



APPENDIX AVAILABLE ON REQUEST

Research Report 143

Measurement and Modeling of Exposure to Selected Air Toxics for Health Effects Studies and Verification by Biomarkers

Roy M. Harrison et al.

Appendix 5. Quality Assurance–Quality Control Results

Note: Appendices Available on the Web appear in a different order than in the original Investigators' Report. HEI has not changed these documents.

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QUALITY ASSURANCE - QUALITY CONTROL**QA-QC in Sampling**

Various blanks have been measured during the sampling campaign in order to monitor possible contamination and to trace sources of artificially introduced contamination during sampling. For this purpose, three different types of blanks have been collected in a total of 6% of samples in order to identify and isolate the source of contamination introduced in the different stages of the sampling procedure. The average and standard deviation of the different types of blanks, namely Travel Blanks (TB), Travel and Exposure Blank (TEB) and Field Blank (FB) are shown in Table A5.1 and Table A5.2 for VOC and PAH dataset respectively. Due to analytical constraints, no travel blanks were collected for PAH.

From the blanks results, it can be seen that the longer the blanks have been exposed to the sampling conditions, the more contamination is shown in the tubes. Benzene and toluene are clear examples of this fact.

Benzene was the compound that showed highest contamination in all three different kinds of blanks. The tubes showing high concentrations of compounds were investigated in order to rule out the possibility that a high concentration in the tube was due to remaining compounds from previous tube uses. The investigation showed that this could not be the cause. For PAH, the Ac-Ph group shows the highest contamination in all kind of blanks, in particular FI and Ph.

A comparison of the blank mass has been made with the average mass collected in the samples. For benzene, this blank contamination represented between 5-10% of the average mass of the samples. The other compounds that are more affected by the blank values are those that have low concentrations in some microenvironments (e.g. pyridine, 3-EP, naphthalene and p-isopropyltoluene in streets or transport). This contamination represents 15-30% of the sample mass. For B(a)P the contamination represents 18% of the sample mass. For the other PAH the contamination represents from 5 to 30% with the highest contamination represented by the Ac-Ph group.

To assess the precision of measurements, duplicate samples were collected for 3% of the total subject population. Figure A5.1 and Figure A5.2 show the correlation of some representative compounds for VOC and PAH respectively. From these figures, it is clear that duplicate samples show an excellent agreement between concurrently collected samples for VOC, and greater variation for PAH.

The rotameters were regularly calibrated using a Gilibrator which in turn was annually calibrated. In general, the agreement between flow rates recorded with rotameters and the Gilibrator was very satisfactory with an average correlation coefficient of 0.92 ± 0.10 . The calibration of the rotameters showed a percentage deviation less than 15% from the Gilibrator. Figure A5.3 present some examples of rotameter calibrations.

An experiment to test the stability of sampled VOC and 1,3-butadiene tubes stored in the fridge before analysis was conducted. Figure A5.4 and Figure A5.5 show the evolution of the concentration of VOC and 1,3-butadiene in standard tubes with storage time.

Figure A5.4 shows that VOC samples stored in the fridge give a constant reading regardless of the time for which they have been stored. For almost all the compounds, the values were around 3% lower than expected. For styrene and 1,2,4-trimethylbenzene, the readings were 11% and 7% lower than expected respectively. There are two compounds showing exceptional behaviour. The first, 3-ethenylpyridine gives readings 17% higher than expected but this value is not constant amongst the different stability test tubes. The other compound is n-hexane, which showed itself to be stable for 19 weeks in the fridge with values just 3% higher than expected, but showed results 20% lower than expected after 21 weeks in the fridge.

Figure A5.5 shows that 1,3-butadiene samples stored in the freezer give a reading 25% lower than expected for low concentrations and a reading 18% lower than expected for middle range concentrations after 8 weeks storage. These losses are

lower when the samples have been stored for just two weeks, when they are 7% lower than expected for the low concentrations and 2% lower than expected for high concentrations.

Due to the fact that the 1,3-butadiene and the VOC samples were analysed with the same GC/MS equipment, it was necessary to store the samples in the freezer while the other analytes were analysed. For logistic reasons, the time that the samples were in the freezer could not be eliminated.

Sampling artifacts

VOC

A common concern about using sorbent tubes with thermal desorption-GC analysis is that artifacts from the sorbent material may interfere chromatographically with the analytes of interest. Artifact interference can be minimized or eliminated by selecting the sorbent or series of sorbents of appropriate strength for the particular target analyte range.

The effect of high humidity on component retention has also been investigated and reported in the literature. The safe sampling volume (SSV) of VOCs on hydrophobic adsorbents such as Tenax, other porous polymers, Carbotrap, and Carbopack are relatively unaffected by atmospheric humidity. However, carbonized molecular-sieve type sorbents such as Carbosieve SIII are affected by high humidity, and SSVs should typically be reduced by a factor of 10 at 90-95% RH (Ciccioli et al. 1986; HSE 1992; Woolfenden 1997).

Artifacts generated during sampling have been reported to be formed via oxidation of the sorbent when sampling high concentration ozone atmospheres (100-500 ppb ozone) onto Tenax tubes (Ciccioli et al. 1992; Woolfenden 1997).

The breakthrough volume of porous polymers varies with ambient air temperature, reducing by a factor of about 2 for each 10°C rise in temperature. It also varies with sampling flow rate, being reduced substantially at flow rates below 5 mL/min or above

500 ml/min (HSE 1992). The theoretical optimum flow rate for a 1/4-inch O.D and 3.5" long tube is 50 mL/min; however, negligible variation in retention volume is in fact observed for pump flow rates varying from 5 to 200 mL/min (Woolfenden 1997). The sampling volumes and flowrates selected in this project are within the ranges recommended by the literature for the type of sorbent materials and length that compose the sorbent tubes. The sampled volumes are the same in all cases, as the flowrates were adjusted to allow collection of the same volume over different specified times (i.e. 57.6 L for VOC and 43.2 L for 1,3-Butadiene). In the case of personal exposure, home microenvironment and workplace sampling the flowrates are in the optimum range, and no effect is expected due to the use of different flowrates for sampling. In the case of other microenvironment sampling, the flowrate is considerably higher compared with the other sampling situations. Although the flowrate is still within the recommended ranges, the safe sampling volume might be reduced, and therefore sampling events with extremely high VOC concentrations might suffer breakthrough. This effect may be limited by the fact that the sampling time is relatively short.

PAH

The importance of sampling artefacts depends mainly on sampling conditions such as temperature or atmospheric concentrations of PAH (Mader and Pankow 2001; Goriaux et al. 2006; Ravindra et al. 2008) and gaseous pollutants such as oxidants, NO_x and SO_x (Lindskog 1983). It is known that filter/adsorbent samplers are prone to sampling artefacts, since PAHs collected on the filter can volatilise from the particles (negative particulate-phase artefact) and vapour-phase molecules can adsorb on the filter or on the collected particles (positive particulate-phase artefact). Loss by volatilisation from the filter (often referred to as "blow off") can be caused by two distinct mechanisms:

- 1) Because of the pressure gradient that exists through a filter, particles deep within the filter will be exposed to gas-phase concentrations of PAHs that are

lower than at the front of the filter. The compounds will therefore tend to be stripped from the filtered particles and then collected on the gas sampling adsorbent downstream of the filter (when present).

2) If the contamination levels decrease or if temperature increases, these changes will shift the partitioning in favour of the gas phase. Several researchers have therefore proposed that the filter should be replaced frequently during a given sampling event, so that collected particles will only be exposed to the concentration and temperature conditions under which they were initially filtered.

The other possible artefact is the adsorption of gas-phase molecules on the filter or on the particles collected on the filter. Gas sorption to filters is related to the surface area of the filters themselves (McMurry 2000; Pozzoli et al. 2004; Goriaux et al. 2006) and to face velocity (i.e. the volumetric flow rate divided by the exposed area of the filter). The apparent concentration of ambient organic aerosol sampled in quartz fibre filters decreases significantly when the face velocity is increased from 10 to 90 cm/s. The cause of this decrease might be due to adsorption of organic gases on the quartz fibre filter (McDow and Huntzicker 1990). Apparent organic carbon concentrations were 22% greater, on average, when measured at a face velocity of 20 cm/s than when measured at 40 cm/s (Turpin et al. 2000). Therefore, the low personal exposure flowrates used for sampling are more prone to increase the concentrations of the more volatile polycyclic aromatic particles. On the other hand, these compounds (the more volatile PAH) are also the ones more subject to artifacts due to different atmospheric conditions. Therefore, although concentrations of these compounds are reported in the tables and figures, caveats apply to the discussion of them. High molecular weight PAH are less affected by atmospheric conditions and face velocity effects, as they are normally mainly in the particle phase, the gas-phase equilibrium is more stable and suffers less from gas adsorption effects.

QA-QC in Analysis

Samples analysed in the same batch as a Laboratory Method Blank (LMB) which showed high concentrations were investigated in order to check if the contamination was common to all the samples or just an isolated case. In most cases, the LMB was around 5-10% the mass found in the samples. High concentrations of n-hexane were linked with the use of adjacent equipment in the lab invalidating the n-hexane data for that batch of samples.

During the analysis stage of the VOC samples, standard checks were analysed at the beginning and end of the batch in order to monitor the performance of the GC/MS system. All the compounds had a standard mass of 100 ng except n-hexane and p-isopropyltoluene which were 200 ng, pyridine and 3-ethenylpyridine were 40 ng and 1,3-butadiene was 4.4 ng. Precision and accuracy was calculated from the replicated performance of the standard checks. Results of the performance of standard checks, precision and accuracy appear in Table A5.3.

In the case of the analysis of PAH samples, a standard of 200 pg/ μ L was checked at the beginning and at the end of the batch and every 5 samples. Precision and accuracy was also calculated from the replicated performance of the standard checks. Results of precision, accuracy and performance of standard checks are shown in Table A5.4.

The average precision and accuracy of the VOC method are $8.6\pm 2.3\%$ and $4.7\pm 2.7\%$ respectively. In the case of the PAH, the average precision and accuracy are $7.9\pm 7.5\%$ and $5.9\pm 5.4\%$ respectively. These values accomplish the quality objectives for air toxics stated by the EPA in the "Quality Assurance Handbook for Air Pollution Systems" which should be a precision of 25% and an accuracy of 20% (USEPA 1998). For all the VOC compounds the value of the precision and accuracy are better than 15%. In the case of the PAH compounds, all of them accomplish the

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EPA ~~standards~~—objective except benzo(b)fluoranthene, which shows values of precision and accuracy slightly worse than the ~~standard~~requirement.

Table A5.5 and Table A5.6 presents the results of the two limits of detection calculated for the VOC and PAH method respectively. These are the Instrument Limit of Detection (IDL) and the Sample Detection Limit (SDL). Table A5.7 presents the results of the Limit of Quantification for the urinary biomarkers analytical method.

The recovery efficiency of the internal and natural standards has been quantified for the PAH analytical method. Results are presented in Table A5.8 and Table A5.9.

The average recovery of the spiked standards is $101.8 \pm 8.6\%$ approx for the internal standards and up to $91.6 \pm 15.6\%$ % for the natural standards. Looking into the different standards, the lowest recoveries are recorded always for the more volatile compounds i.e. acenaphthylene-d8, acenaphthylene and acenaphthene with recovery percentages lower than 85%.

Standard Reference Material (SRM) Analysis

For quality assurance of the PAH measurements, the standard reference material NIST SRM 1649a - (Urban Dust) was chosen. It is an atmospheric particulate material collected in an urban area and is intended for use in evaluating analytical methods for the determination of selected PAH, amongst other pollutants. Before using the SRM as a routine check, five samples were analysed for repeatability and the precision obtained was as presented in Table A5.10. The certified values of concentrations, expressed as mass fractions, are also included in Table A5.10 and in Figure A5.6 are presented together with the mean experimental concentrations obtained when the SRM was treated, extracted and analysed in the same way as the sampled filters. An SRM sample was subsequently analysed every 20 samples as a quality assurance check.

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Table A3.1. Table A5.1. Analytical and sampling blanks in ng, VOC dataset.

Compound	Laboratory Method (LMB) Blank		Travel Blank		Travel and Exposure Blank		Field Blank	
	Average (ng)	STD (ng)	Average (ng)	STD (ng)	Average (ng)	STD (ng)	Average (ng)	STD (ng)
n-Hexane	1.35	3.27	5.36	17.15	1.86	4.0	0.20	0.82
Benzene	0.82	1.96	9.56	5.10	12.02	4.8	15.84	9.61
Toluene	0.80	0.81	4.24	2.63	4.86	3.0	6.59	4.11
Ethylbenzene	0.69	0.80	3.16	3.31	3.23	3.0	3.21	3.12
p-Xylene	0.12	0.23	1.95	2.59	1.52	2.4	1.85	2.40
m-Xylene	0.03	0.02	1.92	2.71	1.73	2.7	2.33	2.58
Pyridine	0.15	0.10	0.74	0.94	0.71	0.9	1.44	1.26
o-Xylene	0.09	0.48	2.26	3.57	2.06	3.2	2.10	3.31
1,3,5-Trimethylbenzene	0.03	0.00	0.24	0.68	0.41	1.4	0.67	1.72
Styrene	1.16	1.03	3.63	1.78	4.15	1.9	4.16	1.70
p-Isopropyltoluene	0.01	0.00	0.73	1.77	0.79	1.7	0.01	0.00
1,2,4-Trimethylbenzene	0.03	0.03	0.36	0.46	0.77	1.1	0.83	0.99
3-Ethenylpyridine	0.51	1.46	1.12	1.62	0.56	1.0	0.73	0.82
Naphthalene	2.32	1.37	6.19	3.93	5.69	3.6	6.05	3.49
1,3-Butadiene	0.01	0.00	4.28	12.15	0.65	0.90	1.22	2.46

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Table A3.2. Table A5.2. Analytical and sampling blanks in ng, PAH dataset.

Compound	Laboratory Method (LMB) Blank		Travel and Exposure Blank		Field Blank	
	Average (ng)	STD (ng)	Average (ng)	STD (ng)	Average (ng)	STD (ng)
Acenaphthylene	37.1	168.6	27.9	23.9	6.6	2.1
Acenaphthene	180.9	888.0	36.1	18.8	24.9	16.8
Fluorene	250.0	1041.2	104.3	98.1	29.9	15.4
Phenanthrene	25.6	16.5	139.2	49.1	30.6	5.4
Anthracene	3.1	6.6	10.6	7.3	4.7	1.9
Fluoranthene	2.4	1.6	11.4	1.1	4.1	0.9
Pyrene	4.1	5.5	36.4	5.9	4.8	3.3
Benzo(a)anthracene	1.1	0.9	1.6	0.4	1.4	1.3
Chrysene	2.0	2.4	5.8	0.2	1.9	0.3
Benzo(b)fluoranthene	1.0	1.0	2.1	1.5	0.8	0.7
Benzo(k)fluoranthene	0.8	0.8	1.6	0.9	0.9	0.3
Benzo(a)pyrene	2.0	2.3	3.5	1.8	4.0	2.2
Indeno(1,2,3-cd)pyrene	3.2	3.0	4.9	2.4	3.8	2.2
Dibenz(a,h)anthracene	1.9	2.2	1.1	0.2	0.9	0.4
Benzo(ghi)perylene	2.4	2.7	7.2	1.3	2.6	0.8
Coronene	1.8	1.7	2.4	1.4	0.5	0.3

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Table A3.3. Table A5.3. Standard check mass (ng), accuracy and precision, VOC dataset.

Compound	Start Standard Check		End Standard Check		Average Standard Check		Precision [#]	Accuracy [#]
	Average (ng)	STD (ng)	Average (ng)	STD (ng)	Average (ng)	STD (ng)	%	%
n-Hexane	218.8	23.0	224.5	22.1	221.7	22.6	10.2	10,9
Benzene	99.6	9.5	84.3	9.3	92.0	9.4	10.2	8,0
Toluene	98.7	6.8	90.2	7.8	94.5	7.3	7.7	5,5
Ethylbenzene	95.7	6.3	91.7	7.7	93.7	7.0	7.5	6,3
p-Xylene	95.1	6.4	92.3	7.1	93.7	6.8	7.3	6,3
m-Xylene	104.1	7.4	101.3	7.2	102.7	7.3	7.1	2,7
Pyridine	40.8	2.2	39.1	2.8	39.9	2.5	6.3	0,3
o-Xylene	99.2	6.0	94.8	6.1	97.0	6.0	6.2	3,0
1,3,5-Trimethylbenzene	91.3	13.7	95.2	7.1	93.2	10.4	11.2	6,8
Styrene	97.7	6.4	94.4	7.2	96.0	6.8	7.1	4,0
p-Isopropyltoluene	192.7	12.4	191.7	17.4	192.2	14.9	7.8	3,9
1,2,4-Trimethylbenzene	97.1	6.2	95.6	7.4	96.3	6.8	7.1	3,7
3-Ethenylpyridine	47.4	4.3	35.9	5.5	41.7	4.9	11.8	4,3
Naphthalene	196.7	12.6	194.9	19.5	195.8	16.0	8.2	2,1
1,3-Butadiene	4.4	0.6	4.2	0.6	4.3	0.6	14.0	2,3

[#] Accuracy and precision as defined in the Section Methods and Study Design

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Table A3.4. Table A5.4. Standard check concentration (pg/μL), precision and accuracy, PAH dataset.

Compound	Average Standard Check		Precision [#]	Accuracy [#]
	Average (pg/μL)	STD (pg/μL)	%	%
Acenaphthalene	197.6	6.5	3.3	1.2
Acenaphthene	202.9	5.7	2.8	1.5
Fluorene	198.6	5.4	2.7	0.7
Phenanthrene	197.4	5.6	2.9	1.3
Anthracene	190.7	6.5	3.4	4.7
Fluoranthene	184.0	5.9	3.2	8.0
Pyrene	189.8	5.5	2.9	5.1
Benzo(a)anthracene	193.1	9.4	4.9	3.5
Chrysene	188.4	32.4	17.2	5.8
Benzo(b)fluoranthene	156.1	43.4	27.8	21.9
Benzo(k)fluoranthene	183.1	34.4	18.8	8.4
Benzo(a)pyrene	181.4	5.0	2.8	9.3
Indeno(1,2,3-cd)pyrene	191.0	18.0	8.4	4.5
Dibenz(a,h)anthracene	175.2	18.7	10.7	12.4
Benzo(ghi)perylene	191.4	7.5	3.9	4.3
Coronene	202.6	23.0	11.3	1.3

[#] Accuracy and precision as defined in the Section Methods and Study Design

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Table A3.5. Table A5.5. Limits of detection, VOC dataset.

Compound	Instrument Limit of Detection		Sample Detection Limit	
	Average (ng)	STD (ng)	Average (ng/m ³)	STD (ng/m ³)
n-Hexane	0.030	0.029	5.1	5.0
Benzene	0.044	0.001	7.7	0.3
Toluene	0.053	0.028	8.1	5.0
Ethylbenzene	0.037	0.036	5.6	5.8
p-Xylene	0.074	0.053	11.2	8.8
m-Xylene	0.071	0.050	10.8	8.3
Pyridine	0.273	0.130	47.4	22.6
o-Xylene	0.056	0.026	10.2	4.1
1,3,5-Trimethylbenzene	0.056	0.041	9.0	6.4
Styrene	0.042	0.016	7.0	2.4
p-Isopropyltoluene	0.024	0.022	4.1	3.9
1,2,4-Trimethylbenzene	0.035	0.014	6.3	2.1
3-Ethenylpyridine	0.620	0.241	109.2	38.9
Naphthalene	0.024	0.013	3.7	2.1
1,3-Butadiene	0.030	0.029	5.1	5.0

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Table A3.6. Table A5.6. Limits of detection, PAH dataset.

Compound	Instrument Limit of Detection		Sample Detection Limit	
	Average (pg/ μ l)	STD (ng)	Average (pg/m ³)	STD (pg/m ³)
Acenaphthylene	1.0	1.0	28.9	29.0
Acenaphthene	5.0	5.9	148.1	176.3
Fluorene	5.0	6.7	149.6	198.9
Phenanthrene	6.7	7.2	132.2	131.5
Anthracene	1.4	2.0	27.0	38.2
Fluoranthene	0.6	0.7	9.7	11.3
Pyrene	0.5	0.5	8.0	7.5
Benzo(a)anthracene	0.2	0.2	2.7	2.1
Chrysene	0.3	0.4	4.1	5.4
Benzo(b)fluoranthene	1.0	0.8	14.9	12.1
Benzo(k)fluoranthene	0.3	0.4	3.5	5.0
Benzo(a)pyrene	0.3	0.4	5.0	5.7
Indeno(1,2,3-cd)pyrene	0.6	0.8	7.6	10.7
Dibenz(a,h)anthracene	0.3	0.4	3.5	4.9
Benzo(ghi)perylene	0.7	0.4	8.0	2.5
Coronene	0.1	0.2	1.2	1.7

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Table A5.7. Limits of detection, Urinary dataset.

Compound	Limit of Detection (ng/mL)
Cotinine	0.05
<i>Trans</i> -3'-Hydroxycotinine	0.10
2-Naphthol	0.50
1-Hydroxyfluorene	0.10
2-Hydroxyfluorene	0.025
3-Hydroxyfluorene	0.10
1-Hydroxyphenanthrene	0.025
2-Hydroxyphenanthrene	0.010
3- + 4-Hydroxyphenanthrene	0.20
1-Hydroxypyrene	0.025

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Table A3.7. Table A5.8. Recovery efficiency of PAH internal standards in blanks.

Compound	Average (%)	STD (%)
Acenaphthylene-d8	75.6	2.3
Phenanthrene-d10	81.2	3.7
Anthracene-d10	82.4	3.3
Pyrene-d10	88.9	3.3
Benzo(a)anthracene-d12	94.3	3.7
Chrysene-d12	88.8	3.9
Benzo(a)pyrene-d12	85.9	4.2
Indeno(1,2,3-cd)pyrene-d12	99.9	10.6
Benzo(ghi)perylene-d12	127.2	10.4

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Table A3.8. Table A5.9. Recovery efficiency of natural standards in blanks.

Compound	Average (%)	STD (%)
Acenaphthylene	82.0	2.5
Acenaphthene	91.0	6.1
Fluorene	98.2	9.8
Phenanthrene	110.1	23.6
Anthracene	90.4	4.4
Fluoranthene	106.0	4.0
Pyrene	98.6	2.0
Benzo(a)anthracene	101.7	5.8
Chrysene	100.3	5.7
Benzo(b)fluoranthene	111	13.2
Benzo(k)fluoranthene	106.7	8.7
Benzo(a)pyrene	105.8	7.8
Indeno(1,2,3-cd)pyrene	107	10.1
Dibenz(ah)anthracene	111.3	20.1
Benzo(ghi)perylene	107.6	7.8
Coronene	118.3	11.5

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Table A3.9. Table A5.10. Certified and experimental concentrations of SRM 1649a.

Compound	Certified Concentration (mg/kg)	Certified Variability (mg/kg)	Mean Experimental Concentration (mg/kg)	Standard Deviation (mg/kg)	Precision (%) (RSD)	Accuracy# (%)
Phenanthrene	4.140	0.370	4.50	0.73	8.5	8.7
Anthracene	0.432	0.082	0.58	0.16	13.5	34.3
Fluoranthene	6.450	0.180	6.75	1.24	12.7	4.7
Pyrene	5.290	0.250	5.49	0.90	11.0	3.8
Benzo(a)anthracene	2.208	0.073	2.15	0.40	16.7	-2.6
Chrysene	3.049	0.060	4.03	0.90	12.4	32.2
Benzo(b)fluoranthene	6.450	0.640	6.74	1.21	12.5	4.5
Benzo(k)fluoranthene	1.913	0.031	2.85	1.08	15.0	49.0
Benzo(a)pyrene	2.509	0.087	2.47	0.10	9.8	-1.6
Indeno(1,2,3-cd)pyrene	3.180	0.720	3.17	0.28	15.0	-0.3
Dibenz(ah)anthracene	0.288	0.023	0.40	0.14	8.7	38.9
Benzo(ghi)perylene	4.010	0.910	4.00	0.34	8.5	-0.2

Expressed as (mean measured concentrations minus certified value) / Certified Value x 100

APPENDIX 5: QUALITY ASSURANCE - QUALITY CONTROL RESULTS

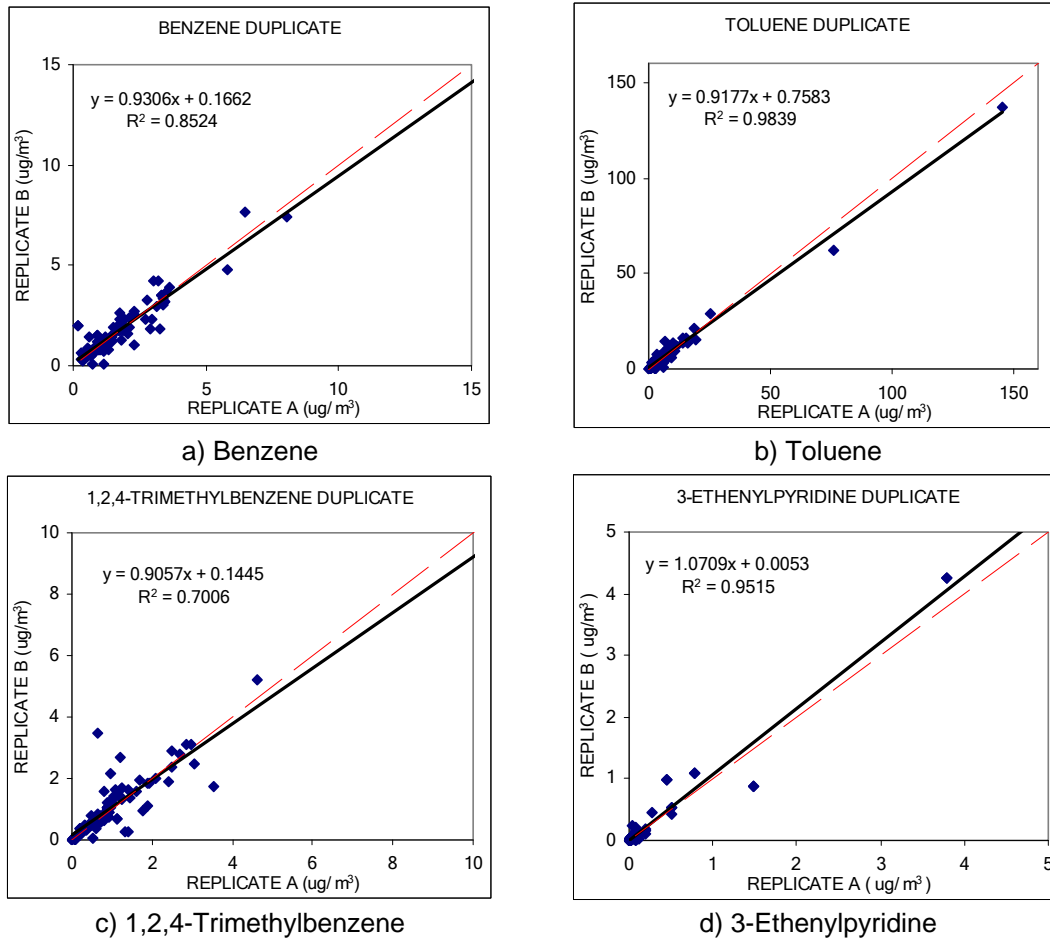


Figure A5.1. Field duplicate samples for (a) benzene, (b) toluene, (c) 1,2,4-trimethylbenzene and (d) 3-ethenylpyridine

APPENDIX 5: QUALITY ASSURANCE - QUALITY CONTROL RESULTS

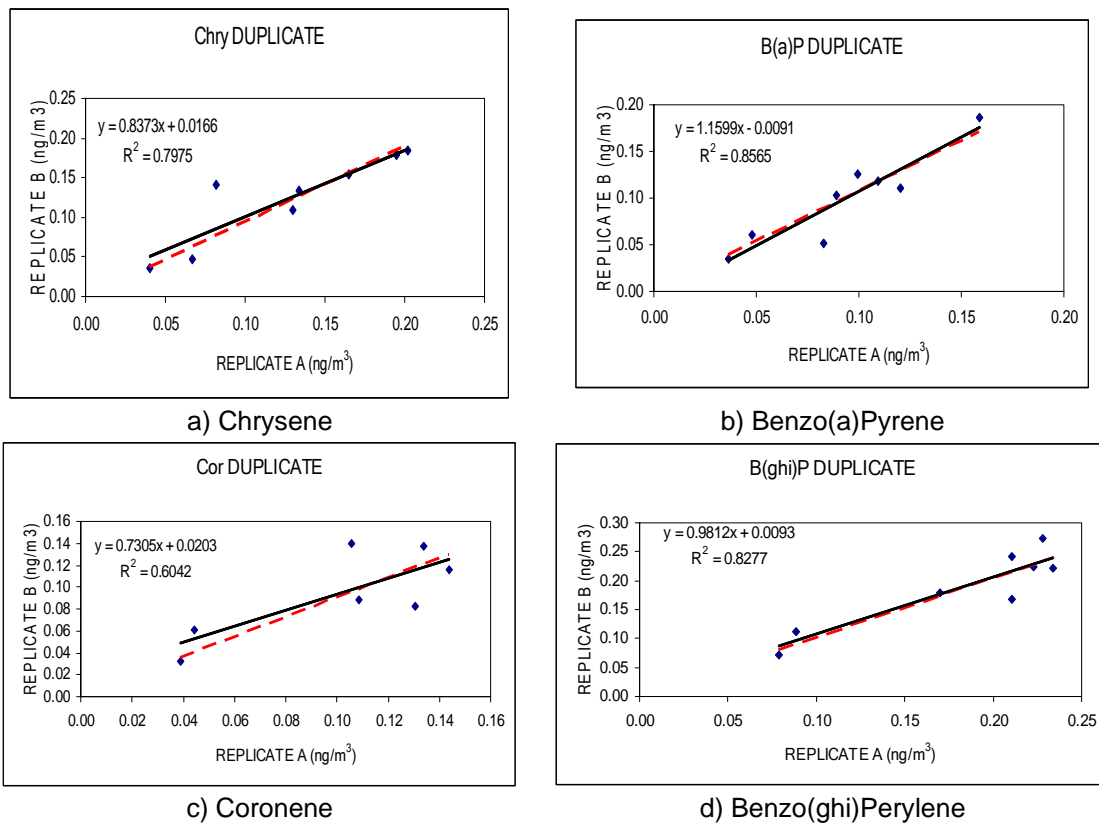
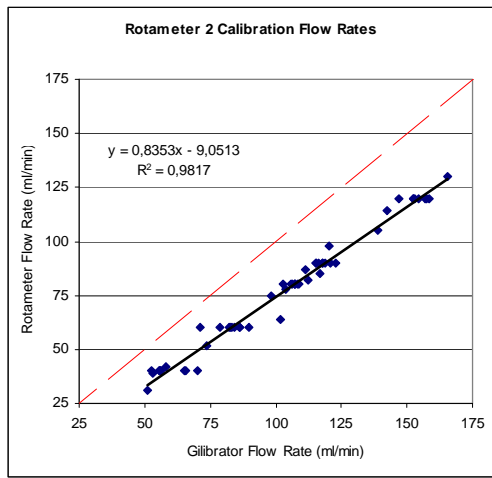
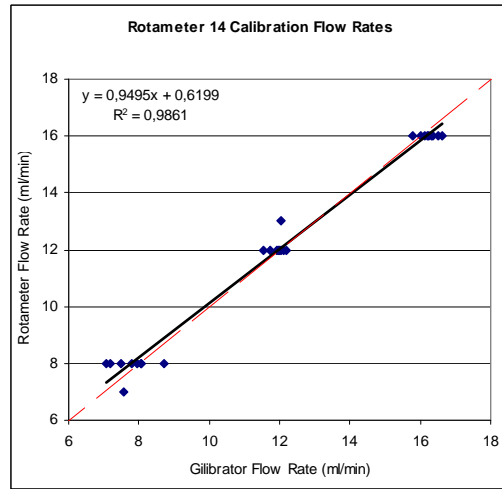


Figure A3.2.Figure A5.2. Field duplicate samples for (a) Chrysene, (b) Benzo(a)pyrene, (c) Coronene and (d) Benzo(ghi)perylene



(a)



(b)

Figure A3.3: Figure A5.3. Calibration curves for rotameters used to measure (a) VOC and 1,3-Butadiene samples and (b) PAH samples

APPENDIX 5: QUALITY ASSURANCE - QUALITY CONTROL RESULTS

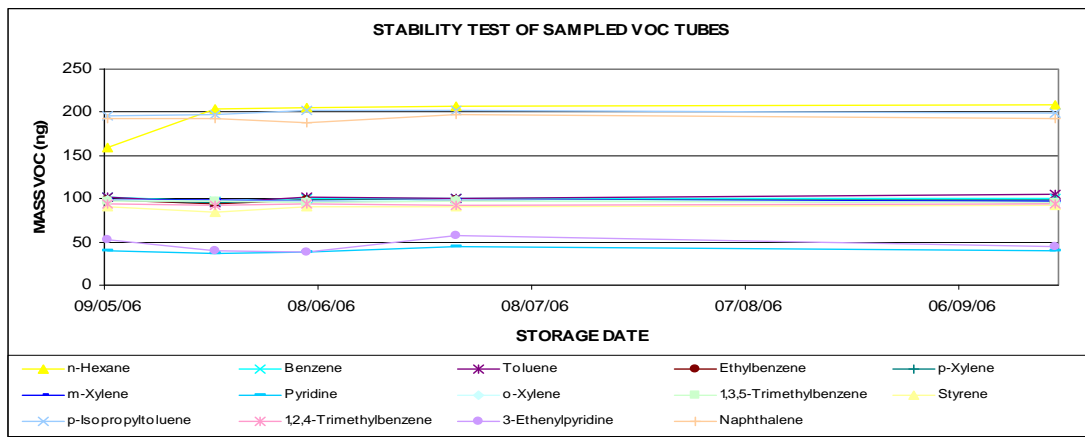


Figure A3.4-Figure A5.4. Storage sample stability test of VOC tubes

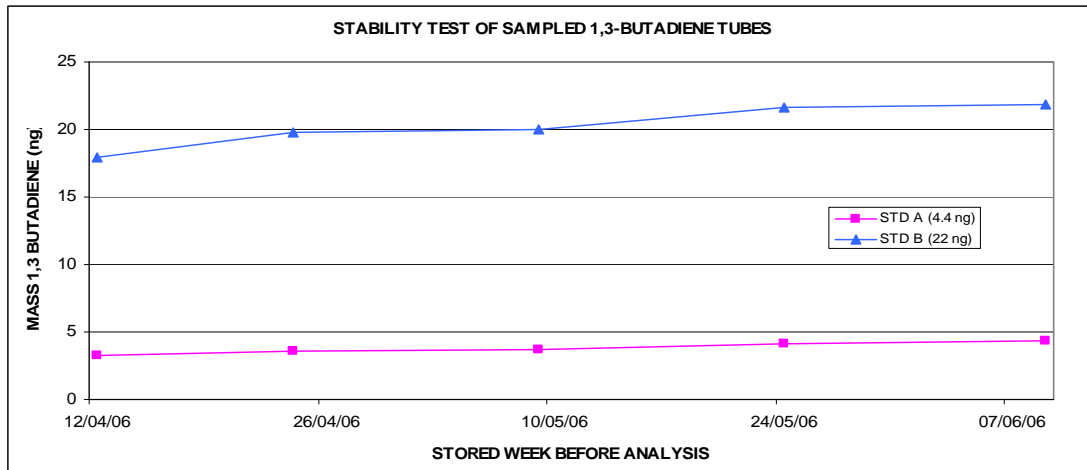


Figure A3.5. Figure A5.5. Storage sample stability test of 1,3-butadiene tubes

APPENDIX 5: QUALITY ASSURANCE - QUALITY CONTROL RESULTS

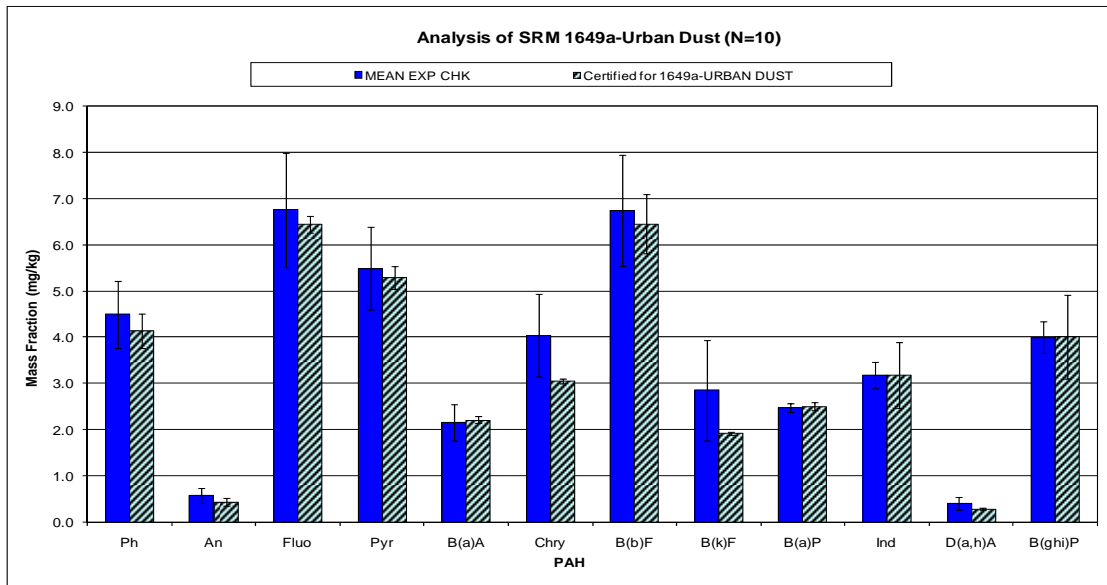


Figure A3.6-Figure A5.6.
1649a.

Average experimental and certified concentrations of SRM