

REFERENCES

1. Amranand, P. Thailand's policy on fuel quality. **Fuels and Lubes Asia Conference**. The Reagent Hotel, Singapore, January 20, 1997.
2. Agency for Toxic Substances and Disease (ATSDR). **Public Health Statement : Polycyclic aromatic hydrocarbons (PAHs)**. December 1990.
3. Westerholm, R., and Li, H.. A multivariate statistical analysis of fuel-related polycyclic aromatic hydrocarbon emissions from heavy-duty diesel vehicles. **Environmental Science & Technology** 28 (May 1994): 965-972.
4. Mortier, R.M., and Orszulik, S.T. **Chemistry and technology of lubricants**. New York: VCH Publishers, 1992.
5. Rathore, H.S. **CRC handbook of chromatography: liquid chromatography of polycyclic aromatic hydrocarbons**. London: CRC Press, 1993.
6. Pucknat, A.W., **Health impacts of polynuclear aromatic hydrocarbons**. New Jersey: Noyes Data Corporation, 1981.
7. Williams, P.T., and Taylor, D.T. Aromatization of tyre pyrolysis oil to yield polycyclic aromatic hydrocarbons. **Fuel** 72 (October 1993): 1469-1474.
8. Obert, E.F. **Internal combustion engines**. 3rd ed. Pennsylvania: International Textbook Company, 1968.
9. Midpanon, S. Effect of organotin in gasoline on exhaust emission from car. **Master's Thesis**, Chulalongkorn University, 1994.

10. Owen, K. **Gasoline and diesel fuel additives**. New York: John Wiley & Sons, 1990.
11. Westberg, K., et al. **The chemistry of air pollution**. New York: MSS Information, 1973.
12. Johnson, D. PAH : Ambient air quality monitoring in British Columbia. **Environmental Protection Programme, Skeena Region**. March 1995.
13. Pederson, P.S., Ingwersen, J., Nielsen, T., and Larsen, E. Effect of fuel, lubricant, and engine operating parameters on the emission of polycyclic aromatic hydrocarbons. **Environmental Science & Technology** 14 (January 1980): 71-79.
14. Rhead, M.M., and Trier, C.J.. Fuel residues and organic combustion products in diesel exhaust emissions: sources, sampling and analysis, **Trends in Analytical Chemistry** 11 (July 1992): 255-259.
15. Collier, A.R., Rhead, M.M., Trier, C.J., and Bell, M.A. Polycyclic aromatic compound profiles from a light-duty direct-injection diesel engine. **Fuel** 74 (March 1995): 362-367.
16. Williams, P.T., Abbass, M.K., and Andrews, G.E. Diesel particulate emissions: the role of unburned fuel. **Combustion and Flame** 75 (1989): 1-25.
17. Williams, P.T., Bartle, K.D., and Andrews, G.E. The relation between polycyclic aromatic compounds in diesel fuels and exhaust particulates. **Fuel** 65 (August 1986): 1150-1158.
18. Laveskog, A. **Testing the effects on exhaust emissions of two gasoline additives in lead-free gasoline: a report for the Adibis**. Motortestcenter, June 1994.

19. Hewitt, C.N. **Instrumental analysis of pollutants**. London: Elsevier Applied Science, 1994.
20. Bruner, F. **Gas chromatographic environmental analysis**. New York: VSH Publishers, 1993.
21. Springer, G.S., and Patterson, D.J. **Engine emissions: pollutant formation and measurement**. New York: Plenum Press, 1973.
22. Alsberg, T., Stenberg, U., Westerholm, R., and Strandell, M. Chemical and biological characterization of organic material from gasoline exhaust particles. **Environmental Science & Technology** 19 (January 1985): 43-50.
23. Westerholm, R.N., Alsberg, T.E., Frommelin, A.B., and Strandell, M.E. Effect of fuel polycyclic aromatic hydrocarbon content on the emissions of polycyclic aromatic hydrocarbons and other mutagenic substances from a gasoline-fueled automobile. **Environmental Science & Technology** 22 (August 1988): 925-930.
24. Mi, H.H., Lee, W.J., Wu, T.L., Lin, T.C., Wang, L.C., and Chao, H.R. PAH emission from a gasoline-powered engine. **Journal of Environmental Science and Health, Part A: Environmental Science and Engineering and Toxic and Hazardous Substance Control** 31 (August 1996): 1981-2003.
25. Khalili, N.R., Scheff, P.A., and Holsen, T.M. PAH source fingerprints for coke ovens, diesel and gasoline engines, highway tunnels, and wood combustion emissions. **Atmospheric Environment** 29 (April 1995): 533-542.

26. Schuermann, D., Lies, K.H., and Klingenberg, H. Unregulated motor vehicle exhaust gas components. **SAE Technical Paper** Number 902116, 1990.
27. Septum, O. The effect of cetane improver on polycyclic aromatic hydrocarbons in diesel exhaust. **Master's Thesis**, Chulalongkorn University, 1996.

APPENDIX A

Standard Calibration Curves for Selected PAHs

Standard Calibration Curves for Selected PAHs

The Polynuclear Aromatic Hydrocarbons Mixture for EPA 610 was used for preparing the standard calibration curve. Figure A1-A7 represent the standard curve of naphthalene, acenaphthylene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, respectively, including their linear equations.

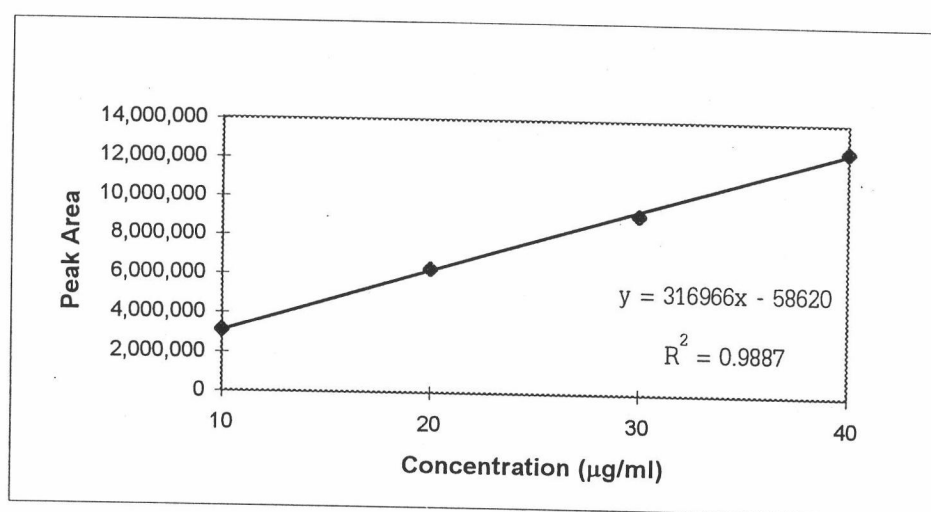


Figure A1 Calibration Curve of Naphthalene

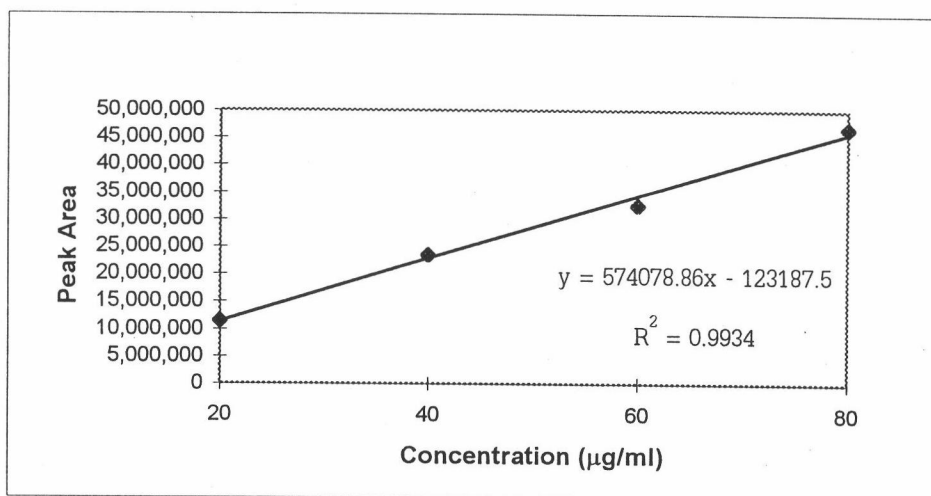


Figure A2 Calibration Curve of Acenaphthylene

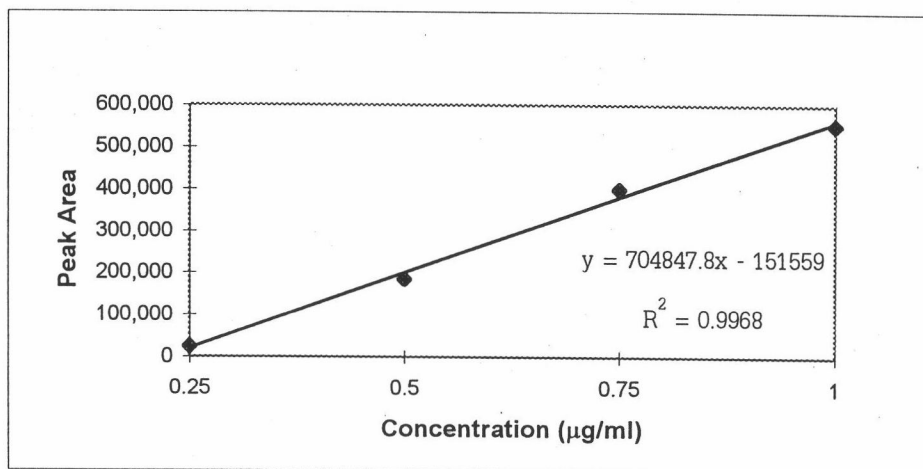


Figure A3 Calibration Curve of Fluorene

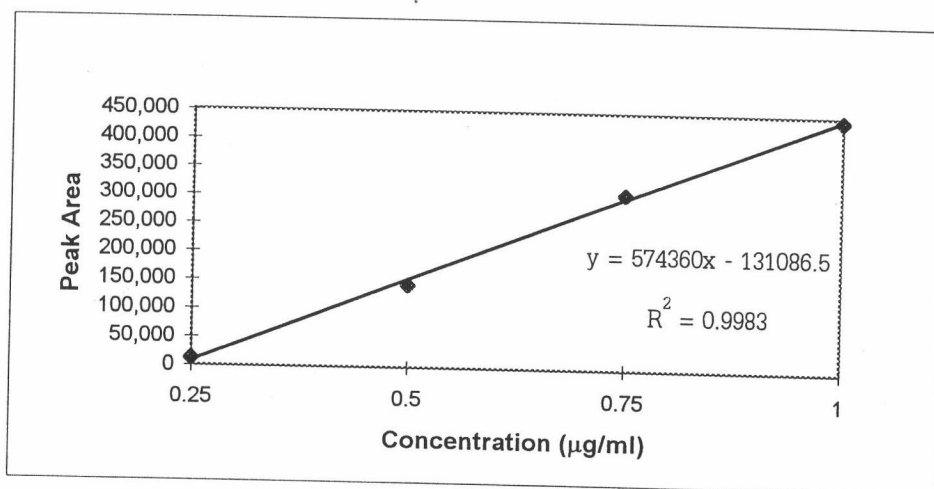


Figure A4 Calibration Curve of Phenanthrene

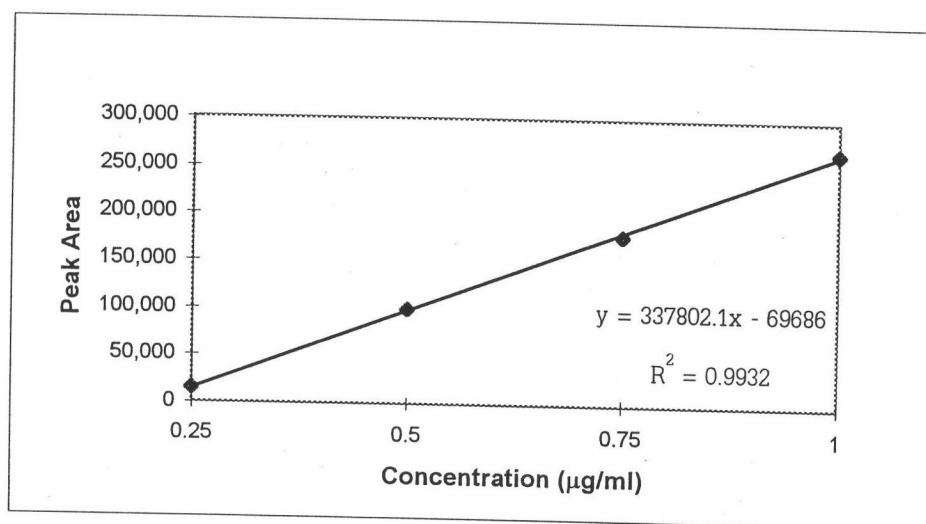


Figure A5 Calibration Curve of Anthracene

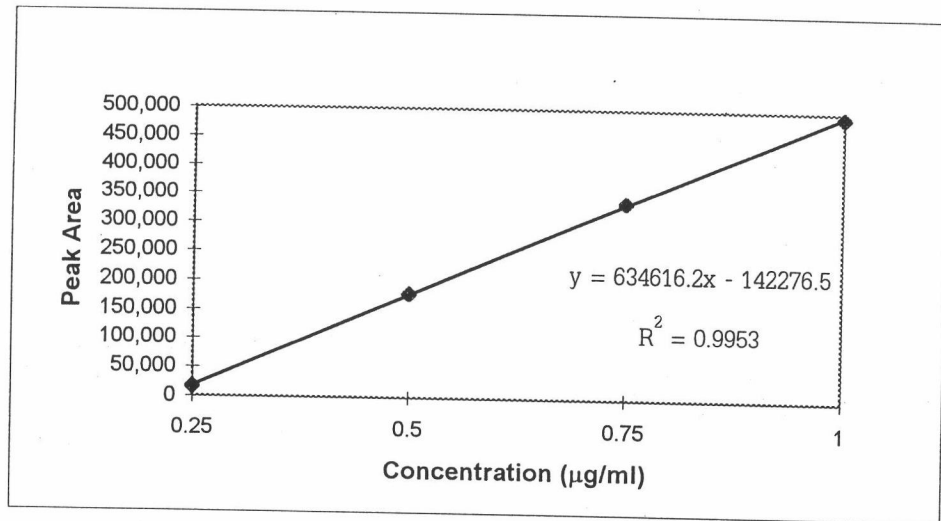


Figure A6 Calibration Curve of Fluoranthene

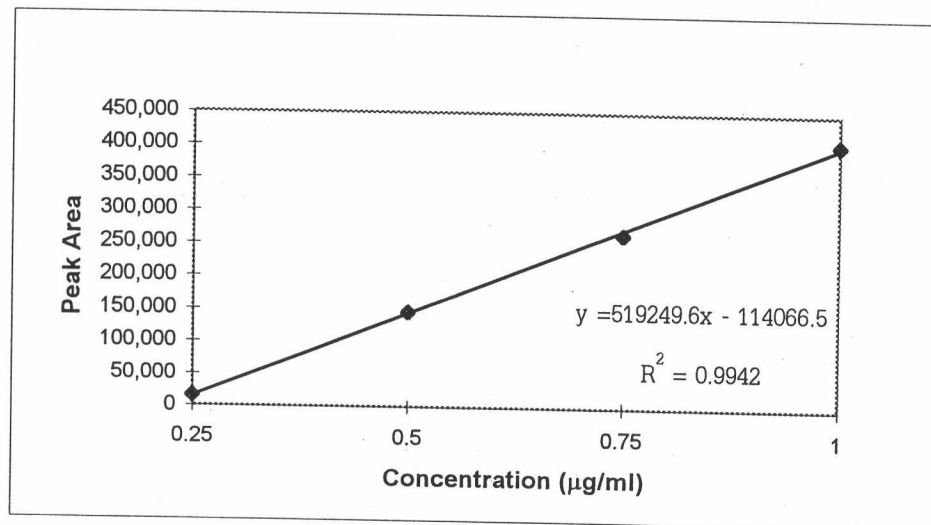


Figure A7 Calibration Curve of Pyrene

APPENDIX B

Performance of Vacuum Pump

Performance of Vacuum Pump

The vacuum pump used in this research was vacuum rotary vane pump, Gast model 0523-V103-G21DX. The performance curve of this pump, obtained from manufacturer specification, is shown in Figure B1.

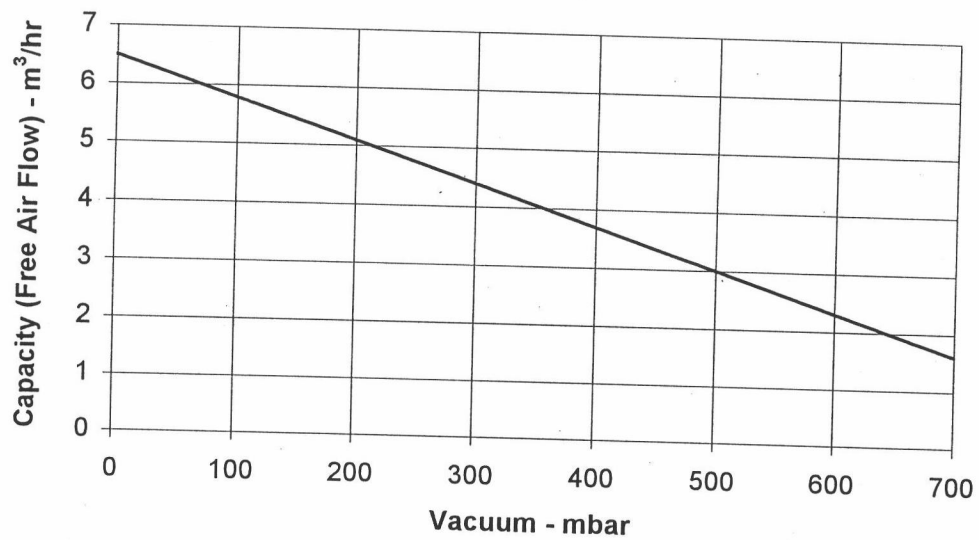


Figure B1 Performance Curve of Vacuum Pump

The linear equation of this curve is :

$$F = (-6.97 \times 10^{-3} \times P) + 6.49$$

where

F := Flow rate of exhaust (m³/hr)

P := Pump pressure (mbar)

APPENDIX C

Gas Chromatogram, Mass Spectra, and Computerized Library
Searching Results of Standard PAHs According to EPA 610

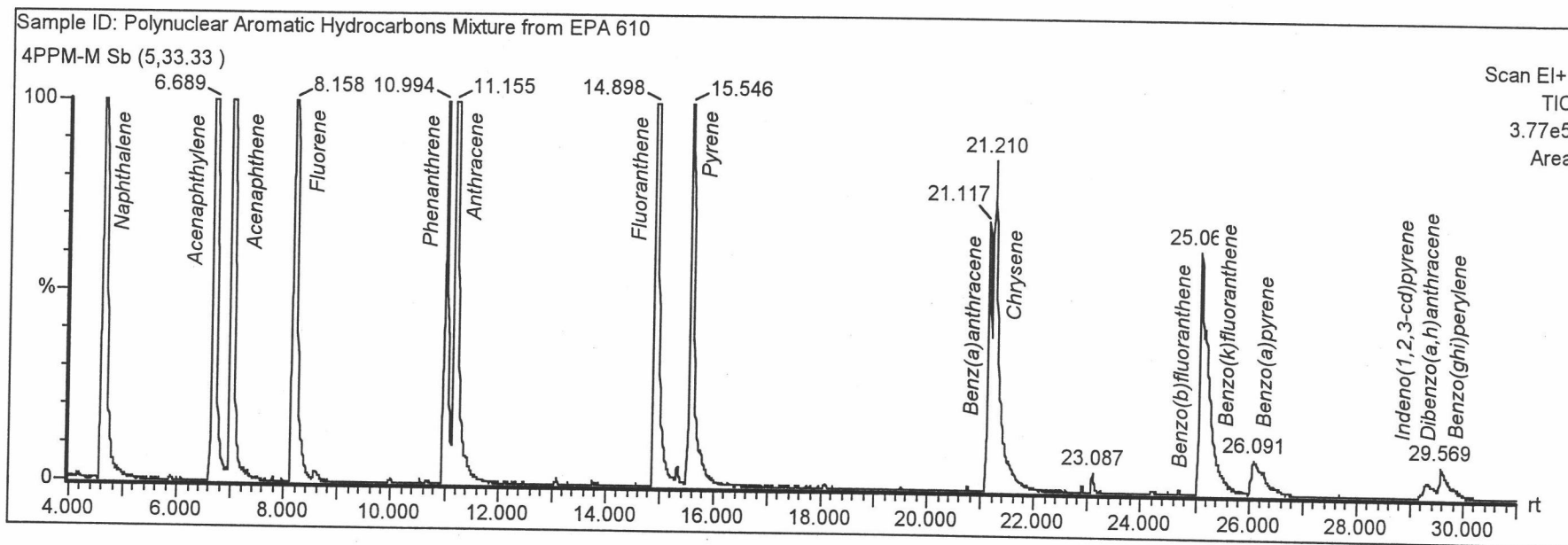
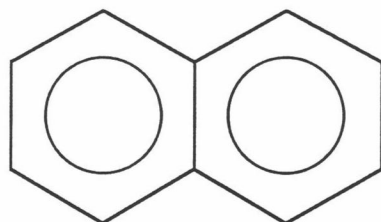


Figure C1 Gas Chromatogram of Standard PAHs Mixture according to EPA 610

Compound Name: NAPHTHALENE
 Synonym: Albocarbon
 Molecular Weight: 128

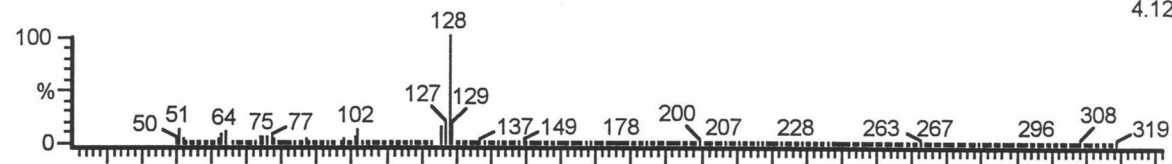
Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

Forward Fit : 919, Reverse Fit : 933



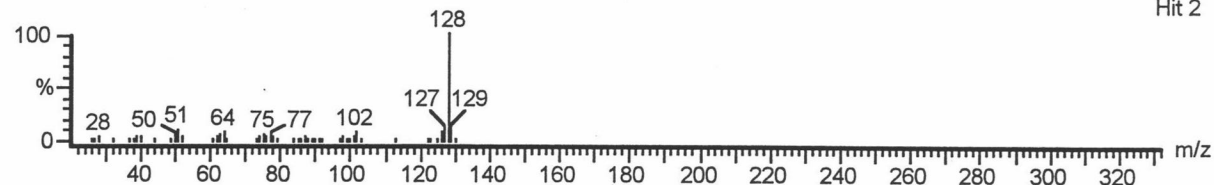
4PPM-M 128 (4.611)

4.12e6



R:933 NIST 5167: NAPHTHALENE

Hit 2



Data File: 4PPM-M

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

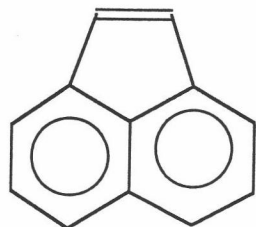
| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|---|---------|------|-----|-----|--------|-------|------------|
| 1 | 1H-INDENE, 1-METHYLENE- | C10H8 | 128 | 919 | 956 | NIST | 5168 | 2471-84-3 |
| 2 | NAPHTHALENE | C10H8 | 128 | 929 | 933 | NIST | 5167 | 91-20-3 |
| 3 | AZULENE | C10H8 | 128 | 880 | 884 | NIST | 5166 | 275-51-4 |
| 4 | CYCLOPROP A INDENE, 6-BROMO-1,1A,6,6A-TETRAHYDRO- | C10H9Br | 208 | 896 | 704 | NIST | 24774 | 55780-41-1 |
| 5 | 1H-INDENE, 1-METHYL- | C10H10 | 130 | 473 | 476 | NIST | 5574 | 767-59-9 |

Figure C2 Mass Spectrum of Standard Naphthalene and its NIST Library Searching Result

Compound Name: ACENAPHTHYLENE
 Synonym: Cyclopenta[de]naphthalene
 Molecular Weight: 152

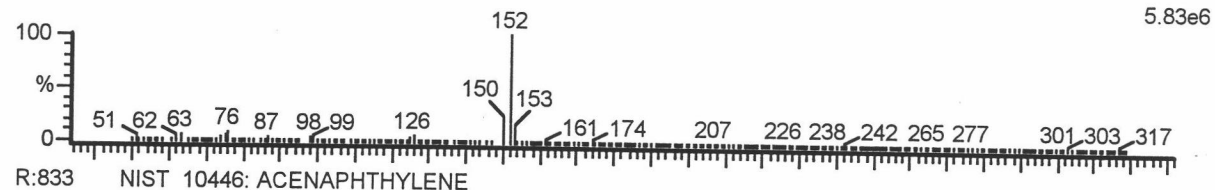
Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

Forward Fit : 828, Reverse Fit : 833

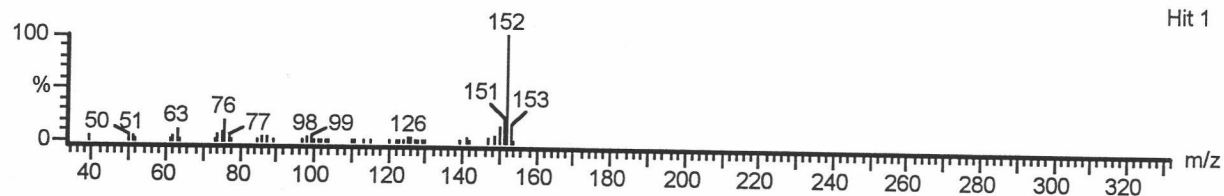


4PPM-M 438 (6.689)

5.83e6



R:833 NIST 10446: ACENAPHTHYLENE



Hit 1

Data File: 4PPM-M

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|-------------------|---|------|-----|-----|--------|-------|----------|
| 1 | ACENAPHTHYLENE | C ₁₂ H ₈ | 152 | 828 | 833 | NIST | 10446 | 208-96-8 |
| 2 | BIPHENYLENE | C ₁₂ H ₈ | 152 | 739 | 745 | NIST | 10447 | 259-79-0 |
| 3 | 1H-PHENALEN-1-ONE | C ₁₃ H ₈ O | 180 | 653 | 660 | NIST | 17920 | 548-39-0 |
| 4 | BENZO C CINNOLINE | C ₁₂ H ₈ N ₂ | 180 | 543 | 555 | NIST | 17854 | 230-17-1 |
| 5 | ACENAPHTHENE | C ₁₂ H ₁₀ | 154 | 493 | 497 | NIST | 11096 | 83-32-9 |

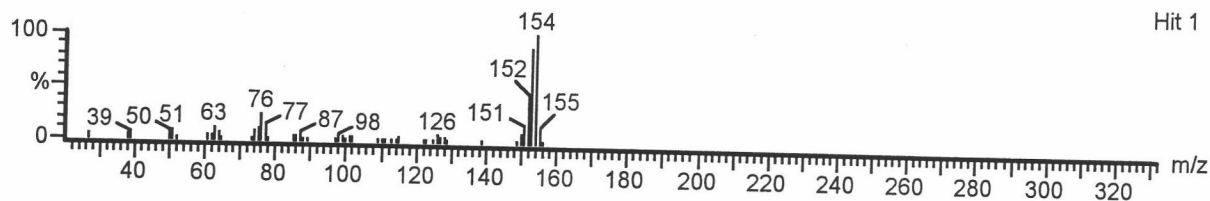
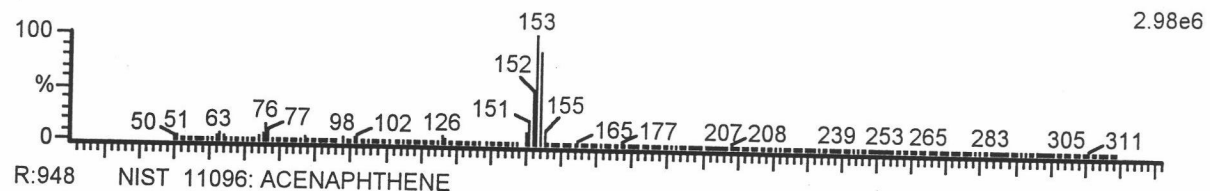
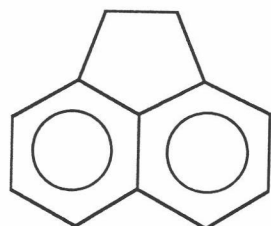
Figure C3 Mass Spectrum of Standard Acenaphthylene and its NIST Library Searching Result

Compound Name: ACENAPHTHENE
 Synonym: Acenaphthylene, 1,2-dihydro-
 Molecular Weight: 154

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

Forward Fit : 947, Reverse Fit : 948

4PPM-M 488 (7.026)



Data File: 4PPM-M

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|-------------------------------------|-----------|------|-----|-----|--------|-------|-----------|
| 1 | ACENAPHTHENE | C12H10 | 154 | 947 | 948 | NIST | 11096 | 83-32-9 |
| 2 | NAPHTHALENE, 2-ETHENYL- | C12H10 | 154 | 901 | 903 | NIST | 11097 | 827-54-3 |
| 3 | 1,4-ETHENONAPHTHALENE, 1,4-DIHYDRO- | C12H10 | 154 | 870 | 894 | NIST | 11095 | 7322-47-8 |
| 4 | BIPHENYL | C12H10 | 154 | 846 | 852 | NIST | 11094 | 92-52-4 |
| 5 | NAPHTHALENE, 1,8-BIS(BROMOMETHYL)- | C12H10Br2 | 312 | 534 | 555 | NIST | 44410 | 2025-95-8 |

Figure C4 Mass Spectrum of Standard Acenaphthene and its NIST Library Searching Result

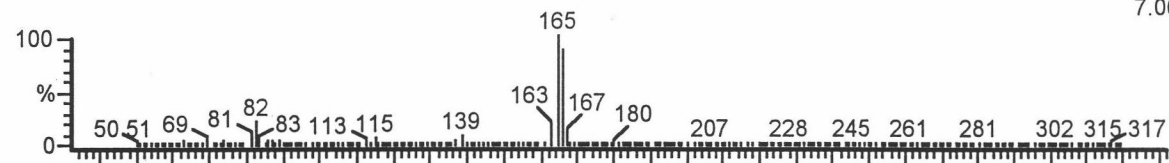
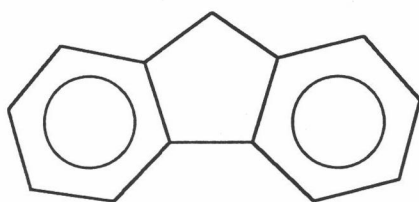
Compound Name: FLUORENE
 Synonym: 9H-Fluorene
 Molecular Weight: 166

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

Forward Fit : 882, Reverse Fit : 889

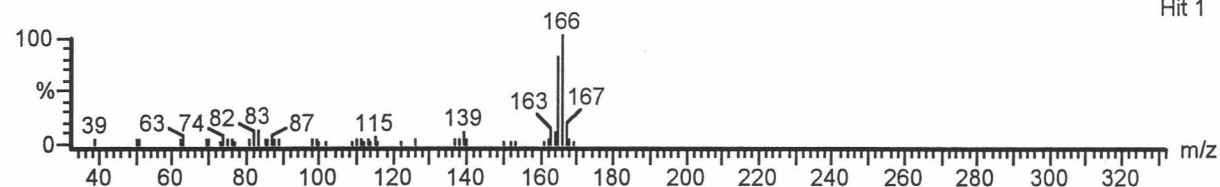
4PPM-M 657 (8.158)

7.00e5



R:889 NIST 14181: FLUORENE

Hit 1



Data File: 4PPM-M

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|-------------------------------|----------|------|-----|-----|--------|-------|------------|
| 1 | FLUORENE | C13H10 | 166 | 882 | 889 | NIST | 14181 | 86-73-7 |
| 2 | 9H-FLUORENE-9-CARBOXYLIC ACID | C14H10O2 | 210 | 797 | 888 | NIST | 25424 | 1989-33-9 |
| 3 | 1H-PHENALENE | C13H10 | 166 | 852 | 877 | NIST | 14180 | 203-80-5 |
| 4 | FLUORENE-9-METHANOL | C14H12O | 196 | 730 | 772 | NIST | 21953 | 24324-17-2 |
| 5 | 2-FLUORENECARBOXALDEHYDE | C14H10O | 194 | 720 | 728 | NIST | 21400 | 30084-90-3 |

Figure C5 Mass Spectrum of Standard Fluorene and its NIST Library Searching Result

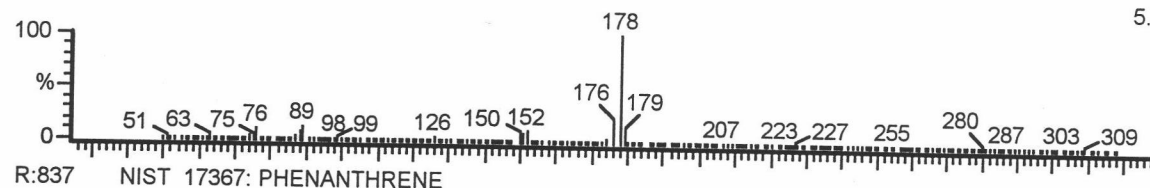
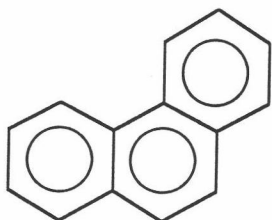
Compound Name: PHENANTHRENE
 Synonym: Phenanthren
 Molecular Weight: 178

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

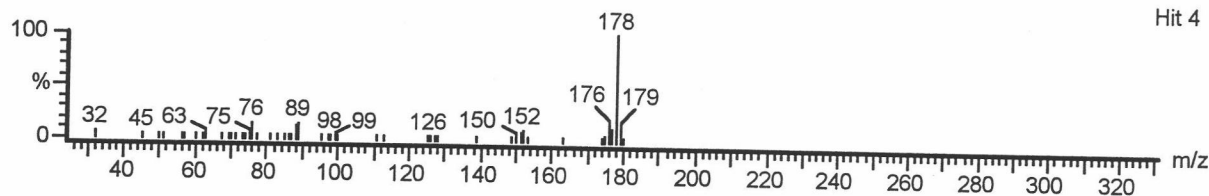
Forward Fit : 824, Reverse Fit : 837

4PPM-M 1081 (10.994)

5.22e5



R:837 NIST 17367: PHENANTHRENE



Hit 4

Data File: 4PPM-M

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|----------------------------------|---------|------|-----|-----|--------|-------|-----------|
| 1 | 9H-FLUORENE, 9-METHYLENE- | C14H10 | 178 | 877 | 942 | NIST | 17369 | 4425-82-5 |
| 2 | ANTHRACENE | C14H10 | 178 | 918 | 921 | NIST | 17368 | 120-12-7 |
| 3 | DIPHENYLETHYNE | C14H10 | 178 | 844 | 847 | NIST | 17370 | 501-65-5 |
| 4 | PHENANTHRENE | C14H10 | 178 | 824 | 837 | NIST | 17367 | 85-01-8 |
| 5 | 5H-DIBENZO A,D CYCLOHEPTEN-5-ONE | C15H10O | 206 | 706 | 709 | NIST | 24438 | 2222-33-5 |

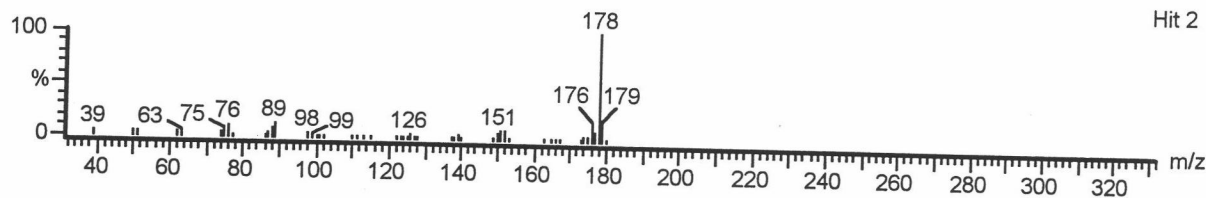
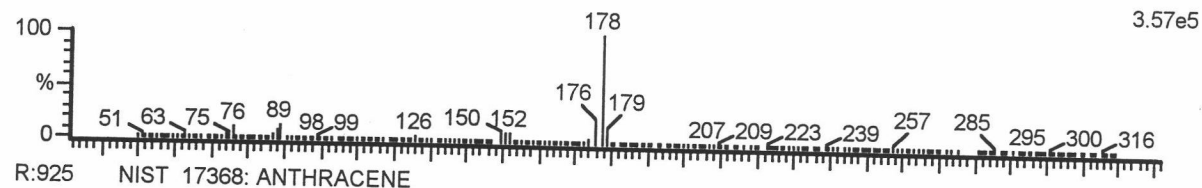
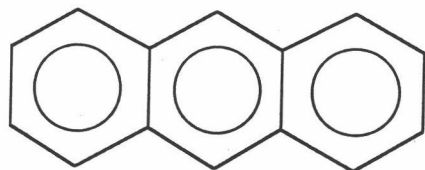
Figure C6 Mass Spectrum of Standard Phenanthrene and its NIST Library Searching Result

Compound Name: ANTHRACENE
 Synonym: Anthracin
 Molecular Weight: 178

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

Forward Fit : 878, Reverse Fit : 925

4PPM-M 1105 (11.155)



Data File: 4PPM-M

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|----------------------------------|---------|------|-----|-----|--------|-------|-----------|
| 1 | 9H-FLUORENE, 9-METHYLENE- | C14H10 | 178 | 878 | 941 | NIST | 17369 | 4425-82-5 |
| 2 | ANTHRACENE | C14H10 | 178 | 919 | 925 | NIST | 17368 | 120-12-7 |
| 3 | DIPHENYLETHYNE | C14H10 | 178 | 841 | 846 | NIST | 17370 | 501-65-5 |
| 4 | PHENANTHRENE | C14H10 | 178 | 826 | 840 | NIST | 17367 | 85-01-8 |
| 5 | 5H-DIBENZO A,D CYCLOHEPTEN-5-ONE | C15H10O | 208 | 702 | 706 | NIST | 24438 | 2222-33-5 |

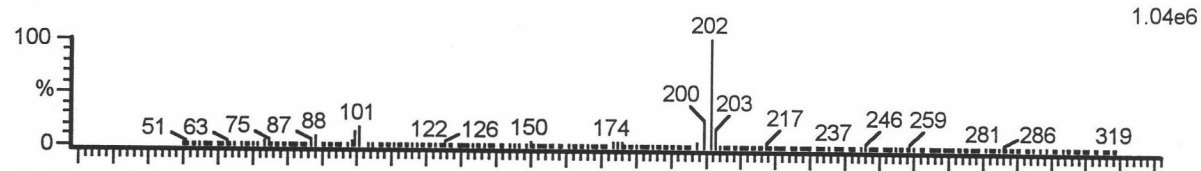
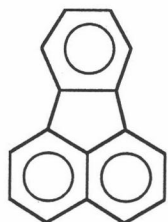
Figure C7 Mass Spectrum of Standard Anthracene and its NIST Library Searching Result

Compound Name: FLUORANTHENE
 Synonym: Benzene, 1,2-(1,8-naphthalenediyl)-
 Molecular Weight: 202

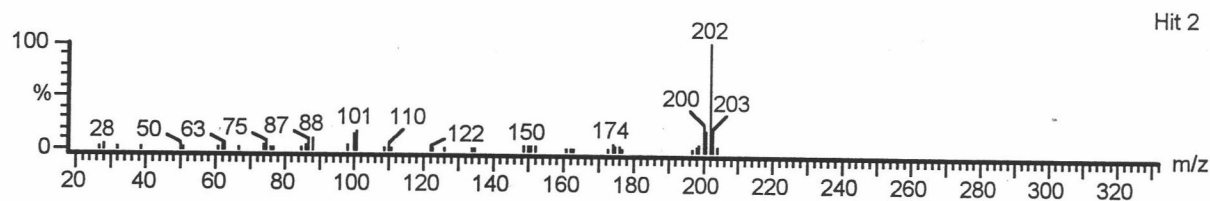
Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

Forward Fit : 859, Reverse Fit : 875

4PPM-M 1665 (14.898)



R:875 NIST 23467: FLUORANTHENE



Hit 2

Data File: 4PPM-M

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|--|---------|------|-----|-----|--------|-------|-----------|
| 1 | PYRENE | C16H10 | 202 | 870 | 887 | NIST | 23469 | 129-00-0 |
| 2 | FLUORANTHENE | C16H10 | 202 | 859 | 875 | NIST | 23467 | 206-44-0 |
| 3 | BENZENE, 1,1'-(1,3-BUTADIENE-1,4-DIYL)BIS- | C16H10 | 202 | 840 | 844 | NIST | 23468 | 886-66-8 |
| 4 | 7H-BENZ DE ANTHRACEN-7-ONE | C17H10O | 230 | 537 | 541 | NIST | 30040 | 82-05-3 |
| 5 | 1-PYRENE-CARBOXALDEHYDE | C17H10O | 230 | 426 | 431 | NIST | 30041 | 3029-19-4 |

Figure C8 Mass Spectrum of Standard Fluoranthene and its NIST Library Searching Result

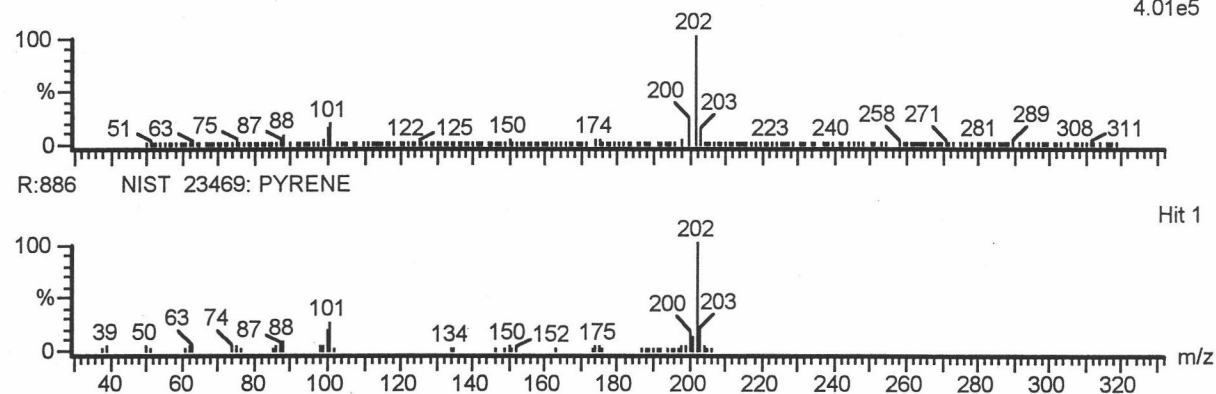
Compound Name: PYRENE
 Synonym: á-Pyrene
 Molecular Weight: 202

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

Forward Fit : 871, Reverse Fit : 886

4PPM-M 1762 (15.546)

4.01e5



Hit 1

Data File: 4PPM-M

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|--|-----------------------------------|------|-----|-----|--------|-------|-----------|
| 1 | PYRENE | C ₁₆ H ₁₀ | 202 | 871 | 886 | NIST | 23469 | 129-00-0 |
| 2 | FLUORANTHENE | C ₁₆ H ₁₀ | 202 | 843 | 861 | NIST | 23467 | 206-44-0 |
| 3 | BENZENE, 1,1'-(1,3-BUTADIYNE-1,4-DIYL)BIS- | C ₁₆ H ₁₀ | 202 | 805 | 810 | NIST | 23468 | 886-66-8 |
| 4 | 7H-BENZ DE ANTHRACEN-7-ONE | C ₁₇ H ₁₀ O | 230 | 527 | 531 | NIST | 30040 | 82-05-3 |
| 5 | 1-PYRENE-CARBOXALDEHYDE | C ₁₇ H ₁₀ O | 230 | 429 | 433 | NIST | 30041 | 3029-19-4 |

Figure C9 Mass Spectrum of Standard Pyrene and its NIST Library Searching Result

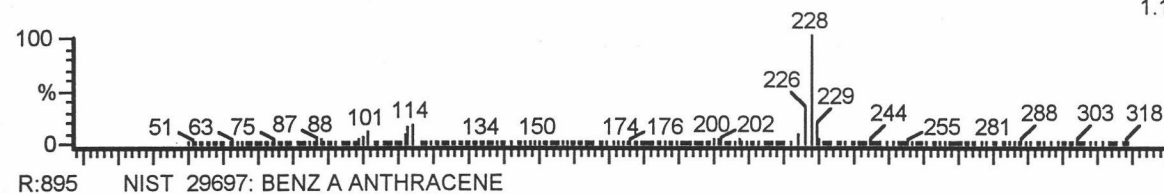
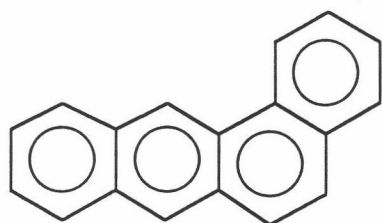
Compound Name: BENZ A ANTHRACENE
 Synonym: Benzanthracene
 Molecular Weight: 228

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

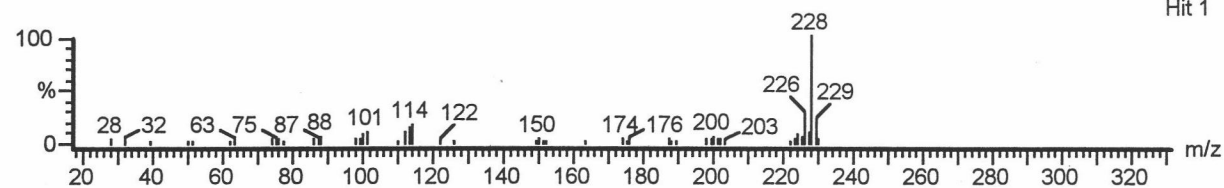
Forward Fit : 879, Reverse Fit : 895

4PPM-M 2596 (21.117)

1.15e5



R:895 NIST 29697: BENZ A ANTHRACENE



Hit 1

Data File: 4PPM-M

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

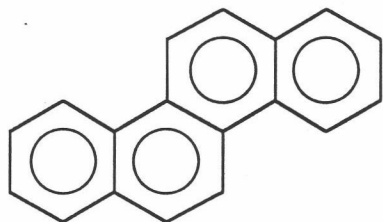
| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|----------------------|---------------------------------|------|-----|-----|--------|-------|----------|
| 1 | BENZ A ANTHRACENE | C ₁₈ H ₁₂ | 228 | 879 | 895 | NIST | 29697 | 56-55-3 |
| 2 | NAPHTHACENE | C ₁₈ H ₁₂ | 228 | 854 | 872 | NIST | 29693 | 92-24-0 |
| 3 | CHRYSENE | C ₁₈ H ₁₂ | 228 | 816 | 863 | NIST | 29696 | 218-01-9 |
| 4 | TRIPHENYLENE | C ₁₈ H ₁₂ | 228 | 809 | 832 | NIST | 29698 | 217-59-4 |
| 5 | BENZO C PHENANTHRENE | C ₁₈ H ₁₂ | 228 | 772 | 791 | NIST | 29694 | 195-19-7 |

Figure C10 Mass Spectrum of Standard Benz(a)anthracene and its NIST Library Searching Result

Compound Name: CHRYSENE
 Synonym: Benzo[a]phenanthrene
 Molecular Weight: 228

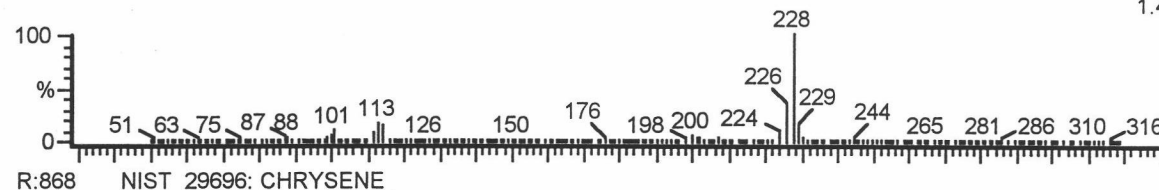
Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

Forward Fit : 849, Reverse Fit : 868

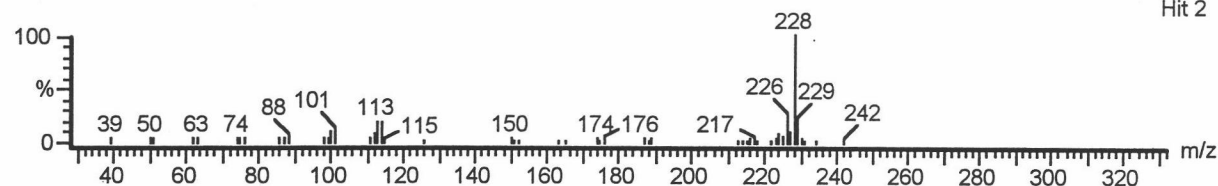


4PPM-M 2610 (21.210)

1.41e5



R:868 NIST 29696: CHRYSENE



Hit 2

Data File: 4PPM-M

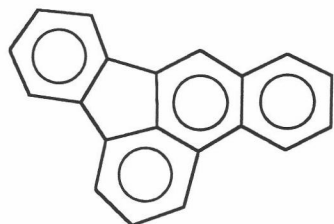
Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|----------------------|---------|------|-----|-----|--------|-------|----------|
| 1 | BENZ A ANTHRACENE | C18H12 | 228 | 882 | 896 | NIST | 29697 | 56-55-3 |
| 2 | CHRYSENE | C18H12 | 228 | 818 | 888 | NIST | 29696 | 218-01-9 |
| 3 | NAPHTHACENE | C18H12 | 228 | 849 | 868 | NIST | 29693 | 92-24-0 |
| 4 | TRIPHENYLENE | C18H12 | 228 | 803 | 826 | NIST | 29698 | 217-59-4 |
| 5 | BENZO C PHENANTHRENE | C18H12 | 228 | 782 | 797 | NIST | 29694 | 195-19-7 |

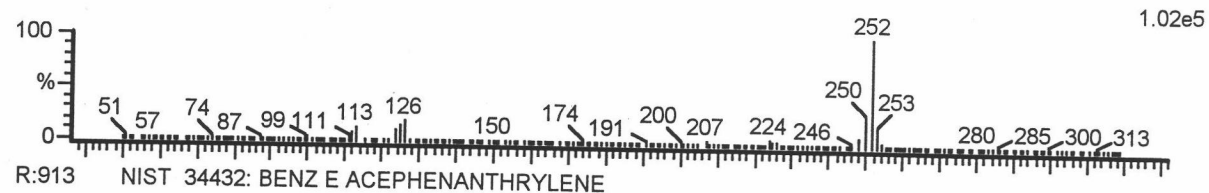
Figure C11 Mass Spectrum of Standard Chrysene and its NIST Library Searching Result

Compound Name: BENZ E ACEPHENANTHRYLENE Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610
 Synonym: Benzo[b]fluoranthene
 Molecular Weight: 252

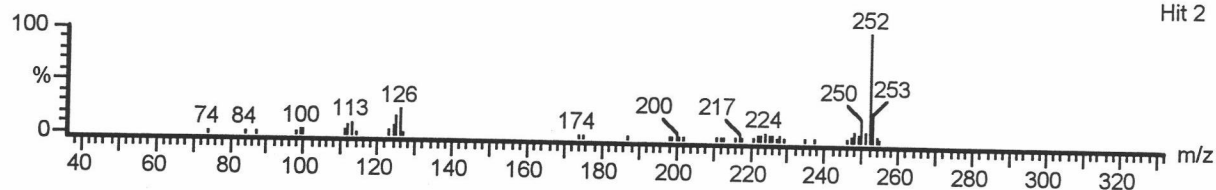
Forward Fit : 886, Reverse Fit : 913



4PPM-M 3187 (25.063)



R:913 NIST 34432: BENZ E ACEPHENANTHRYLENE



Hit 2

Data File: 4PPM-M

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|--------------------------|---------------------------------|------|-----|-----|--------|-------|----------|
| 1 | BENZO J FLUORANTHENE | C ₂₀ H ₁₂ | 252 | 901 | 925 | NIST | 34435 | 205-82-3 |
| 2 | BENZ E ACEPHENANTHRYLENE | C ₂₀ H ₁₂ | 252 | 886 | 913 | NIST | 34432 | 205-99-2 |
| 3 | BENZO K FLUORANTHENE | C ₂₀ H ₁₂ | 252 | 868 | 904 | NIST | 34434 | 207-08-9 |
| 4 | PERYLENE | C ₂₀ H ₁₂ | 252 | 871 | 901 | NIST | 34430 | 198-55-0 |
| 5 | BENZO E PYRENE | C ₂₀ H ₁₂ | 252 | 872 | 894 | NIST | 34433 | 192-97-2 |

Figure C12 Mass Spectrum of Standard Benzo(b)fluoranthene and its NIST Library Searching Result

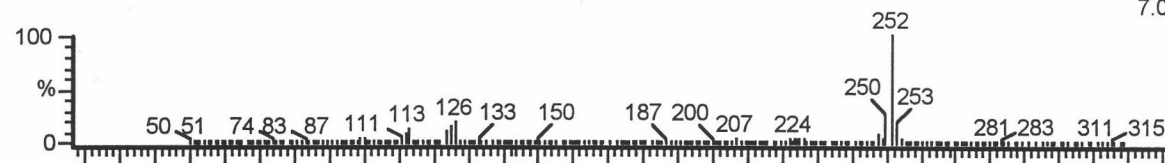
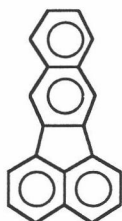
Compound Name: BENZO K FLUORANTHENE
 Synonym: Dibenzo[b,jk]fluorene
 Molecular Weight: 252

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

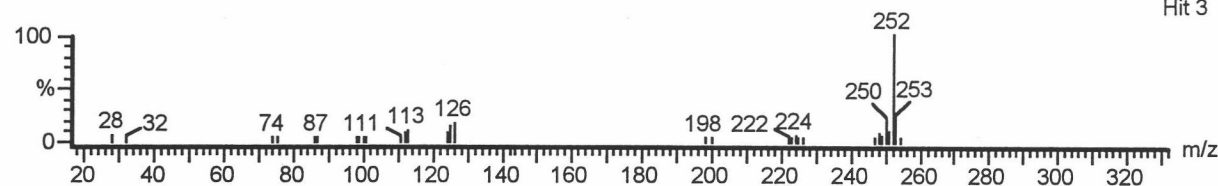
Forward Fit : 880, Reverse Fit : 915

4PPM-M 3201 (25.157)

7.07e4



R:915 NIST 34434: BENZO K FLUORANTHENE



Hit 3

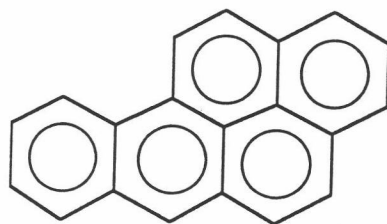
Data File: 4PPM-M

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|--------------------------|---------------------------------|------|-----|-----|--------|-------|----------|
| 1 | BENZO J FLUORANTHENE | C ₂₀ H ₁₂ | 252 | 898 | 934 | NIST | 34435 | 205-82-3 |
| 2 | BENZ E ACEPHENANTHRYLENE | C ₂₀ H ₁₂ | 252 | 881 | 922 | NIST | 34432 | 205-99-2 |
| 3 | BENZO K FLUORANTHENE | C ₂₀ H ₁₂ | 252 | 868 | 915 | NIST | 34434 | 207-08-9 |
| 4 | BENZO E PYRENE | C ₂₀ H ₁₂ | 252 | 880 | 913 | NIST | 34433 | 192-97-2 |
| 5 | PERYLENE | C ₂₀ H ₁₂ | 252 | 871 | 913 | NIST | 34430 | 198-55-0 |

Figure C13 Mass Spectrum of Standard Benzo(k)fluoranthene and its NIST Library Searching Result

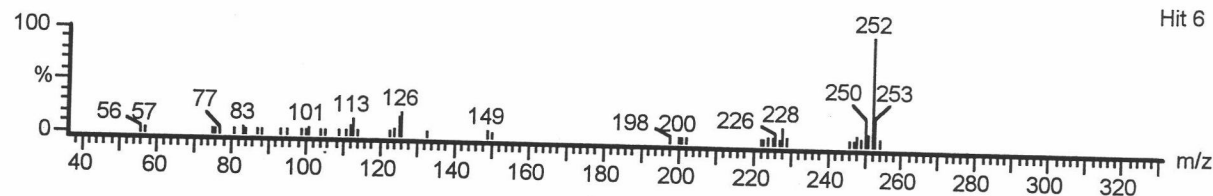
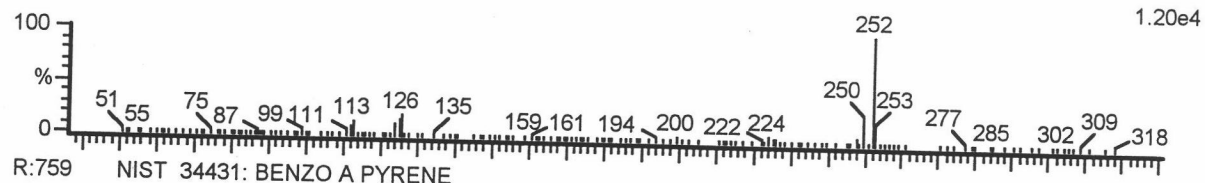
Compound Name: BENZO A PYRENE
 Synonym: Benz[a]pyrene
 Molecular Weight: 252



Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

Forward Fit : 740, Reverse Fit : 759

4PPM-M 3341 (26.091) Cm (3337:3345-(3322:3336+3417:3458))



Data File: 4PPM-M

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|---|---------|------|-----|-----|--------|-------|------------|
| 1 | BENZO J FLUORANTHENE | C20H12 | 252 | 912 | 933 | NIST | 34435 | 205-82-3 |
| 2 | BENZ E ACEPHENANTHRYLENE | C20H12 | 252 | 890 | 917 | NIST | 34432 | 205-99-2 |
| 3 | BENZO K FLUORANTHENE | C20H12 | 252 | 885 | 913 | NIST | 34434 | 207-08-9 |
| 4 | PERYLENE | C20H12 | 252 | 884 | 912 | NIST | 34430 | 198-55-0 |
| 5 | BENZO E PYRENE | C20H12 | 252 | 880 | 901 | NIST | 34433 | 192-97-2 |
| 6 | BENZO A PYRENE | C20H12 | 252 | 740 | 759 | NIST | 34431 | 50-32-8 |
| 7 | 1H-INDENE, 1,1'-(1,2-ETHANEDIYLIDENE)BIS- | C20H14 | 254 | 603 | 676 | NIST | 34834 | 72088-04-1 |
| 8 | BENZO A PYRENE, 4,5-DIHYDRO- | C20H14 | 254 | 609 | 637 | NIST | 34832 | 57652-66-1 |

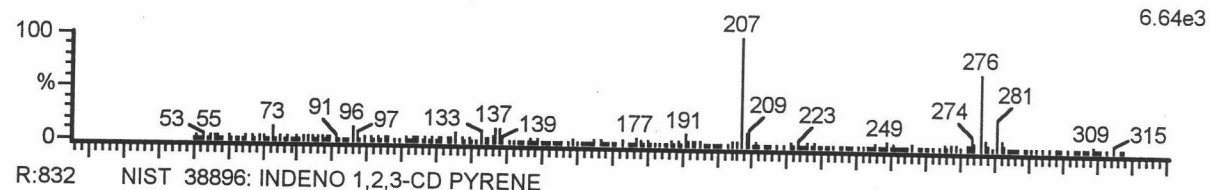
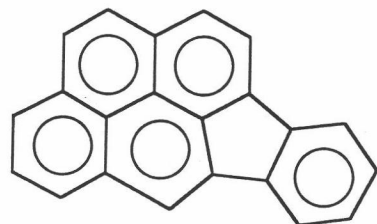
Figure C14 Mass Spectrum of Standard Benzo(a)pyrene and its NIST Library Searching Result

Compound Name: INDENO 1,2,3-CD PYRENE
 Synonym: o-Phenyleneperylene
 Molecular Weight: 276

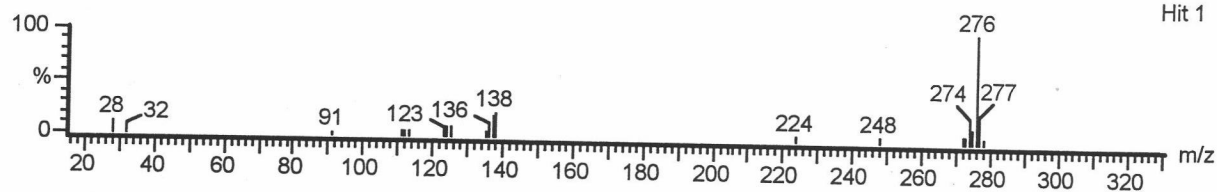
Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

Forward Fit : 390, Reverse Fit : 832

4PPM-M 3810 (29.222)



R:832 NIST 38896: INDENO 1,2,3-CD PYRENE



Hit 1

Data File: 4PPM-M

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|--|-------------|------|-----|-----|--------|-------|----------|
| 1 | INDENO 1,2,3-CD PYRENE | C22H12 | 276 | 286 | 832 | NIST | 38896 | 193-39-5 |
| 2 | BENZO GHI PERYLENE | C22H12 | 276 | 300 | 818 | NIST | 38894 | 191-24-2 |
| 3 | 1,12-BENZPERYLENE | C22H12 | 276 | 280 | 761 | NIST | 38893 | 0-00-0 |
| 4 | 3,3-DIETHOXY-1,1,1,5,5,5-HEXAMETHYLTRISILOXANE | C10H28O4Si3 | 296 | 390 | 697 | NIST | 41981 | 0-00-0 |
| 5 | DIBENZO DEF,MNO CHRYSENE | C22H12 | 276 | 255 | 663 | NIST | 38895 | 191-26-4 |

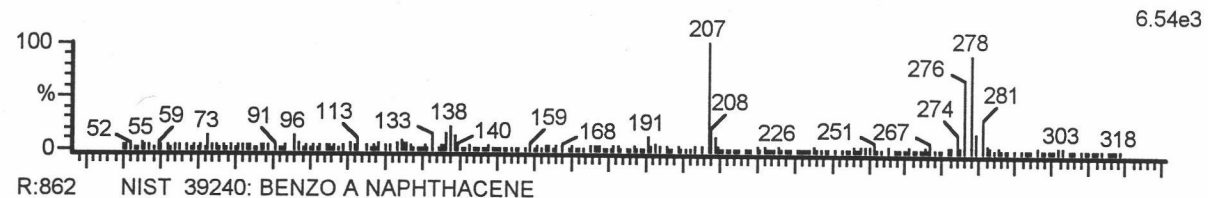
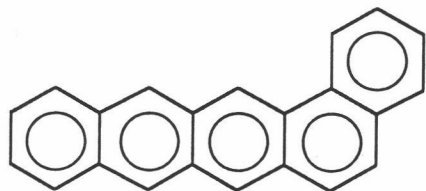
Figure C15 Mass Spectrum of Standard Indeno(1,2,3-cd)pyrene and its NIST Library Searching Result

Compound Name: BENZO A NAPHTHACENE
 Synonym:
 Molecular Weight: 278

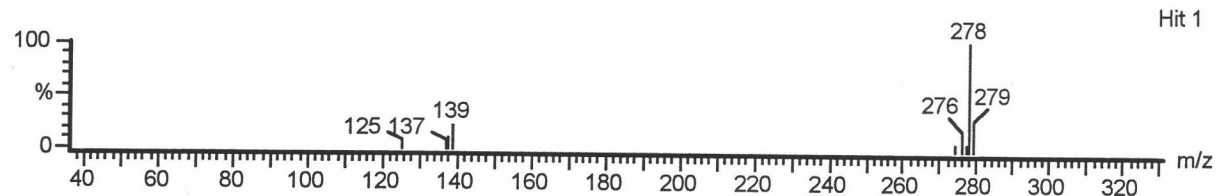
Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

Forward Fit : 486, Reverse Fit : 862

4PPM-M 3823 (29.309)



R:862 NIST 39240: BENZO A NAPHTHACENE



Data File: 4PPM-M

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|----------------------------|---------|------|-----|-----|--------|-------|----------|
| 1 | BENZO A NAPHTHACENE | C22H14 | 278 | 371 | 862 | NIST | 39240 | 226-88-0 |
| 2 | DIBENZ A,J ANTHRACENE | C22H14 | 278 | 369 | 862 | NIST | 39242 | 224-41-9 |
| 3 | 1,2:7,8-DIBENZPHENANTHRENE | C22H14 | 278 | 421 | 741 | NIST | 39237 | 0-00-0 |
| 4 | BENZO B CHRYSENE | C22H14 | 278 | 426 | 724 | NIST | 39241 | 214-17-5 |
| 5 | DIBENZ A,H ANTHRACENE | C22H14 | 278 | 344 | 882 | NIST | 39243 | 53-70-3 |

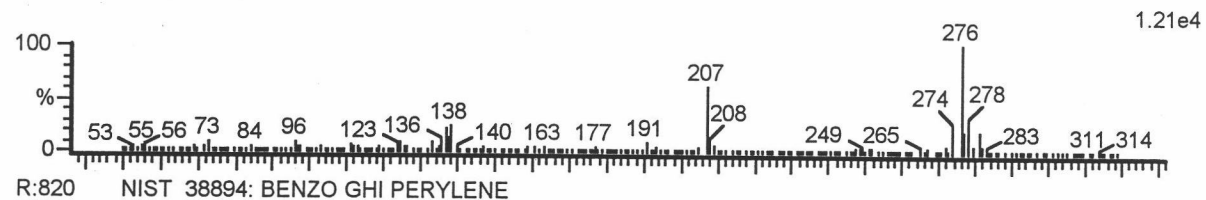
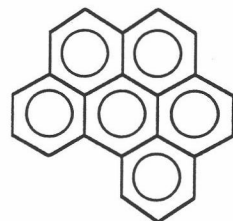
Figure C16 Mass Spectrum of Standard Dibenzo(a,h)anthracene and its NIST Library Searching Result

Compound Name: BENZO GHI PERYLENE
 Synonym: Benzo-1,12-perylene
 Molecular Weight: 276

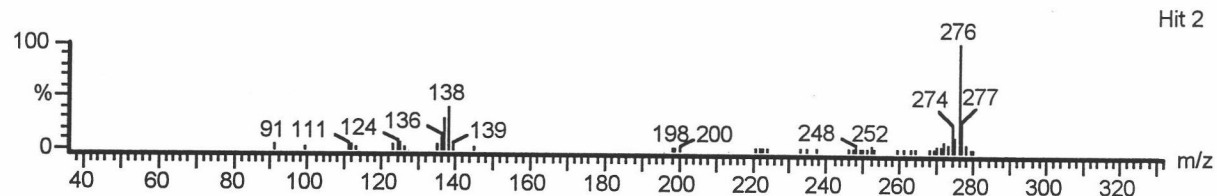
Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

Forward Fit : 466, Reverse Fit : 820

4PPM-M 3862 (29.569)



R:820 NIST 38894: BENZO GHI PERYLENE



Hit 2

Data File: 4PPM-M

Sample ID: Polynuclear Aromatic Hydrocarbons Mixture from EPA 610

| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|----------------------------|---------|------|-----|-----|--------|-------|----------|
| 1 | INDENO 1,2,3-CD PYRENE | C22H12 | 276 | 466 | 823 | NIST | 38896 | 193-39-5 |
| 2 | BENZO GHI PERYLENE | C22H12 | 276 | 489 | 820 | NIST | 38894 | 191-24-2 |
| 3 | 1,12-BENZPERYLENE | C22H12 | 276 | 454 | 769 | NIST | 38893 | 0-00-0 |
| 4 | DIBENZO DEF,MNO CHRYSENE | C22H12 | 276 | 385 | 651 | NIST | 38895 | 191-26-4 |
| 5 | 1,2:7,8-DIBENZPHENANTHRENE | C22H14 | 278 | 355 | 562 | NIST | 39237 | 0-00-0 |

Figure C17 Mass Spectrum of Standard Benzo(*ghi*)perylene and its NIST Library Searching Result

APPENDIX D

The Study of PAHs in Material used for Sampling and the Recovery
and Repeatability of the Analytical Method

Contaminants of PAHs from materials for sampling the exhaust emission, repeatability, and recovery of an analytical method were studied. The results are shown in Table D1-D3 [27].

Table D1 PAHs in Blank Glass Microfiber Filter (GF) and Blank Polyurethane Foams (PUF)

| PAHs | Blank GF (µg/ml) | Blank PUF (µg/ml) |
|---------------------|------------------|-------------------|
| Naphthalene | 0.00 | 1.16 |
| Methylnaphthalene | 0.00 | 1.18 |
| Dimethylnaphthalene | 0.00 | 1.50 |
| Acenaphthene | 0.00 | 1.07 |

Table D2 Repeatability of the Analytical Method

| PAHs | Repeatability (µg/ml) | | | SD |
|---------------------|-----------------------|-------|-------|-------|
| | 1 | 2 | 3 | |
| Naphthalene | 15.47 | 14.44 | 15.63 | 0.645 |
| Methylnaphthalene | 19.30 | 14.67 | 19.17 | 2.636 |
| Dimethylnaphthalene | 14.86 | 12.89 | 14.31 | 1.016 |
| Acenaphthene | 11.08 | 11.25 | 10.35 | 0.478 |
| Phenanthrene | 1.06 | 1.06 | 1.07 | 0.005 |
| Methylphenanthrene | 3.08 | 3.17 | 2.97 | 0.100 |
| Fluoranthene | 0.35 | 0.37 | 0.33 | 0.175 |
| Pyrene | 1.66 | 1.63 | 1.65 | 0.015 |

Table D3 Recovery of the Extraction Method

| PAHs | First Extraction ($\mu\text{g/ml}$) | Second extraction ($\mu\text{g/ml}$) | % Recovery |
|---------------------|---|--|-----------------------|
| Naphthalene | 15.47 | 2.88 | 81.38 |
| Methylnaphthalene | 19.30 | 0.57 | 97.04 |
| Dimethylnaphthalene | 14.86 | 1.34 | 90.98 |
| Acenaphthene | 11.08 | 0.00 | 100.00 |
| Phenanthrene | 1.06 | 0.00 | 100.00 |
| Methylphenanthrene | 3.08 | 0.00 | 100.00 |
| Fluoranthene | 0.35 | 0.00 | 100.00 |
| Pyrene | 1.66 | 0.00 | 100.00 |

From Table D1-D3, it can be seen that some low molecular weight PAHs contaminate the polyurethane foams. Repeatability of the analytical method indicates a good precision. High molecular weight PAHs have better precision than the low ones because the latter can easily be lost during sampling, extraction, and storage. The recovery of high molecular weight PAHs by extraction was better than that of the low molecular weight PAHs.

APPENDIX E

Total Ion Chromatogram of Gasoline Exhaust Emission and
Ion Chromatogram, Mass Spectra, and Computerized Searching Results
of Selected PAHs in Gasoline Engine Exhaust

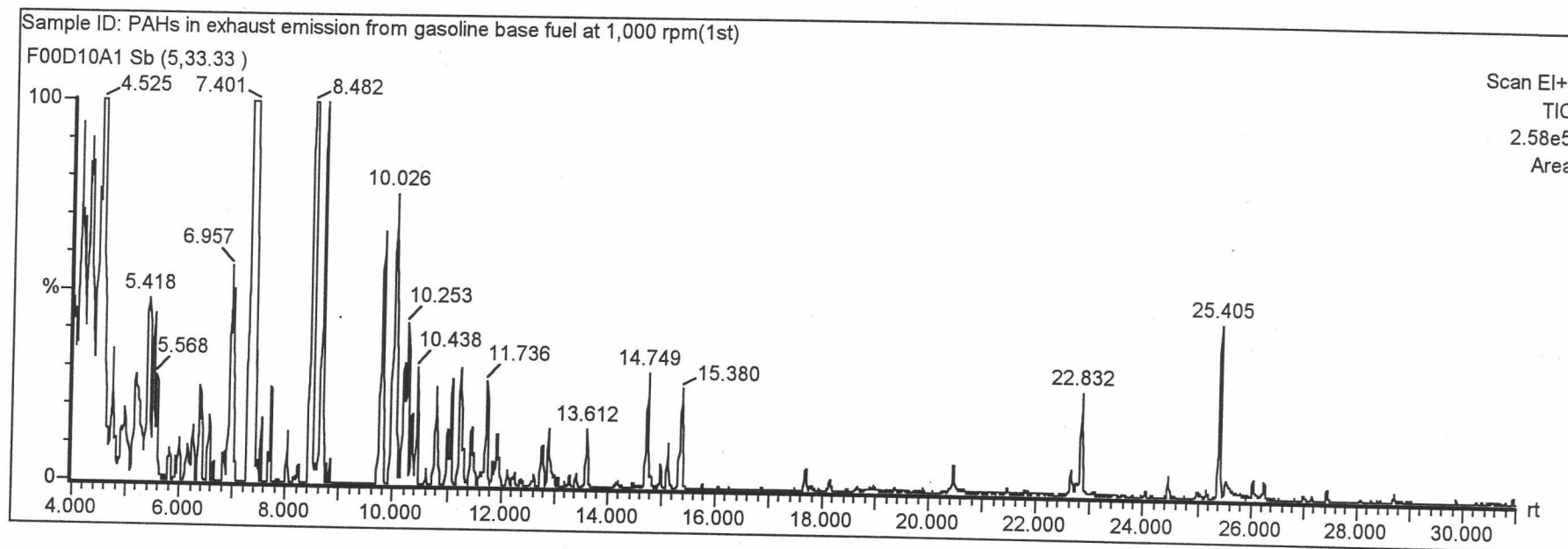
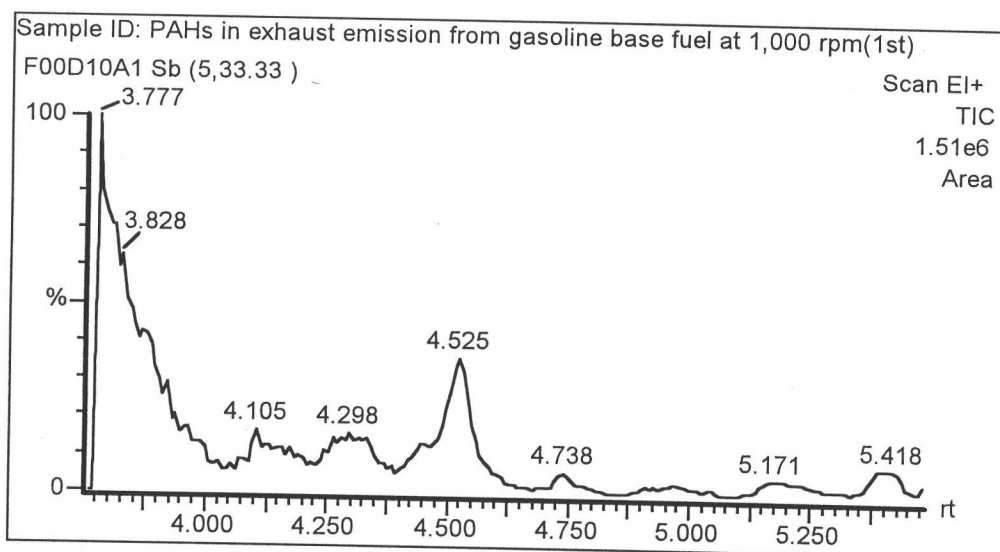
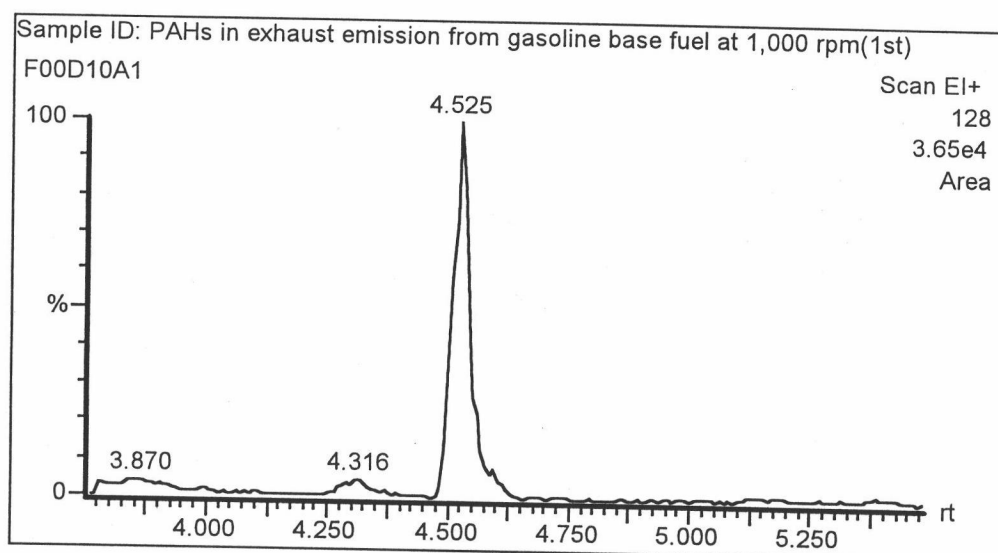


Figure E1 Total Ion Chromatogram of Gasoline Test Engine Exhaust Emission



(a)



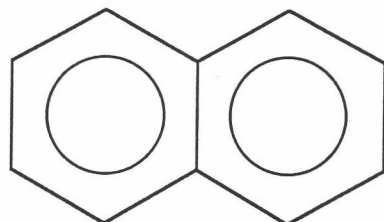
(b)

Figure E2 (a) Total Ion Chromatogram of Naphthalene Fraction
(b) Selected Ion Chromatogram of Naphthalene at $m/z = 128$
(c) Mass Spectrum of Naphthalene Fraction and its NIST
Library Searching Result

Compound Name: NAPHTHALENE
 Synonym: Albocarbon
 Molecular Weight: 128

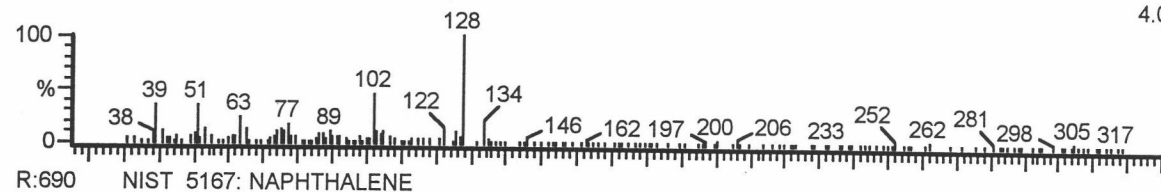
Sample ID: PAHs in exhaust emission from gasoline base fuel at 1,000 rpm(1st)

Forward Fit : 562, Reverse Fit : 690



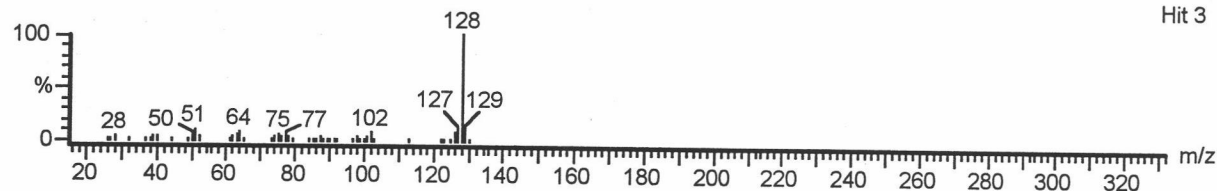
F00D10A1 89 (4.525) Cm (89-(89:90+88:89))

4.00e3



R:690 NIST 5167: NAPHTHALENE

Hit 3



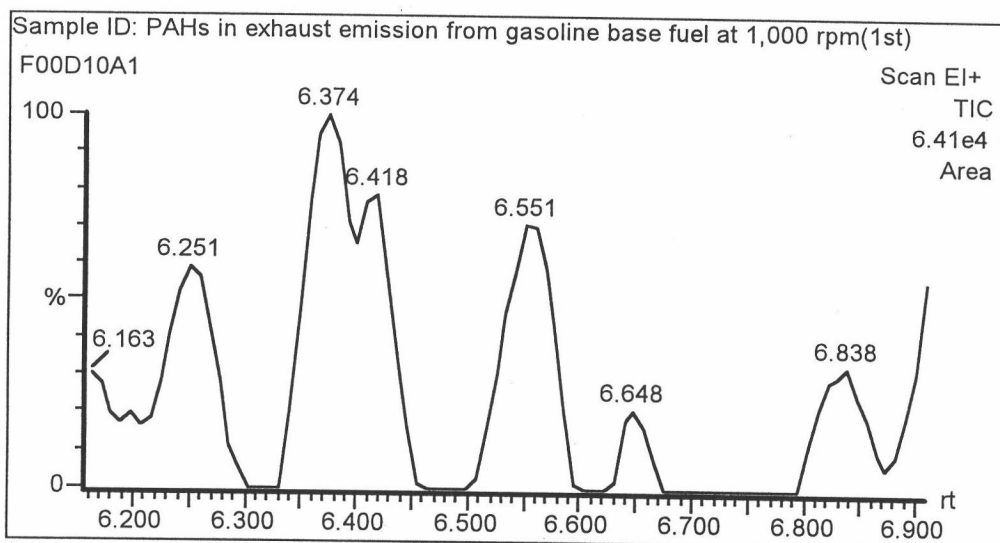
Data File: F00D10A1

Sample ID: PAHs in exhaust emission from gasoline base fuel at 1,000 rpm(1st)

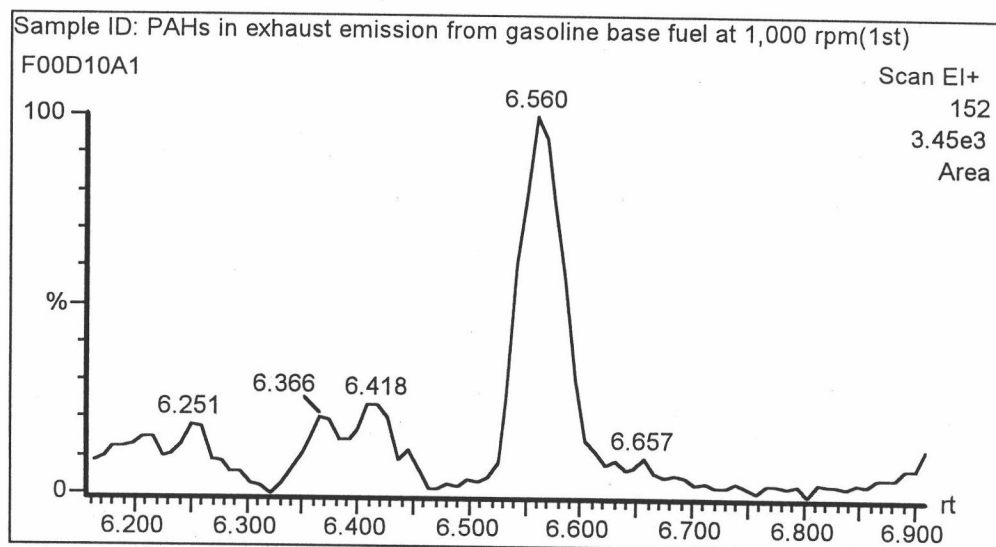
| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|---|----------|------|-----|-----|--------|-------|------------|
| 1 | 1H-INDENE, 1-METHYLENE- | C10H8 | 128 | 562 | 823 | NIST | 5168 | 2471-84-3 |
| 2 | 4,2,2 PROPELLA-2,4,7,9-TETRAENE | C10H8 | 128 | 652 | 805 | NIST | 5169 | 88090-34-0 |
| 3 | NAPHTHALENE | C10H8 | 128 | 582 | 690 | NIST | 5167 | 91-20-3 |
| 4 | BENZENE, 1-ETHENYL-3-METHOXY- | C9H10O | 134 | 415 | 630 | NIST | 6157 | 626-20-0 |
| 5 | 2H-THIETE, 2-METHYLENE-4-PHENYL-, 1,1-DIOXIDE | C10H8O2S | 192 | 445 | 622 | NIST | 20649 | 16793-43-4 |

(c)

Figure E2 (continued)



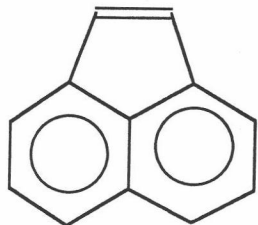
(a)



(b)

Figure E3 (a) Total Ion Chromatogram of Acenaphthylene Fraction
 (b) Selected Ion Chromatogram of Acenaphthylene at $m/z = 152$
 (c) Mass Spectrum of Acenaphthylene Fraction and its NIST
 Library Searching Result

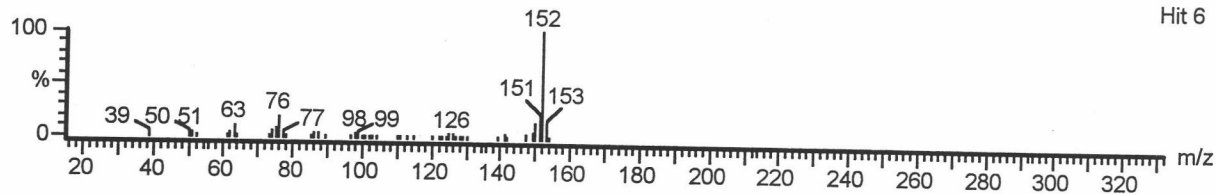
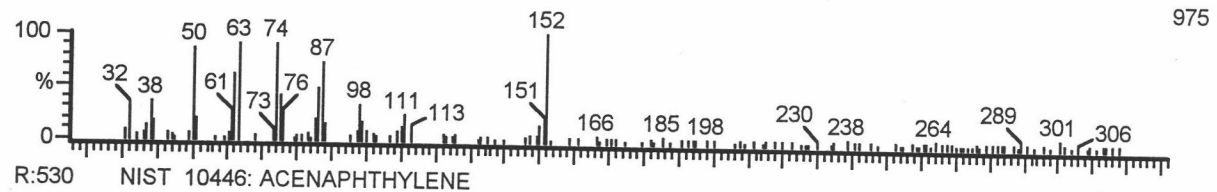
Compound Name: ACENAPHTHYLENE
 Synonym: Cyclopenta[de]naphthalene
 Molecular Weight: 152



Sample ID: PAHs in exhaust emission from gasoline base fuel at 1,000 rpm(1st)

Forward Fit : 354, Reverse Fit : 530

F00D10A1 320 (6.586) Cm (320:322-(322:325+306:313))



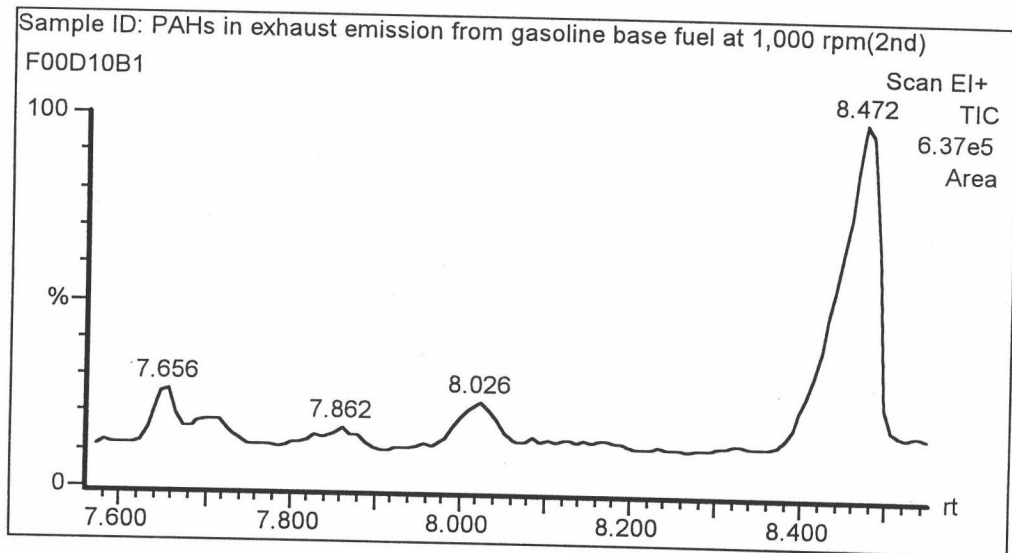
Data File: F00D10A1

Sample ID: PAHs in exhaust emission from gasoline base fuel at 1,000 rpm(1st)

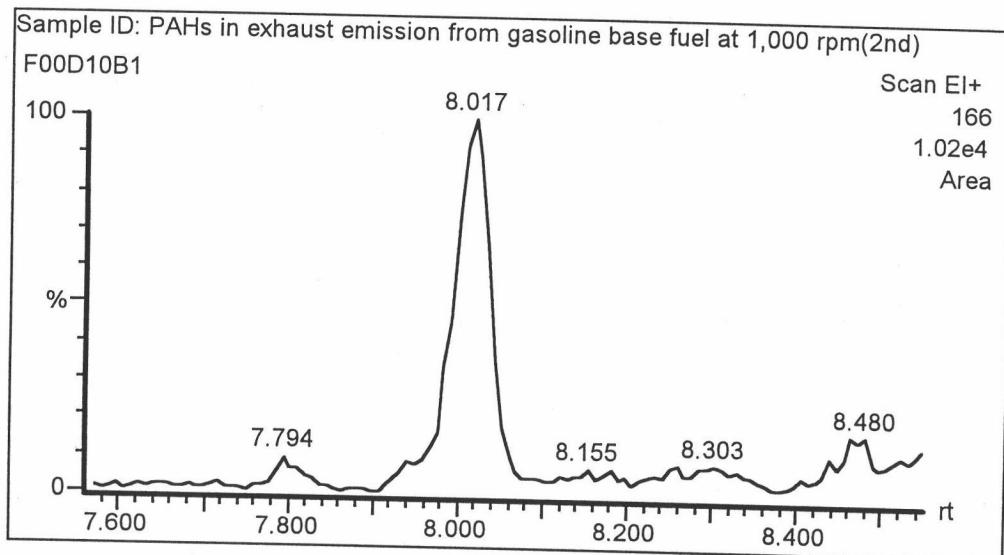
| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|---|------------|------|-----|-----|--------|-------|------------|
| 1 | BIPHENYLENE | C12H8 | 152 | 650 | 718 | NIST | 10447 | 259-79-0 |
| 2 | PROPANAL, 3-(METHYLTHIO)-, (2,4-DINITROPHENYL)HYDRA | C10H12O4N4 | 284 | 205 | 585 | NIST | 40035 | 7372-40-8 |
| 3 | 4-CHLOROBUTEN-3-YNE | C4H3Cl | 86 | 175 | 564 | NIST | 649 | 40589-38-8 |
| 4 | 1,2,3-BUTATRIENE, 1-CHLORO- | C4H3Cl | 86 | 169 | 546 | NIST | 648 | 20658-21-3 |
| 5 | 1-BUTEN-3-YNE, 1-CHLORO-, (E)- | C4H3Cl | 86 | 164 | 531 | NIST | 651 | 20374-91-8 |
| 6 | ACENAPHTHYLENE | C12H8 | 152 | 449 | 530 | NIST | 10446 | 208-96-8 |

(c)

Figure E3 (continued)



(a)



(b)

Figure E4 (a) Total Ion Chromatogram of Fluorene Fraction
 (b) Selected Ion Chromatogram of Fluorene at $m/z = 166$
 (c) Mass Spectrum of Fluorene Fraction and its NIST
 Library Searching Result

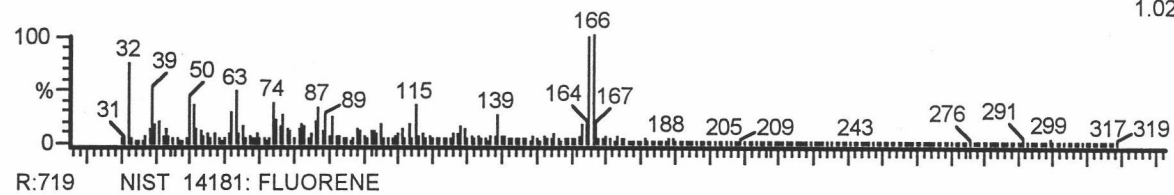
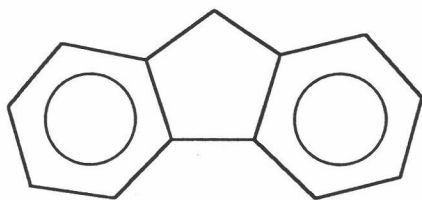
Compound Name: FLUORENE
 Synonym: 9H-Fluorene
 Molecular Weight: 166

Sample ID: PAHs in exhaust emission from gasoline base fuel at 1,000 rpm(2nd)

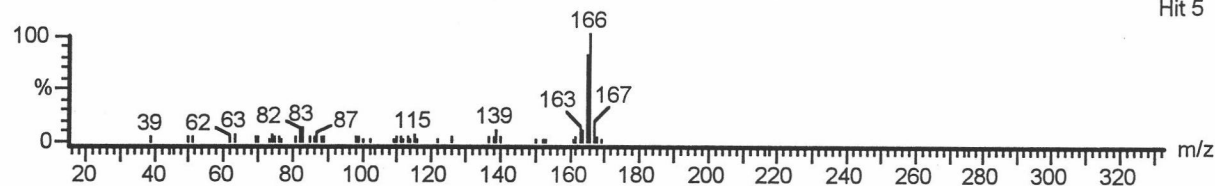
Forward Fit : 502, Reverse Fit : 719

F00D10B1 501 (8.017)

1.02e4



R:719 NIST 14181: FLUORENE



Hit 5

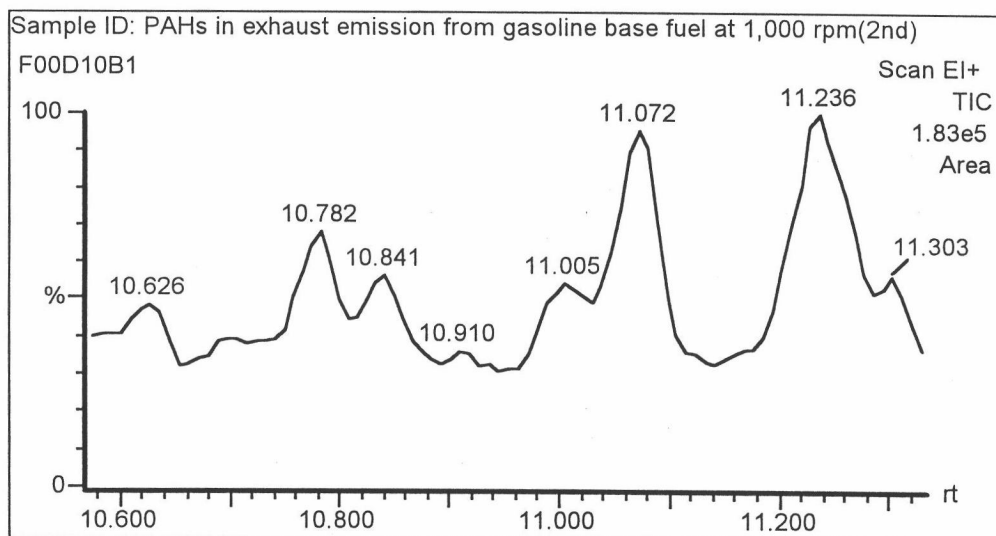
Data File: F00D10B1

Sample ID: PAHs in exhaust emission from gasoline base fuel at 1,000 rpm(2nd)

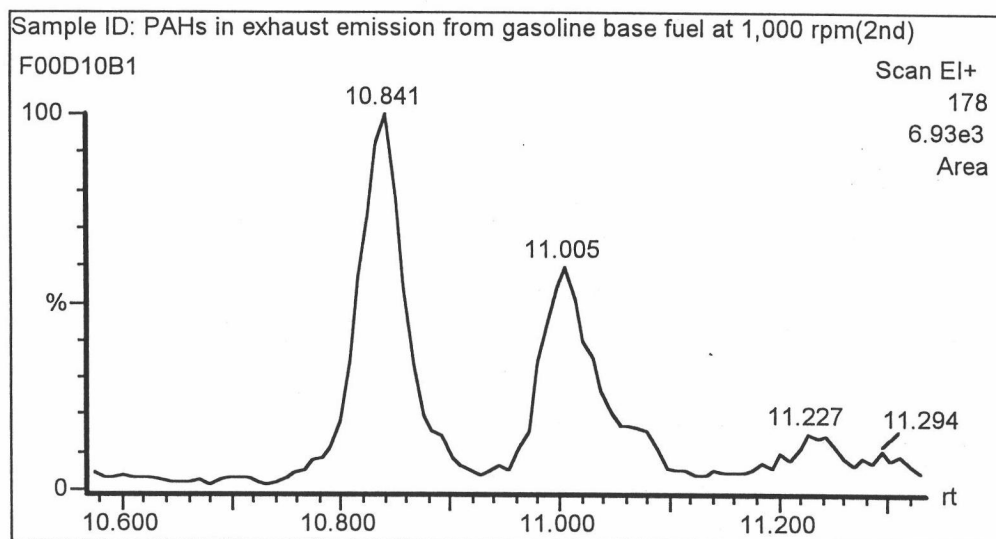
| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|------------------------------------|----------|------|-----|-----|--------|-------|----------|
| 1 | 11H-DIBENZO C,F 1,2 DIAZEPINE | C13H10N2 | 194 | 605 | 838 | NIST | 21360 | 256-91-7 |
| 2 | 1H-PHENALENE | C13H10 | 166 | 502 | 751 | NIST | 14180 | 203-80-5 |
| 3 | 9,10-ANTHRACENEDIONE, 2-METHYL- | C15H10O2 | 222 | 468 | 734 | NIST | 28174 | 84-54-8 |
| 4 | BENZENE, 1,1'-(DIAZOMETHYLENE)BIS- | C13H10N2 | 194 | 445 | 719 | NIST | 21363 | 883-40-9 |
| 5 | FLUORENE | C13H10 | 166 | 532 | 719 | NIST | 14181 | 86-73-7 |
| 6 | 9,10-ANTHRACENEDIONE, 1-METHYL- | C15H10O2 | 222 | 465 | 714 | NIST | 28178 | 954-07-4 |

(c)

Figure E4 (continued)



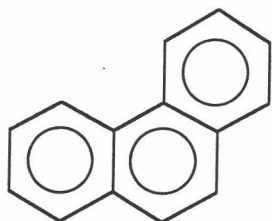
(a)



(b)

Figure E5 (a) Total Ion Chromatogram of Phenanthrene Fraction
(b) Selected Ion Chromatogram of Phenanthrene at $m/z = 178$
(c) Mass Spectrum of Phenanthrene Fraction and its NIST
Library Searching Result

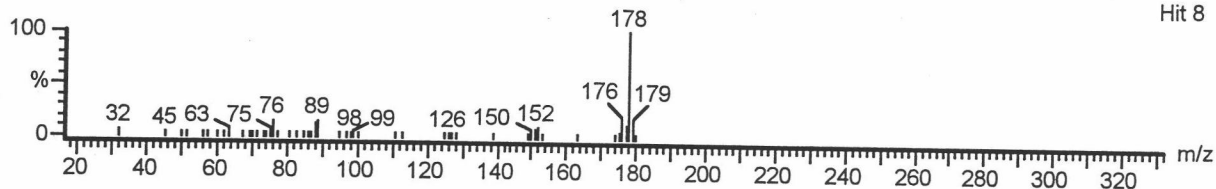
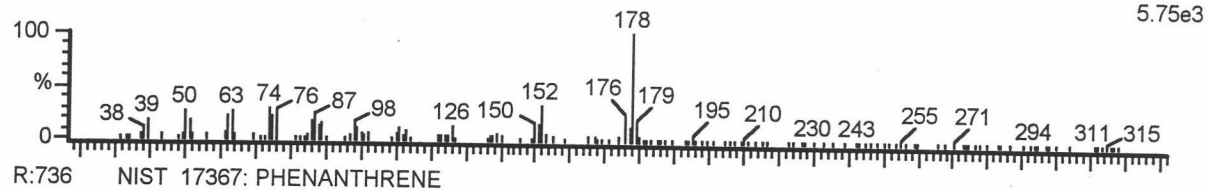
Compound Name: PHENANTHRENE
 Synonym: Phenanthren
 Molecular Weight: 178



Sample ID: PAHs in exhaust emission from gasoline base fuel at 1,000 rpm(2nd)

Forward Fit : 541, Reverse Fit : 736

F00D10B1 829 (10.841) Cm (828:830-(833:842+814:823))



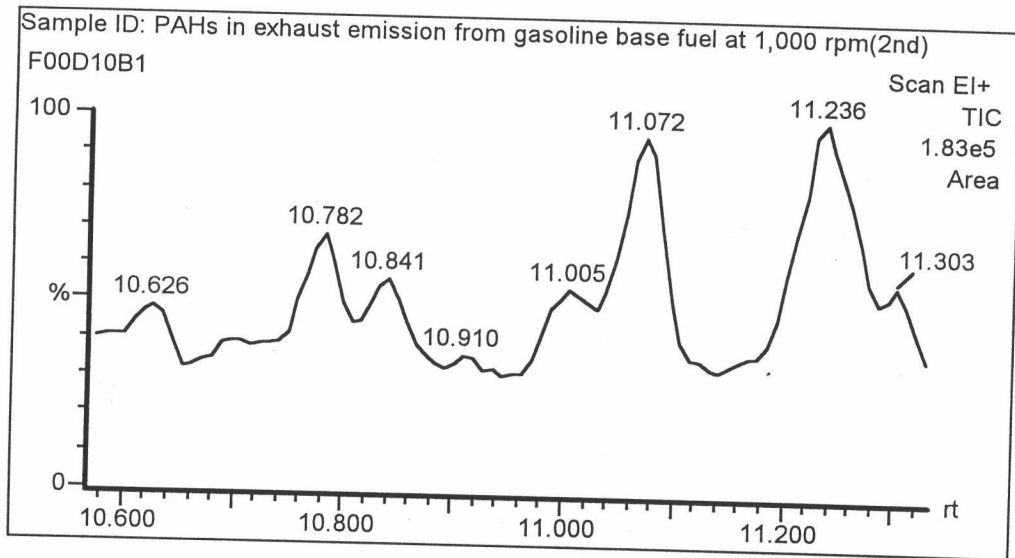
Data File: F00D10B1

Sample ID: PAHs in exhaust emission from gasoline base fuel at 1,000 rpm(2nd)

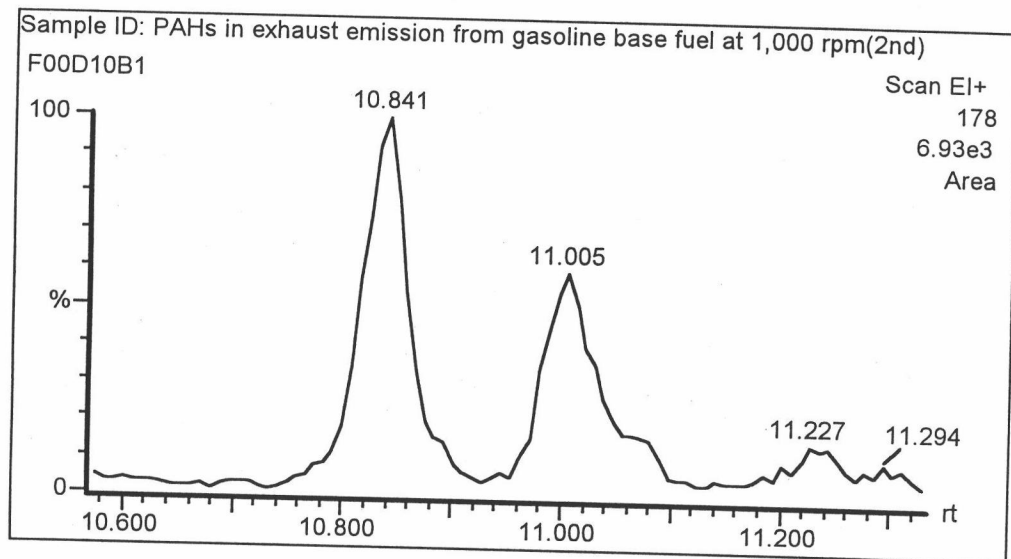
| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|---|-----------|------|-----|-----|--------|-------|------------|
| 1 | 9H-FLUORENE, 9-METHYLENE- | C14H10 | 178 | 598 | 899 | NIST | 17369 | 4425-82-5 |
| 2 | DIPHENYLETHYNE | C14H10 | 178 | 834 | 868 | NIST | 17370 | 501-65-5 |
| 3 | 1,2,4,5-BENZENETETRACARBONITRILE | C10H2N4 | 178 | 430 | 810 | NIST | 17129 | 712-74-3 |
| 4 | 4-HYDROXY-5-METHYL-3-PHENYL-Delta.(2)-1,2,4-OXADIAZ | C9H10O2N2 | 178 | 361 | 770 | NIST | 17115 | 16227-04-6 |
| 5 | BIPHENYLENE | C12H8 | 152 | 518 | 763 | NIST | 10447 | 259-79-0 |
| 6 | ANTHRACENE | C14H10 | 178 | 727 | 762 | NIST | 17368 | 120-12-7 |
| 7 | CINNOLINE, 4-PHENYL- | C14H10N2 | 206 | 667 | 750 | NIST | 24392 | 21874-06-6 |
| 8 | PHENANTHRENE | C14H10 | 178 | 654 | 736 | NIST | 17367 | 85-01-8 |
| 9 | 9,10-ETHANOANTHRACENE, 9,10-DIHYDRO- | C16H14 | 206 | 503 | 714 | NIST | 24479 | 5675-64-9 |

(c)

Figure E5 (continued)



(a)



(b)

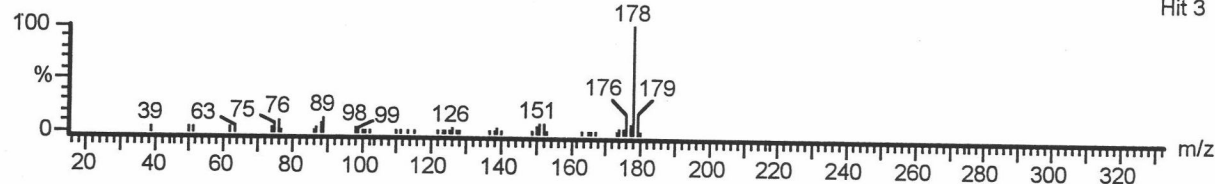
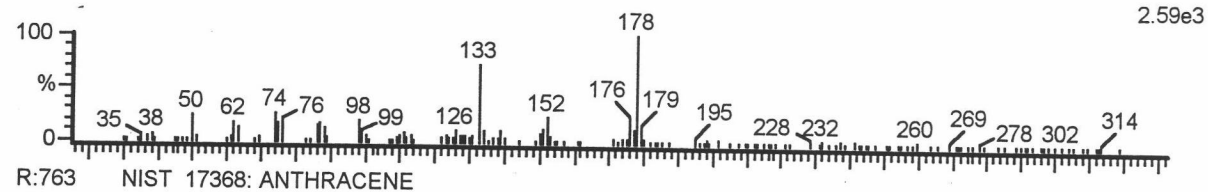
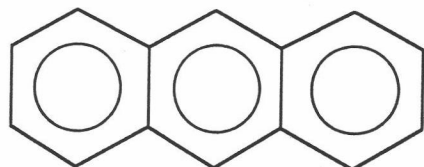
Figure E6 (a) Total Ion Chromatogram of Anthracene Fraction
 (b) Selected Ion Chromatogram of Anthracene at $m/z = 178$
 (c) Mass Spectrum of Anthracene Fraction and its NIST
 Library Searching Result

Compound Name: ANTHRACENE
 Synonym: Anthracin
 Molecular Weight: 178

Sample ID: PAHs in exhaust emission from gasoline base fuel at 1,000 rpm(2nd)

Forward Fit : 578, Reverse Fit : 763

F00D10B1 848 (11.005) Cm (846:848-(843:845+853:860))



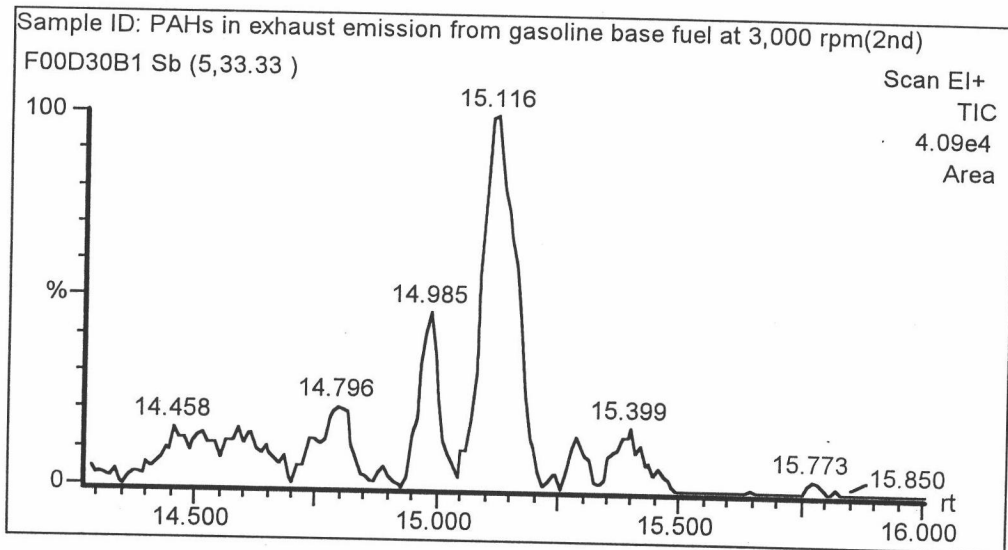
Data File: F00D10B1

Sample ID: PAHs in exhaust emission from gasoline base fuel at 1,000 rpm(2nd)

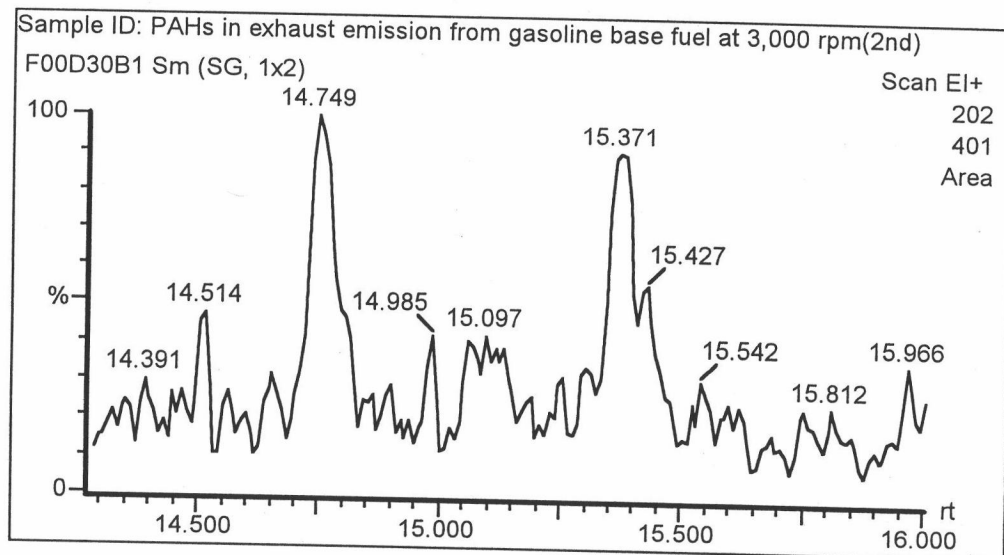
| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|---|---------|------|-----|-----|--------|-------|------------|
| 1 | 9H-FLUORENE, 9-METHYLENE- | C14H10 | 178 | 511 | 907 | NIST | 17369 | 4425-82-5 |
| 2 | DIPHENYLETHYNE | C14H10 | 178 | 665 | 832 | NIST | 17370 | 501-65-5 |
| 3 | ANTHRACENE | C14H10 | 178 | 608 | 763 | NIST | 17368 | 120-12-7 |
| 4 | 7,8-DIPHENYLBICYCLO 4.2.1 NONA-2,4,7-TRIENE | C21H18 | 270 | 578 | 752 | NIST | 37860 | 54049-09-1 |
| 5 | PHENANTHRENE | C14H10 | 178 | 562 | 737 | NIST | 17367 | 85-01-8 |

(c)

Figure E6 (continued)



(a)



(b)

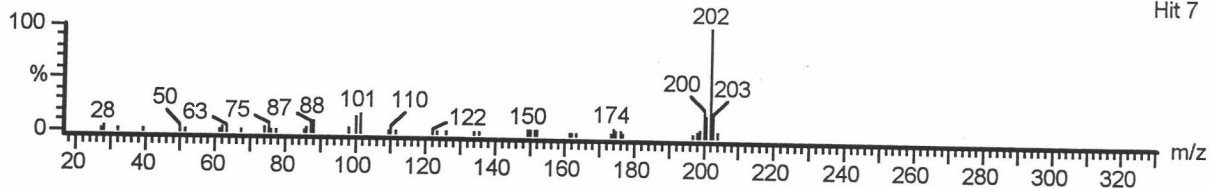
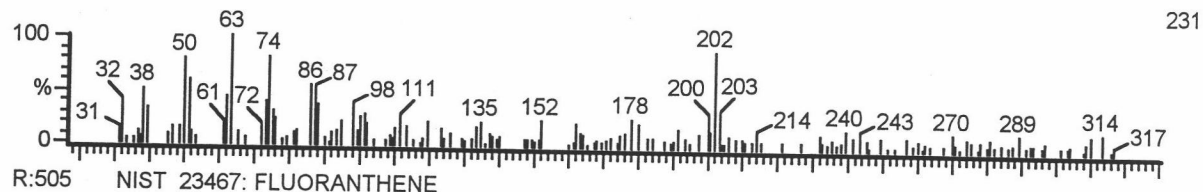
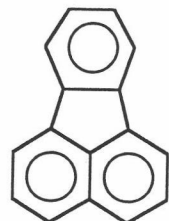
Figure E7 (a) Total Ion Chromatogram of Fluoranthene Fraction
(b) Selected Ion Chromatogram of Fluoranthene at $m/z = 202$
(c) Mass Spectrum of Fluoranthene Fraction and its NIST
Library Searching Result

Compound Name: FLUORANTHENE
 Synonym: Benzene, 1,2-(1,8-naphthalenediy)-
 Molecular Weight: 202

Sample ID: PAHs in exhaust emission from gasoline base fuel at 3,000 rpm(2nd)

Forward Fit : 216, Reverse Fit : 505

F00D30B1 1176 (14.739) Cm (1175:1178-(1170:1173+1180:1184))



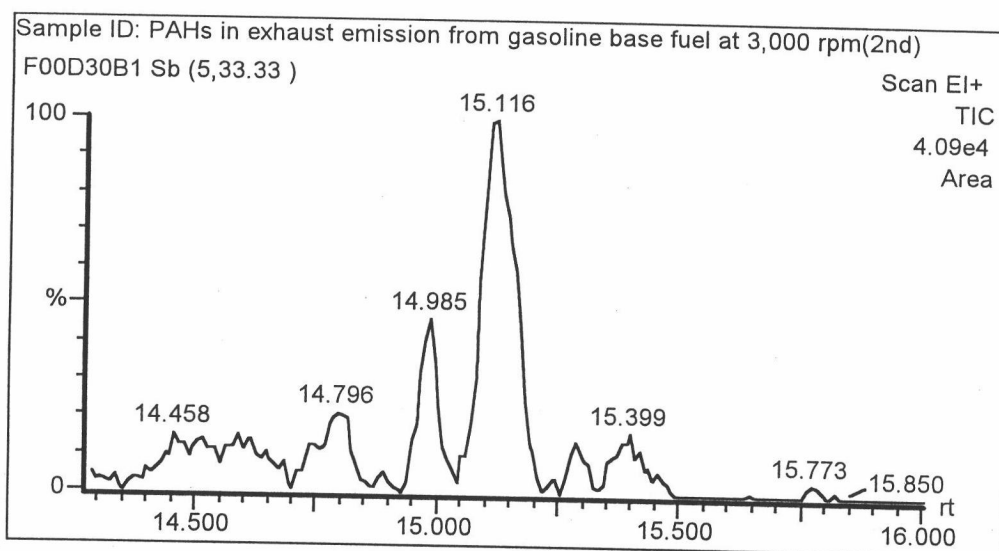
Data File: F00D30B1

Sample ID: PAHs in exhaust emission from gasoline base fuel at 3,000 rpm(2nd)

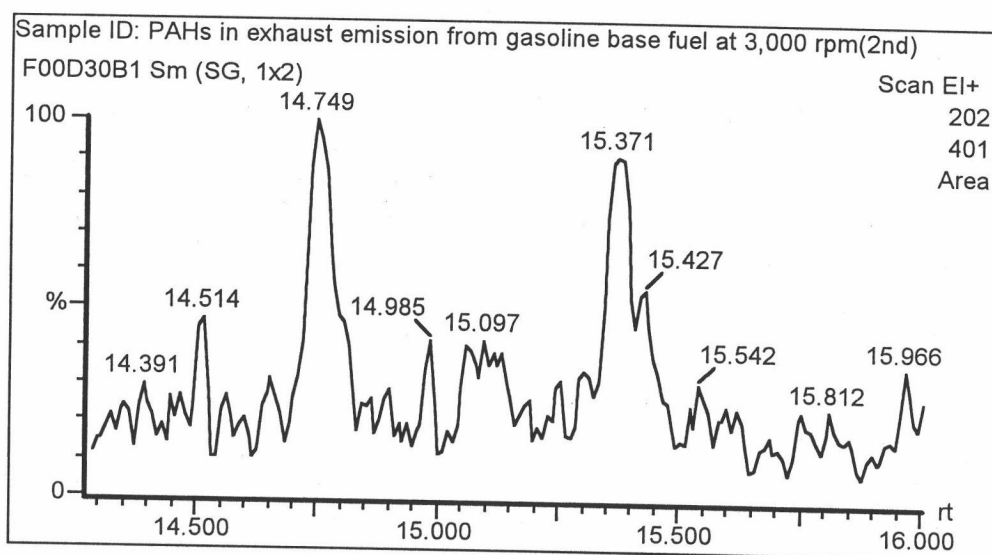
| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|--|------------|------|-----|-----|--------|-------|------------|
| 1 | 3,10B-DIHYDROFLUORANTHENE | C16H12 | 204 | 161 | 661 | NIST | 23993 | 37980-07-7 |
| 2 | 1,9-DIHYDROPYRENE | C16H12 | 204 | 146 | 645 | NIST | 23986 | 0-00-0 |
| 3 | TRYPTOPHAN, BIS(TRIMETHYLSILYL)- | C17H28O2N2 | 348 | 134 | 568 | NIST | 49026 | 61445-27-0 |
| 4 | 2,3-DIHYDROFLUORANTHENE | C16H12 | 204 | 173 | 555 | NIST | 23987 | 30339-87-8 |
| 5 | PROPANAL, 3-(METHYLTHIO), (2,4-DINITROPHENYL)HYDRA | C10H12O4N4 | 284 | 126 | 539 | NIST | 40035 | 7372-49-8 |
| 6 | L-TRYPTOPHAN, N,1-BIS(TRIMETHYLSILYL), TRIMETHYLSI | C20H38O2N2 | 420 | 136 | 512 | NIST | 55314 | 55429-28-2 |
| 7 | FLUORANTHENE | C16H10 | 202 | 370 | 505 | NIST | 23467 | 206-44-0 |
| 8 | PYRENE | C16H10 | 202 | 343 | 481 | NIST | 23469 | 129-00-0 |

(c)

Figure E7 (continued)



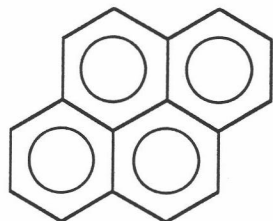
(a)



(b)

Figure E8 (a) Total Ion Chromatogram of Pyrene Fraction
(b) Selected Ion Chromatogram of Pyrene at $m/z = 202$
(c) Mass Spectrum of Pyrene Fraction and its NIST
Library Searching Result

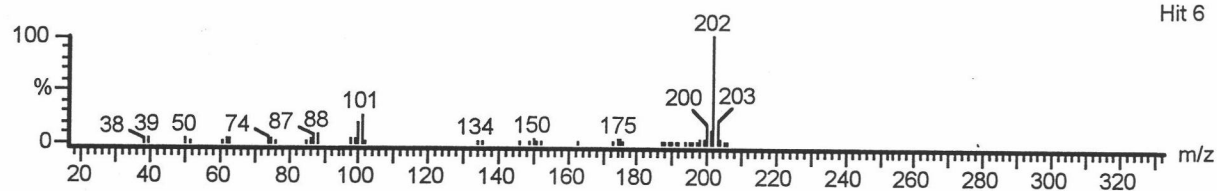
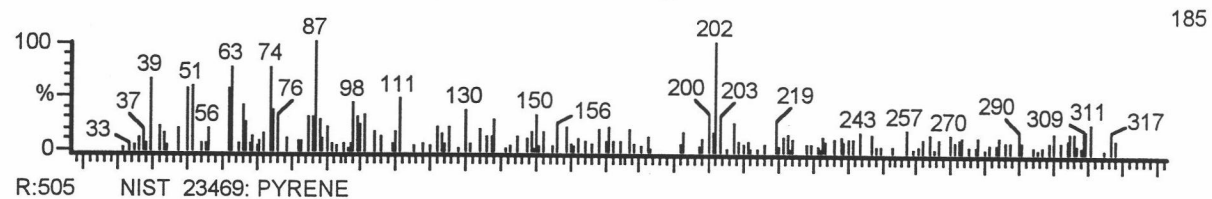
Compound Name: PYRENE
 Synonym: á-Pyrene
 Molecular Weight: 202



Sample ID: PAHs in exhaust emission from gasoline base fuel at 3,000 rpm(2nd)

Forward Fit : 231, Reverse Fit : 505

F00D30B1 1244 (15.381) Cm (1242:1244-(1246:1249+1237:1240))



Data File: F00D30B1

Sample ID: PAHs in exhaust emission from gasoline base fuel at 3,000 rpm(2nd)

| Hit | Compound Name | Formula | M.W. | for | REV | Librar | Entry | CAS |
|-----|--|------------|------|-----|-----|--------|-------|------------|
| 1 | 3,10B-DIHYDROFLUORANTHENE | C16H12 | 204 | 167 | 658 | NIST | 23993 | 37980-07-7 |
| 2 | 1,9-DIHYDROPYRENE | C16H12 | 204 | 146 | 596 | NIST | 23986 | 0-00-0 |
| 3 | 1H-BENZOTRIAZOLE, 5-CHLORO-1-(4-CHLOROPHENYL)- | C12H7N3Cl2 | 263 | 179 | 575 | NIST | 36378 | 29328-99-2 |
| 4 | METHYL 2-O-METHYL-BETA.-D-XYLOPYRANOSIDE | C7H14O5 | 178 | 152 | 556 | NIST | 17049 | 7381-12-6 |
| 5 | 2,3-DIHYDROFLUORANTHENE | C16H12 | 204 | 180 | 548 | NIST | 23987 | 30339-87-8 |
| 6 | PYRENE | C16H10 | 202 | 322 | 505 | NIST | 23469 | 129-00-0 |
| 7 | FLUORANTHENE | C16H10 | 202 | 348 | 505 | NIST | 23467 | 206-44-0 |

(c)

Figure E8 (continued)

APPENDIX F

Concentration of PAHs in Gasoline Test Engine Exhaust Emission

Table F1 Concentration of PAHs in Gasoline Test Engine Exhaust Emission

| Fuel | rpm | Concentration of PAHs in Gasoline Test Engine Exhaust ($\mu\text{g}/\text{m}^3$ of exhaust) | | | | | | | |
|------------|-------|--|----------------|----------|--------------|--------------|--------------|--------------|-------|
| | | Naphthalene | Acenaphthylene | Fluorene | Phenanthrene | Anthracene | Fluoranthene | Pyrene | Total |
| Base fuel | 1,000 | 22.73 | 27.10 | 1.96 | 1.41 | 1.64 | 1.74 | 2.58 | 59.16 |
| | 1,500 | 9.22 | 4.29 | 1.07 | 1.14 | 1.13 | 1.06 | 1.14 | 19.05 |
| | 2,000 | 14.47 | 15.10 | 1.28 | 1.24 | 1.23 | 1.03 | 1.09 | 35.44 |
| | 2,500 | 33.59 | 18.41 | 1.29 | 1.30 | 1.28 | 1.04 | 1.09 | 58.00 |
| | 3,000 | 13.32 | 11.53 | 1.15 | 1.17 | 1.28 | 1.42 | 1.92 | 31.80 |
| + 300 ppm | 1,000 | 5.32 | 15.56 | 1.37 | 1.20 | 1.21 | 1.02 | 1.08 | 26.76 |
| Dispersant | 1,500 | 5.25 | 4.60 | 1.12 | 1.17 | 1.17 | 0.07 | 1.03 | 14.41 |
| | 2,000 | 8.31 | 14.08 | 1.31 | 1.21 | 1.18 | 1.07 | 1.00 | 28.16 |
| | 2,500 | 16.67 | 9.78 | 1.19 | 1.09 | 1.02 | undetectable | undetectable | 29.74 |
| | 3,000 | 54.83 | 17.28 | 1.06 | undetectable | undetectable | undetectable | undetectable | 73.17 |

Table F1 (continued)

| Fuel | rpm | Concentration of PAHs in Gasoline Test Engine Exhaust (mg/m ³ of exhaust) | | | | | | | |
|------------|-------|--|----------------|--------------|--------------|--------------|--------------|--------------|-------|
| | | Naphthalene | Acenaphthylene | Fluorene | Phenanthrene | Anthracene | Fluoranthene | Pyrene | Total |
| + 400 ppm | 1,000 | 10.13 | 3.24 | 1.05 | 1.05 | 1.12 | 1.04 | 2.18 | 19.82 |
| Dispersant | 1,500 | 4.08 | 3.35 | 1.00 | 1.05 | 1.04 | undetectable | undetectable | 10.52 |
| | 2,000 | 11.19 | 7.18 | 1.11 | 1.12 | 1.08 | undetectable | undetectable | 21.68 |
| | 2,500 | 5.28 | 2.48 | 1.00 | 1.04 | 0.95 | undetectable | undetectable | 10.75 |
| | 3,000 | 4.72 | 3.38 | 1.05 | 1.20 | 1.14 | undetectable | undetectable | 11.48 |
| + 500 ppm | 1,000 | 31.43 | 1.57 | undetectable | undetectable | undetectable | undetectable | undetectable | 33.00 |
| Dispersant | 1,500 | 5.79 | 3.25 | 1.01 | undetectable | undetectable | undetectable | undetectable | 10.05 |
| | 2,000 | 9.17 | 11.73 | 1.05 | 1.07 | 0.98 | undetectable | undetectable | 24.00 |
| | 2,500 | 11.55 | 6.69 | 1.13 | 1.10 | 1.04 | undetectable | undetectable | 21.51 |
| | 3,000 | 14.24 | 7.95 | 1.85 | 1.11 | 1.04 | 1.06 | 1.08 | 28.33 |

Table F1 (continued)

| Fuel | rpm | Concentration of PAHs in Gasoline Test Engine Exhaust ($\mu\text{g}/\text{m}^3$ of exhaust) | | | | | | | |
|------------|-------|--|----------------|--------------|--------------|--------------|--------------|--------------|--------|
| | | Naphthalene | Acenaphthylene | Fluorene | Phenanthrene | Anthracene | Fluoranthene | Pyrene | Total |
| + 600 ppm | 1,000 | 36.95 | undetectable | undetectable | undetectable | undetectable | undetectable | undetectable | 36.95 |
| Dispersant | 1,500 | 14.81 | 1.93 | 1.00 | undetectable | undetectable | undetectable | undetectable | 17.74 |
| | 2,000 | 34.85 | 3.00 | 0.99 | undetectable | undetectable | undetectable | undetectable | 38.84 |
| | 2,500 | 21.73 | 8.47 | 1.21 | 1.13 | 1.08 | undetectable | undetectable | 33.62 |
| | 3,000 | 33.90 | 22.92 | 1.85 | 1.21 | 1.24 | 1.05 | 1.06 | 63.23 |
| + 700 ppm | 1,000 | 152.55 | 10.68 | 1.10 | 1.04 | 0.95 | undetectable | undetectable | 166.32 |
| Dispersant | 1,500 | 30.48 | 6.60 | 1.07 | 1.15 | 1.06 | undetectable | undetectable | 40.36 |
| | 2,000 | 31.83 | 15.14 | 1.26 | 1.22 | 1.20 | undetectable | undetectable | 50.64 |
| | 2,500 | 111.13 | 21.79 | 1.11 | 1.06 | 0.97 | undetectable | undetectable | 136.06 |
| | 3,000 | 22.09 | 40.18 | 1.54 | 1.42 | 1.46 | 1.10 | 1.11 | 68.90 |

VITA

Mr.Kant Wacharakitiphong was born on May 1, 1973 in Bangkok, Thailand. He received his Bachelor of Science degree in Industrial Chemistry from the Department of Chemistry, Faculty of Science, King Mongkut's Institute of Technology Ladkrabang in 1994. He began his studies towards the Master's degree (Multidisciplinary) in 1994, and completed the program in 1997.

