</sub> (lb/hr)
	38.9369	38.9369	39.2581	ZI
	104.9937	107.4690	107.9436	pmr <sub>avg</sub> Multiplier
ZCO	38.0110	37.5839	37.8136	
ZO <sub>2</sub>	0.0000	0.0000	0.0000	
ZN <sub>2</sub>	16.3700	16.7000	16.5700	
	79.3700	79.1700	79.2300	
F Factor	357.1366	397.5358	381.2070	ZEA
	9280.0000	9280.0000	9280.0000	HI (10 <sup>6</sup> BTU/hr.)
	18.6098	16.7621	18.0116	f <sub>p</sub> (lb/g·10 <sup>6</sup> BTU)
	2.0425	2.2422	2.0994	

Calculation Summary

SOURCE WW Date 9/16/81  
 LOCATION \_\_\_\_\_

ENTRY	RUN 1	RUN 2	RUN 3	ANSWER
Ave. $\Delta H$ (in H <sub>2</sub> O) <input type="checkbox"/>	1.2600	1.2100	1.3070	
$P_{atm}$ (in Hg) <input type="checkbox"/>	29.8100	29.8000	29.8200	
$P_g$ (gage) (in H <sub>2</sub> O) <input type="checkbox"/>	29.9026	29.8890	29.9161	$P_m$ (in Hg)
$T_m$ (°R) <input type="checkbox"/>	-8.5000	-8.5000	-8.5000	
$V_m$ (ft <sup>3</sup> ) <input type="checkbox"/>	29.1850	29.1750	29.1950	$P_g$ (in Hg)
$V_{lq}$ (ml) <input type="checkbox"/>	552.0000	550.0000	552.0000	
	48.9280	48.9400	50.8070	$V_{mstd}$ (ft <sup>3</sup> )
	46.9404	47.1011	48.7650	
	66.5000	62.0000	71.5000	$V_{vstd}$ (ft <sup>3</sup> )
	3.1455	2.9326	3.3820	$V_{std}$ (ft <sup>3</sup> )
	50.0858	50.0337	52.1469	$ZM$
	6.2801	5.8613	6.4854	$M_d$
	0.9372	0.9414	0.9351	
$MW_d$ <input type="checkbox"/>	29.3400	29.3400	29.3300	$M$
$T_s$ (°R) <input type="checkbox"/>	28.6278	28.6753	28.5952	
$\sqrt{\Delta p}$ <input type="checkbox"/>	776.0000	795.0000	792.0000	
$n\Delta p$ <input type="checkbox"/>	26.5611	26.2640	27.3781	
$C_p$ <input type="checkbox"/>	40.0000	40.0000	40.0000	Ave $\sqrt{\Delta p}$
$D_s$ (in) <input type="checkbox"/>	0.6640	0.6566	0.6845	
	0.8400	0.8400	0.8400	$v_s$ (ft/sec)
	45.9501	45.9588	47.8684	
	37.4400	37.4400	37.4400	$A_s$ (ft <sup>2</sup> )
	7.6454	7.6454	7.6454	$Q_s$ (ft <sup>3</sup> /min)
	21078.	21082.	21958.	$Q_{std}$ (ft <sup>3</sup> /min)
$W_t$ (gm) <input type="checkbox"/>	14040.	13702.	14335.	
	0.1848	0.1761	0.2807	$pmr_c$ (lb/hr)
	6.8533	6.3803	10.2088	
$D_n$ (in) <input type="checkbox"/>	0.2440	0.2440	0.2430	
	0.0468	0.0468	0.0464	$A_n$ (in <sup>2</sup> )
$\theta$ (min) <input type="checkbox"/>	80.0000	80.0000	80.0000	
	7.1955	6.8568	11.0197	$pmr_a$ (lb/hr)
	104.9937	107.4690	107.9436	$ZI$
	7.0244	6.6185	10.6143	$pmr_{avg}$ (lb/hr)
$ZCO$ <input type="checkbox"/>	0.0000	0.0000	0.0000	
$ZO_2$ <input type="checkbox"/>	16.3700	16.7000	16.5700	
$ZN_2$ <input type="checkbox"/>	79.3700	79.1700	79.2300	
	357.1366	397.5358	381.2070	$ZEA$
F Factor <input type="checkbox"/>	9280.0000	9280.0000	9280.0000	
	18.6098	16.7621	18.0116	HI (10 <sup>6</sup> BTU/hr.
	0.3775	0.3949	0.5893	$pmr_u$ (lbs/10 <sup>6</sup> BTU)

SUMMARY OF ANALYTICAL VALUES FOR  
PARTICULATE DETERMINATION

	RUN <u>WW1</u>	RUN <u>WW2</u>	RUN <u>WW3</u>
A. Particulate			
(1) CH <sub>2</sub> Cl <sub>2</sub> Wash, Parts 1 & 2 (RTI)	<u>.1534</u>	<u>.1627</u>	<u>.2579</u>
(2) Acetone Scrub, Part 1 (Cary Lab)	<u>.0314</u>	<u>.0134</u>	<u>.0228</u>
TOTAL	<u>.1848</u>	<u>.1761</u>	<u>.2807</u>
B. Moisture Collected			
(1) Part 5 (Catch Bottle)	<u>54</u> }	<u>50</u> }	<u>59</u> }
(2) Part 6 (Impingers)			
(3) Part 7 (Silica Gel)	<u>12.5</u>	<u>12.0</u>	<u>12.5</u>
TOTAL	<u>66.5ml</u>	<u>62.0ml</u>	<u>71.5ml</u>

Ref 4

A Polyyclic Aromatic Material Emissions Study of a Residential Wood-Burning Boiler

SOURCE CATEGORY: Wood Waste

EXCLUSION CRITERIA CHECKLIST

REFERENCE NEAAT Technical Bulletin No. 4100 May 1998

CRITERIA	YES	NO
1. Test series averages are reported in units that can be converted to the selected reporting units?	✓	
2. Test series represent compatible test methods?	✓	
3. In tests in which emission control devices were used, the control devices are fully specified?	✓	
4. Is it clear whether or not the emissions were controlled (or not controlled)?	✓	

Form filled out by ESD / H. M. ...

Date 1/24/02

INDICATE WHETHER ANSWER IS YES OR NO WITH AN "X" IN APPROPRIATE BOX.

IF ALL ANSWERS ARE "YES" PROCEED TO METHODOLOGY/DETAIL CRITERIA CHECKLIST.

SOURCE CATEGORY Wood Waste  
 METHODOLOGY/DETAIL CRITERIA CHECKLIST

REFERENCE Acoust. Tech. Publication No. 400

CRITERIA	YES	NO	COMMENTS
1. Is the manner in which the source was operated well documented in the report?	✓		Summary of Seismic boiler tests
Was the source operating within typical parameters during the test?	✓		
2. Did sampling procedures deviate from standard methods?	✓		Method of sampling not standard in detail
If so, were the deviations well documented?	✓		
Were the deviations appropriate?	✓		
Comment on how any alterations in sampling procedure may have influenced the results.			Plausible explanation given for deviations
3. Were there wide variations in the results?		✓	
If yes, can the variations be adequately explained by information in the report?			NA
If the variations are not well explained, should the data be considered of poor quality?			NA
4. Do the test reports contain the raw data sheets?	✓		Some raw data sheets not complete
Are the nomenclature and equations used equivalent to those specified by the EPA?		✓	Some confusion in use of terms
Comment on the consistency and completeness of the results.			Consistency not complete

Form filled out by [Signature]  
 Date 10/10/77

INDICATE YES OR NO WITH AN "X" IN THE APPROPRIATE BOX. FILL IN COMMENTS.

IF, BASED ON ABOVE ANSWERS, THE SOURCE REPORT PROVIDES ADEQUATE DETAIL AND DEMONSTRATES SOUND METHODOLOGY, PROCEED TO RATING THE DATA IN THE RATING CRITERIA CHECKLIST.

SOURCE CATEGORY Wood Waste  
 RATING CRITERIA CHECKLIST

Reference NCA-91 Tech. Report No. 400

RATING CRITERIA	YES	NO
A Tests performed by a sound methodology and reported in enough detail for adequate validation?		
B Tests were performed by a generally sound methodology, but not enough detail for adequate validation?	✓	
C Were tests based on untested or new methodology that lacks significant amount of background data?		
D Were tests based on generally unacceptable methods, but may provide order-of-magnitude values for the source?		

**COMMENTS**

*Handwritten notes:*  
 This source standard, presumably for wood waste, is not a complete document. The only data available is for GC/MS.  
 Analysis of POMs was not done by standard methods but by a comparable GC/MS method. However, analysis was also done by a non-standard GC method. Only the GC/MS data should be used. Also, the PNA, GAF and DDT data are not available in the report and this may not be valid.

Form filled out by [Signature]  
 Date 7-14-90

BASED ON ANSWERS AND COMMENTS ABOVE, ASSIGN A RANK TO THIS LITERATURE SOURCE:

F PNA, DDT, PNA 3 GC/MS data only

RANK ASSIGNED TO EMISSION SOURCE DATA

EPAL  
5/11/92

NCA~~ST~~ Technical Bulletin No. 400 - May 93

## A Polycyclic Organic Materials Emissions Study for Industrial Wood-Fired Boilers

- o Original program/report developed by the NC Dept. of Natural Resources and Community Development.
  - o Measurement program carried out on small- to medium-size wood-fired boilers
  - o Seven boilers were sampled: 4 were Horizontal Water Tube boilers, one Underfeed stoker, one Fluidized bed unit, and a 300psi water tube boiler
  - o Tested equal number of dry and wet wood fired boilers
- #10 Based on Megan Day's review of analytical techniques, only specified PAH results in Table 6-4 utilized for ET development.
- This data derived from boilers HH and EL

NCAESI Tech. Bulletin No. 400 - POM Emissions For Industrial Wood-Fired Boilers

TEST	Boiler T-PE Maximum Input, 10 <sup>6</sup> BTU/hr	APC/D	Average PMEmissions, lb/10 <sup>6</sup> Btu	Average PMEmissions, lb/10 <sup>6</sup> Btu	Average Total POM, ug/kg	Average Naphthalene, ug/kg	<del>Naphthalene</del> lb/ton
K	100 HP HRT Boiler (5.2)	None	Wood 0.311	2.80	2256	1809	<del>3.6E-3</del> 3.6E-3
EA	45,000 lb/hr Water-tube Spreader (55)	Multiclone Wood	0.473	4.26	1526	1344	<del>2.7E-3</del> 2.7E-3
BP	HRT Boiler (37.2)	Multiclone Wood w/ Re-injection	0.356	3.20	70.6	47.7	<del>9.5E-5</del> 9.5E-5
HH	Double pass Fire-tube Under-feed Stoker (13)	Multiclone Wood	0.286	2.57	3028	2739	<del>6.5E-3</del> 6.5E-3
SF	HRT Boiler (13.5)	None	Wood 0.437	3.93	700	540	<del>1.1E-3</del> 1.1E-3
EL	HRT Boiler 150HP (16)	None	Wood/ Bark 1.053	9.48	2435	2131	<del>4.3E-3</del> 4.3E-3
WW	Fluidized bed combustor (70.8)	Multiclone Bark	0.454	4.09	1153	434	<del>8.7E-4</del> 8.7E-4
Overall Mean				4.33	2059	1319	<del>0.6E-3</del> 0.6E-3

<sup>a</sup> Based on 4500 Btu/lb wood (at 50% moisture) \* 2,000  $\frac{\text{lb}}{\text{ton}}$  =  $9 \times 10^6 \frac{\text{Btu}}{\text{ton}}$