

CONFIDENTIAL

UK SMOKE CONSTITUENTS STUDY

Final Report

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United Kingdom (UK) Smoke Constituents Study

Executive Summary

A large study of brands of cigarettes has been undertaken to determine the yield ratings of 44 selected constituents in mainstream cigarette smoke as identified by the UK Department of Health (DoH).

The study protocol was drawn up by the DoH and the project funded by the Tobacco Manufacturers' Association (TMA) who agreed to act as the client to oversee the delivery of the project via a project management group (PMG). Twenty-five brands were selected in July 2001, representing approximately 58 % of the UK market at that time and covering a range of the design parameters of products sold in the UK marketplace. Samples were obtained towards the end of 2001 from a single production batch of current specification to minimise effects due to variations in the manufacturing process. For each brand/analyte, five samples were smoked using standard ISO puffing parameters. Additionally, Kentucky Reference cigarettes were included in the study to allow for evaluation of the quality of the data.

Before any work was undertaken, the method to be used to determine a set of analyte yields was put through a rigorous validation process to show that it was capable of meeting the needs of the study. Where practicable, data obtained from the validation exercises was compared with data published externally to demonstrate reproducibility of results. An evaluation of each method has been made with the exception of 'tar', nicotine and carbon monoxide (TNCO) as UKAS accredited ISO methods were already in place for these analytes.

Approximately 7000 results were obtained during the course of the study and these have been reported in a series of 12 'stand alone' reports, each with Annexes giving information about the method used and validation data obtained. Statistical analysis of each set of results has been undertaken. Each mean analyte yield has been reported with a \pm value to indicate the measurement uncertainty associated with the result.

Results showed that for most analytes there was a factor of about 10 between the lowest and highest yields as there is for 'tar'. However, nitrogen containing analytes tended to have a much wider range of yields.

For many brands there is good evidence of a linear relationship between both 'tar' (Nicotine Free Dry Particulate Matter) and carbon monoxide yield and the yield of most analytes. Linear regression analysis showed that twenty-nine analytes had a correlation coefficient with 'tar' yields of > 0.80 of which twenty-two had a correlation coefficient of > 0.90 . Similarly twenty-four analytes had a correlation coefficient with carbon monoxide yields of > 0.80 of which fifteen analytes had a correlation coefficient of > 0.90 . The volatile analyte yields tended to correlate better with carbon monoxide yields.

For some smoke constituents the yields obtained from a small number of brands appeared to deviate from the otherwise good linear relationships with 'tar' or CO yields. For example, the yield of N-nitrosornicotine (NNN) for one brand was about seven times higher than any other brand. Most likely, this reflects the use of dark air cured tobacco, with a previously reported high nitrosamines content, in the tobacco blend of the cigarette. In other cases further work would be required to establish why certain brands give unexpectedly low or high yields for some analytes and this was outside the scope of the current investigation.

The aim of the study was to provide data on analyte yields in cigarette smoke for UK brands. The project has been successfully completed and careful analysis of the data generated will provide some information about the role of cigarette design in influencing analyte yields in cigarette smoke.

Introduction

The objective of the UK Smoke Constituents Study was to determine the yield ratings of selected smoke constituents in mainstream smoke as identified by the United Kingdom Department of Health for selected brands of cigarette which were representative of those sold in the UK in 2001.

This work was undertaken by Arista Laboratories Europe and LGC Limited at the request of the DoH and funded by the TMA in accordance with the Study Protocol provided by, and agreed with, the UK DoH. In agreement with the client and the DoH, some of the analysis was carried out at Arista Laboratories USA.

Arista Laboratories Europe¹ acquired the smoke constituent analytical business of LGC Limited, on the 23rd December 2002.

Background

The benchmark study was originally to be commissioned by the DoH, and so the study protocol was designed by DoH who appointed LGC (Teddington) Ltd² as the contractor. Following discussions between TMA and DoH, the TMA agreed to fund the work and take on the responsibility of acting as the client to oversee the delivery of the project. The Tobacco Products Group of LGC commenced the project and reported results for ammonia, benzo[a]pyrene, carbonyls, hydrogen cyanide, nitrogen monoxide and TNCO. Arista Laboratories Europe then acquired the smoke constituent analytical business of LGC and took on the responsibility of completing the study, the SVC analysis being a joint effort. In agreement with the client, some of work was sub-contracted to Arista Laboratories USA to speed up delivery by April 2003.

The purpose of the study was to carry out a large survey on brands sold within the UK to determine 44 different analyte yields in cigarette smoke. Twenty-five brands of cigarettes were selected for the study representing a 58% share of the UK market in July 2001. The selection criteria include a range of 'tar' yields, filter ventilation, paper permeability, cigarette circumference and length, tobacco weight, blend and product market share. The list of brands chosen, their physical characteristics and analytes determined are listed in the appendices (Pages 17 & 18). Market share information is given in the Study Protocol (presented as an Annexe to this report).

TNCO yields for brands sold in the UK are determined using ISO methods and ISO conditions. Therefore, it was deemed appropriate to determine other smoke constituent yields using the same ISO parameters to condition and smoke cigarettes.

There are no universally accepted or inter-laboratory validated test methods available for determining smoke constituent yields other than 'tar', nicotine and carbon monoxide. Therefore, in house methods were used and/or developed and subjected to a validation process. The validation process included subjecting the method and validation data to critical review by the project management group.

¹ Arista Laboratories Europe is Europe's largest independent smoke analysis laboratory and provides analytical and consultancy services in the area of tobacco and tobacco products to both public and private sector companies.

² LGC (Teddington) Ltd was renamed LGC Limited in 2002.

Method Selection, Validation and Quality Control

If appropriate, a literature search was undertaken to identify methods suitable for determining analyte yields in cigarette smoke. The final decision as to which method to choose e.g. what type of trap, how many cigarettes to smoke, extraction and analytical technique to use was based on the following criteria.

The method must be:

- Capable of smoking and analysing samples within a reasonable time frame;
- Capable of producing positive results for the vast majority of smoke constituents for the brands used in the benchmark study;
- Discriminating enough to distinguish between high, medium and low analyte yields typically found in cigarette smoke for UK brands;
- Repeatable over a period of time, i.e. similar samples smoked and analysed on different days gave reasonable precision;
- Efficient in trapping the analyte but should not significantly affect the smoking to ISO conditions, e.g. the puff profile is not significantly distorted when using a liquid trap.

Validation involved proving that the method selected was suitable for undertaking the benchmark study. The validation process varied depending on whether the method was already in use and had been previously validated. It would normally include the following:

- Evaluation of calibration curve – range and linearity;
- Determination of a suitable reporting limit for the method. The concentration of the bottom standard was normally used to calculate the reporting limit so that only smoke yields above this concentration were reported;
- Check on trapping efficiency;
- Precision experiments;
- Reproducibility experiments - smoking of samples for which results obtained by other laboratories using similar samples were available for comparison ³;
- Robustness – trying out different samples (high ‘tar’, American blend, menthol, etc.) to check that the method could handle a range of blends and manufacturers specifications.

In an unplanned duplication, styrene was determined twice in the study using different methods in different laboratories. This provided an enhanced opportunity to look at the precision, bias and accuracy in a single direct comparison for this analyte (see Commentary on Page 10).

Quality Control procedures used throughout the study included:

- Standard laboratory checks of equipment; e.g. balances, pipettes, smoking machines
- Use of internal, recovery and calibration standards
- Prescribed limits for QC solution(s) and calibration curve acceptability
- Checks for good chromatography
- Data checks, i.e. calculation and transcription errors

³ S W Purkis, C A Hill and I A Bailey, Current measurement reliability of selected smoke analytes, *Beiträge zur Tabakforschung International*, 2003, **20**, 314 - 324

Results

Individual reports (see Page 15 for the list of reports) contain the sets of analyte results for the 25 brands used in the study. Each report in addition, contains a summary table of the mean yields, graphs of analyte versus 'tar' & CO yields and statistical analysis of the data along with the method used to obtain the results, validation data and other pertinent information.

Table 1 in this report contains a summary of the range of results for each analyte for the 25 brands tested along with the coefficients obtained from the regression analysis. Analytes are grouped by chemical family (e.g. carbonyls) and loosely by yield order.

Table 2 shows the range of concentrations found in the study for Kentucky Reference cigarette 1R4F which was smoked as part of the study. For most analytes, 1R5F was also smoked (optional under the study protocol) and these results have been reported. Arista Laboratories USA uses 2R4F as part of its routine quality control procedure so for some analytes it was possible to report results for this brand even though it was not intended to be part of the study protocol.

Only values obtained in the study have been included in Table 2 so, e.g. results obtained in a validation exercise to show repeatability within a single smoking run have been excluded. Therefore, the sample standard deviation gives an estimate of the repeatability of the method over a short period of time within one laboratory, i.e., smoking on different days, different channels, one or more operators, one analytical instrument and one or two smoking machines.

Table 1: Range of results & regression analysis (analyte yield versus NFDPM & CO yield)

Analyte	Range of mean results for brands tested	Units	Regression analysis of analyte yield versus NFDPM $y =$	R^2	Regression analysis of analyte yield versus carbon monoxide $y =$	R^2
NFDPM	1.0 - 13	mg cig ⁻¹	Not applicable		see below	
Nicotine	0.11 – 0.91	mg cig ⁻¹	0.0676x + 0.0896	0.94	Not required	
Carbon monoxide	1.0 – 13	mg cig ⁻¹	0.967x + 0.632	0.89	Not applicable	
Ammonia	<1.3 – 18.8	µg cig ⁻¹	0.599x – 0.296	0.37	0.541x – 0.056	0.32
Hydrogen cyanide	9.1 – 142	µg cig ⁻¹	11.5x – 4.03	0.93	11.2x – 6.00	0.93
Nitrogen monoxide	13.7 – 296	µg cig ⁻¹	11.3x + 6.72	0.54	11.4x + 1.51	0.58
Acetaldehyde	73.0– 872	µg cig ⁻¹	57.1x + 51.8	0.87	58.6x + 18.3	0.97
Acetone	39.1 – 360	µg cig ⁻¹	23.6x + 32.2	0.89	24.0x + 20.2	0.97
Acrolein	4.3 – 87.8	µg cig ⁻¹	5.34x + 1.20	0.84	5.43x - 1.61	0.91
Butyraldehyde	5.5 – 51.2	µg cig ⁻¹	3.46x + 3.06)	0.89	3.43x + 1.93	0.92
Crotonaldehyde	<2 – 33.3	µg cig ⁻¹	2.41x – 2.13	0.90	2.34x – 2.47	0.89
Formaldehyde	<2 – 56.3	µg cig ⁻¹	3.49x - 4.45	0.69	3.46x – 5.53	0.72
Methyl ethyl ketone	8.2 – 98.5	µg cig ⁻¹	6.81x + 4.59	0.90	6.85x + 1.72	0.96
Propionaldehyde	5.7– 62.1	µg cig ⁻¹	4.11x + 4.14	0.88	4.17x + 2.16	0.96
Phenol	0.91 – 46.2	µg cig ⁻¹	2.01x – 2.69	0.61	1.41x + 1.38	0.31
Catechol	10.1 – 70.7	µg cig ⁻¹	4.68x + 9.24	0.82	4.22x + 11.1	0.71
ortho-Cresol	<0.41 – 10.0	µg cig ⁻¹	0.473x – 0.443	0.68	0.353x + 0.348	0.39
meta & para-Cresol	0.78 – 21.7	µg cig ⁻¹	1.10x – 0.716	0.73	0.850x + 0.908	0.46
Hydroquinone	8.46 – 62.4	µg cig ⁻¹	4.21x + 7.27	0.82	3.85x + 8.53	0.72
Resorcinol	<0.33 – 1.47	µg cig ⁻¹	0.104x + 0.0844	0.85	0.0973x + 0.0981	0.79
1,3 butadiene	4.66 – 42.2	µg cig ⁻¹	2.68x + 4.68	0.86	2.78x + 2.90	0.97
Isoprene	48.9 – 369	µg cig ⁻¹	26.0x + 52.5	0.86	26.1x + 41.8	0.92
Acrylonitrile	<1.3 – 13.2	µg cig ⁻¹	0.938x - 0.392	0.92	0.916x - 0.572	0.93
Benzene	6.25 – 57.5	µg cig ⁻¹	3.73x + 5.66	0.87	3.80x + 3.67	0.95
Toluene	7.56 – 101	µg cig ⁻¹	7.06x + 3.12	0.90	7.07x + 0.295	0.96
Styrene (VOC method)	<0.8 – 12.1	µg cig ⁻¹	0.924x – 1.42	0.89	0.904x – 1.61	0.90
Pyridine	0.83 – 21.3	µg cig ⁻¹	1.04x – 2.24	0.68	0.933x – 1.76	0.58
Quinoline	<0.02 – 0.44	µg cig ⁻¹	0.0274x + 0.0025	0.87	0.0236x + 0.0228	0.68
Styrene (SVC method)	0.93 – 9.70	µg cig ⁻¹	0.716x – 0.461	0.92	0.693x – 0.542	0.90
Benzo[a]pyrene	1.68 – 16.0	ng cig ⁻¹	1.06x + 1.16	0.82	1.01x + 1.14	0.79
NAB	1.1 – 44.2	ng cig ⁻¹	1.05x – 1.22	0.22	0.979x – 1.06	0.20
NAT	7.8 – 148	ng cig ⁻¹	4.91x + 3.29	0.38	4.50x + 4.75	0.34
NNK	6.6 – 258	ng cig ⁻¹	6.10x – 9.14	0.21	5.90x – 9.91	0.21
NNN	5.2 – 500	ng cig ⁻¹	9.65x – 20.6	0.14	9.03x – 19.2	0.12
1-Naphthylamine	1.34 – 15.8	ng cig ⁻¹	0.632x + 1.36	0.65	0.565x + 1.66	0.55
2-Naphthylamine	0.86 – 10.3	ng cig ⁻¹	0.372x + 0.889	0.54	0.344x + 0.969	0.49
3-Aminobiphenyl	0.52 – 2.87	ng cig ⁻¹	0.0907x + 0.219	0.45	0.0854x + 0.227	0.42
4-Aminobiphenyl	0.41 – 2.06	ng cig ⁻¹	0.0645x + 0.221	0.46	0.0591x + 0.241	0.41
Mercury	<0.25 – 2.8	ng cig ⁻¹	0.166x + 0.428	0.72	0.168x + 0.347	0.78
Arsenic	nd – 4.5	ng cig ⁻¹	0.747x – 4.81	3 results	0.493x – 1.80	3 results
Cadmium	<1.2 – 90.3	ng cig ⁻¹	3.03x – 5.73	0.32	3.01x – 6.70	0.33
Chromium	nd	ng cig ⁻¹	Insufficient results		Insufficient results	
Lead	nd – 31.0	ng cig ⁻¹	1.87x – 2.31	0.75	1.91x – 3.43	0.75
Nickel	nd	ng cig ⁻¹	Insufficient results		Insufficient results	
Selenium	nd – 10.3	ng cig ⁻¹	Insufficient results		Insufficient results	

Table 2: Summary of results for 1R4F, 1R5F and 2R4F obtained in the study

Analyte	Number of determinations	Units	1R4F (mean \pm std dev)	1R5F (mean \pm std dev)	2R4F (mean \pm std dev)
NFDPM	20	mg cig ⁻¹	9.06 \pm 0.32	1.92 \pm 0.27	Not tested
Nicotine	20	mg cig ⁻¹	0.71 \pm 0.03	0.16 \pm 0.01	Not tested
Carbon monoxide	20	mg cig ⁻¹	12.3 \pm 0.37	3.36 \pm 0.23	Not tested
Ammonia	5	μ g cig ⁻¹	6.2 \pm 1.10	Not tested	Not tested
Hydrogen cyanide	5	μ g cig ⁻¹	125 \pm 9.88	22.8 \pm 1.07	Not tested
Nitrogen monoxide	5	μ g cig ⁻¹	277 \pm 14.9	98.7 \pm 4.43	Not tested
Acetaldehyde	5	μ g cig ⁻¹	709 \pm 58.7	183 \pm 12.7	Not tested
Acetone	5	μ g cig ⁻¹	299 \pm 23.3	87.4 \pm 3.9	Not tested
Acrolein	5	μ g cig ⁻¹	55.0 \pm 3.87	12.6 \pm 1.02	Not tested
Butyraldehyde	5	μ g cig ⁻¹	40.3 \pm 2.87	9.57 \pm 0.30	Not tested
Crotonaldehyde	5	μ g cig ⁻¹	16.8 \pm 2.45	2.77 \pm 0.30	Not tested
Formaldehyde	5	μ g cig ⁻¹	18.3 \pm 2.40	3.13 \pm 0.73	Not tested
Methyl ethyl ketone	5	μ g cig ⁻¹	76.5 \pm 6.45	18.4 \pm 1.07	Not tested
Propionaldehyde	5	μ g cig ⁻¹	52.8 \pm 4.27	13.7 \pm 0.81	Not tested
Phenol	5 (19 for 2R4F)	μ g cig ⁻¹	7.54 \pm 0.88	<0.72	5.02 \pm 1.01
Catechol	5 (19 for 2R4F)	μ g cig ⁻¹	38.0 \pm 2.68	8.42 \pm 0.50	39.8 \pm 1.67
ortho-Cresol	5 (19 for 2R4F)	μ g cig ⁻¹	2.31 \pm 0.25	<0.41	1.69 \pm 0.26
meta & para-Cresol	5 (19 for 2R4F)	μ g cig ⁻¹	5.88 \pm 0.60	0.67 \pm 0.09	4.69 \pm 0.66
Hydroquinone	5 (19 for 2R4F)	μ g cig ⁻¹	34.2 \pm 2.32	6.66 \pm 0.71	31.1 \pm 1.10
Resorcinol	5 (19 for 2R4F)	μ g cig ⁻¹	0.64 \pm 0.06	<0.33	0.74 \pm 0.04
1,3 butadiene	5 (17 for 2R4F)	μ g cig ⁻¹	31.0 \pm 1.61	12.6 \pm 1.76	34.5 \pm 2.15
Isoprene	5 (17 for 2R4F)	μ g cig ⁻¹	343 \pm 26.3	136 \pm 12.3	397 \pm 20.4
Acrylonitrile	5 (17 for 2R4F)	μ g cig ⁻¹	8.07 \pm 0.67	2.17 \pm 0.42	8.90 \pm 0.70
Benzene	5 (17 for 2R4F)	μ g cig ⁻¹	40.6 \pm 2.52	15.7 \pm 1.47	47.9 \pm 2.08
Toluene	5 (17 for 2R4F)	μ g cig ⁻¹	72.3 \pm 5.23	23.0 \pm 3.16	82.1 \pm 4.21
Styrene (VOC method)	5 (17 for 2R4F)	μ g cig ⁻¹	5.29 \pm 0.46	1.51 \pm 0.28	5.56 \pm 0.43
Pyridine	5	μ g cig ⁻¹	4.14 \pm 0.24	1.70 \pm 0.22	Not tested
Quinoline	5	μ g cig ⁻¹	0.22 \pm 0.04	0.08 \pm 0.02	Not tested
Styrene (SVC method)	5	μ g cig ⁻¹	5.63 \pm 0.26	2.93 \pm 0.23	Not tested
Benzo[a]pyrene	5	ng cig ⁻¹	7.07 \pm 0.91	1.80 \pm 0.54	Not tested
NAB	5 (18 for 2R4F)	ng cig ⁻¹	16.1 \pm 1.12	7.2 \pm 0.72	14.5 \pm 0.94
NAT	5 (18 for 2R4F)	ng cig ⁻¹	113 \pm 12.5	52.6 \pm 6.51	115 \pm 14.6
NNK	5 (18 for 2R4F)	ng cig ⁻¹	93.0 \pm 5.93	23.9 \pm 2.39	123 \pm 9.72
NNN	5 (18 for 2R4F)	ng cig ⁻¹	107 \pm 4.99	53.6 \pm 4.39	144 \pm 10.5
1-Aminonaphthalene	5 (24 for 2R4F)	ng cig ⁻¹	8.74 \pm 1.01	2.04 \pm 0.29	8.23 \pm 1.16
2-Aminonaphthalene	5 (24 for 2R4F)	ng cig ⁻¹	6.71 \pm 0.70	1.57 \pm 0.10	5.62 \pm 0.78
3-Aminobiphenyl	5 (24 for 2R4F)	ng cig ⁻¹	1.66 \pm 0.14	0.50 \pm 0.05	1.39 \pm 0.17
4-Aminobiphenyl	5 (24 for 2R4F)	ng cig ⁻¹	1.30 \pm 0.12	0.42 \pm 0.02	1.06 \pm 0.15
Mercury	5 (25 for 2R4F)	ng cig ⁻¹	4.3 \pm 0.32	1.4 \pm 0.09	2.4 \pm 0.10
Arsenic	5 (26 for 2R4F)	ng cig ⁻¹	6.5 \pm 0.30	nd	3.62 \pm 0.36
Cadmium	5 (26 for 2R4F)	ng cig ⁻¹	62.8 \pm 10.7	9.6 \pm 0.77	49.7 \pm 7.5
Chromium	5 (26 for 2R4F)	ng cig ⁻¹	nd	nd	nd
Lead	5 (26 for 2R4F)	ng cig ⁻¹	41.4 \pm 3.22	4.4 \pm 0.43	13.7 \pm 1.6
Nickel	5 (26 for 2R4F)	ng cig ⁻¹	nd	nd	nd
Selenium	5 (26 for 2R4F)	ng cig ⁻¹	<2.3	nd	<2.3

Samples

The manufacturers of the 25 brands were identified, contacted and asked to provide 2000 cigarettes (i.e. 10 outers) from a single 'current' production batch. Samples were received in late November through to early December 2001. The individual packets were 'mixed' and stored in plastic containers at 4 °C until required. Two brands were supplied in packets of 10 cigarettes – Regal King Size and Superkings Lights. One batch of cigarettes was replaced before commencement of the study as it was found that there was an unusually wide variation in the filter length for the brand.

Use of Dixon's Outlier Test

It was agreed as part of the study protocol that Dixon's outlier test would be performed on each set of results. A judgement then had to be made as to whether to use the original result or recalculate the mean excluding the outlier.

In practice, the findings from the outlier test were not used to eliminate results. Most outliers fell into one of two categories:

- a. Four of the results were very close to each other and so the test identified the fifth result as an 'outlier'. Elimination of the 'outlier' would lead to a set of result with an artificially high precision.
- b. Low 'tar' yield brands would often give a wider spread of analyte yields compared to other brands. Eliminating an 'outlier' for one of these brands would give a false impression of the precision that could be credibly achieved by the method for low analyte concentrations.

Therefore, it was agreed with the PMG to perform the outlier test as required in the study protocol but to report the original mean using all five results.

Repeat and Original Results

It should be noted that methods had QC procedures in place to eliminate rogue results, e.g. where the calibration of an instrument drifted out of acceptable limits. In these cases, the analysis would be repeated and the result reported marked with an 'r'. Obviously if a mistake was made, e.g. an incorrect amount of internal standard solution added, then the analysis would be repeated. In this situation the second analysis would be treated as the original result.

Regression Analysis

Regression analysis has been carried out for each analyte yield versus NFDPM and versus carbon monoxide. Table 1 contains the results of the regression analysis.

Data points for all 25 brands have been included in the analysis except where no analyte was detected. In practice, three analytes had insufficient data points to perform regression analysis (chromium, nickel and selenium) and only three data points were used for arsenic. For the other analytes, the full set of 25 data points were used to perform the analysis with the occasional exception for a low 'tar' brand where the analyte concentration was too low to be measured. Individual reports show how many points have been used for each analyte.

For some analytes, it may have been appropriate to exclude some outlying brands to obtain a better fit for the remaining data points. However, in the absence of pre-defined criteria for data point exclusion, it was decided to include data points for all cigarette brands in the regression analysis.

Commentary

One of the intentions of the study was to identify major differences between brands (if any) and to indicate if there is a relationship between analytes and ‘tar’/carbon monoxide yields. The data from the study is also intended to provide “benchmark data” for informed discussion on the role of cigarette design, if any, on analyte delivery. In understanding the data and relationships derived, allowance has to be made for the methods used and their uncertainty of measurement

a) Method Accuracy

Although not in the original design, styrene yields were determined for the 25 brands using the methods for volatiles by Arista Laboratories USA and for semi volatiles by Arista Laboratories Europe/LGC Limited. This provided an opportunity to evaluate the accuracy (precision and bias) between these methods.

Styrene with a melting point of -31°C ⁴, boiling point of 145°C and flash point of 31°C lies somewhere between being a volatile compound and a semi volatile compound. Therefore, either method could be considered suitable for determining styrene yields. Both methods worked satisfactorily to the extent that styrene was detected in sufficient quantities ($\mu\text{g cig}^{-1}$) to be measured with a reasonable degree of precision as shown by the CVs for each brand. Results obtained by the two methods are shown below.

VOC method	Styrene	SVC method	Styrene
<i>Ascending yield order</i>	$\mu\text{g/cig}$	<i>Ascending yield order</i>	$\mu\text{g/cig}$
Silk Cut Ultra King Size	0.38	Silk Cut Ultra King Size	0.93
Lambert & Butler Ultra Lights	0.63	Lambert & Butler Ultra Lights	1.09
Camel Ultra Lights	1.30	Silk Cut Extra Mild	1.47
Silk Cut Extra Mild	1.34	Camel Ultra Lights	1.84
Superkings Ultra Lights	1.82	Superkings Ultra Lights	2.04
Mayfair Menthol King Size	2.31	Mayfair Menthol King Size	2.45
Marlboro Lights King Size	2.74	Red Band Lights King Size	2.49
Silk Cut King Size	2.96	Marlboro Lights King Size	2.67
Red Band Lights King Size	3.43	Silk Cut King Size	3.31
Consulate Menthol	4.59	Lambert & Butler Lights King Size	4.07
Lambert & Butler Lights King Size	4.89	Superkings Lights	4.42
Superkings Lights	4.94	Consulate Menthol	4.45
Vogue Superslims	5.12	Vogue Superslims	4.93
Mayfair Lights King Size	5.44	Mayfair Lights King Size	5.36
Rothman Royals 120s	6.05	Rothman Royals 120s	5.82
Berkely Superkings	6.73	Berkely Superkings	6.09
Senior Service	7.06	Senior Service	6.52
Benson & Hedges King Size	7.70	Regal Filter	6.93
Rothman Royals King Size	8.86	Benson & Hedges King Size	7.22
Regal Filter	9.14	Rothman Royals King Size	7.70
Superkings	9.46	Superkings	7.94
Marlboro King Size	9.97	Marlboro King Size	8.13
Lambert & Butler King Size	10.7	Lambert & Butler King Size	8.61
Regal King Size	11.8	Gitanes Caporal Filter	9.53
Gitanes Caporal Filter	12.1	Regal King Size	9.70

The list above shows that the brand yield order is similar for both methods. However, the list also shows that there are difference in the values between the two methods and that the VOC method tends to give higher yields. This may well be due to differences in the way that the smoke is trapped by the two methods, one uses a Cambridge filter pad and solid sorbent tube, the other a very cold impinger containing methanol and fitted with a Grade 0 sinter. It should also be remembered that these values have been obtained using the ISO regime and that the values will be significantly different with other

⁴ Information obtained from Aldrich

smoking regimes though it is probable that the brand yield order will be similar as shown in previous work⁵.

b) Method Performance and Measurement Uncertainty

For each group of analytes, a method was selected to determine yields based on the selection criteria (see Method Selection, Validation and Quality Control)

For a few analytes, i.e. 'tar', nicotine and carbon monoxide, there is data available to show the method's precision, bias and reproducibility between laboratories.

The methods performed reasonably well for most sets of analytes measured in the study, in that analytes were detected and quantified with a reasonable degree of precision. Results for 1R4F were of the same order as values reported by other laboratories and in some cases there was good agreement between the value obtained in the study and published values. In other cases, there was a significant spread of results between laboratories for a particular analyte e.g. phenol so it is not easy to make a judgement about the method's accuracy.

A general statement that can be made about most of the analytical methods used is that measurement uncertainty increases with decreasing analyte concentration. Consequently brands such as Silk Cut Ultra King Size would often have large Coefficient of Variations compared to many other brands. This is not particularly surprising as it has been noted elsewhere that there is a link between accuracy and analyte concentration. The following is taken from the Valid Analytical Measurement web site (www.vam.org.uk):

"The way in which accuracy varies with the concentration of analyte being determined was demonstrated graphically by Horwitz *et al*¹ who collected together data showing the coefficient of variation which can be achieved by inter-laboratory studies at varying concentrations.

The coefficient of variation reported was typically 4% for a concentration of 100 mg kg⁻¹ and 32% for a concentration of 0.01 mg kg⁻¹. Advances in analytical techniques have made the end determination of a method more sensitive so that smaller amounts of an analyte can be measured. The perception of the analyst and the client is that lower and lower levels of analytes can be determined reliably because of advances in end measurement instrumentation, but caution needs to be exercised in the interpretation of the results of trace analysis at the lowest levels.

REFERENCE

1. Reprinted from the JAOAC, Volume 63, No 6, p. 1344-1354. Copyright 1980 by AOAC International".

The ICP-MS method used had difficulty in measuring analyte concentrations reliably due to the low levels of metals in mainstream cigarette smoke. Therefore, for nickel and chromium no analyte was detected for any of the brands and for selenium and arsenic most brands had yields that were too low to be quantified with a reasonable degree of precision. However the method could quantifiably measure yields of lead and cadmium in cigarette smoke. NB It may be that a brand does not contain any chromium in which case the method should not detect any analyte in the cigarette smoke!

Analyte yields may be dependent on fairly subtle variations in the method used. Determination of ammonia yields in cigarette smoke is a good example. In the study, ammonia was trapped by bubbling the cigarette smoke through a solution of malic acid and the ammonium ion concentration determined using an ion chromatograph fitted with a conductivity cell. Experiments showed that the ammonium ion concentration of the sample solutions increased during the first 36 hours. Therefore, the time specified in the method between smoking and analysis of the sample solution will have an effect on ammonia yields. It is a moot point as to whether a more representative yield is obtained by attempting to measure the maximum ammonium ion concentration or the ammonium ion concentration as soon as possible after smoking. Not all brands will exhibit exactly the same behaviour (i.e. reaching a maximum concentration after n hours) due to differences in the smoke matrix. Additionally, sample

⁵ Reports on previous work are available on the SCOTH web site (www.doh.gov.uk/scoth)

solutions are filtered before analysis and this may have an effect on any equilibrium between ammonium ions in solution and ammonia/ammonium ions 'attached' to the particulate phase.

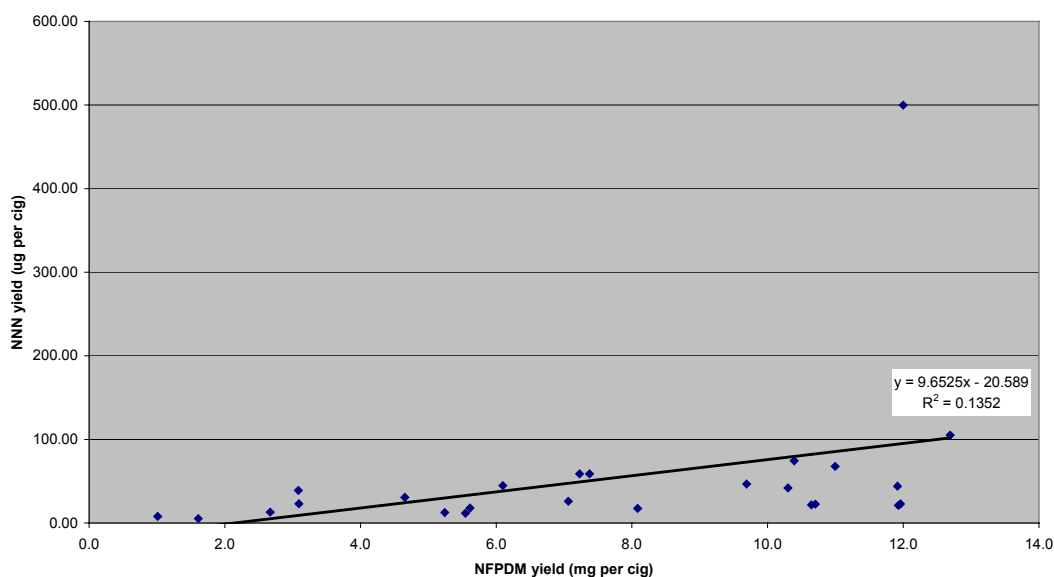
Samples were taken for a single production batch. If samples had been taken for analysis from several production batches over a period of time then there would be a wider spread of results due to variations in (a) the materials used to manufacture the cigarette, (b) the production process and (c) the analytical procedure used to determine the analyte yield(s).

c) Study Findings

Taking into account the comments above, the following observations can be made about the results obtained in the study:

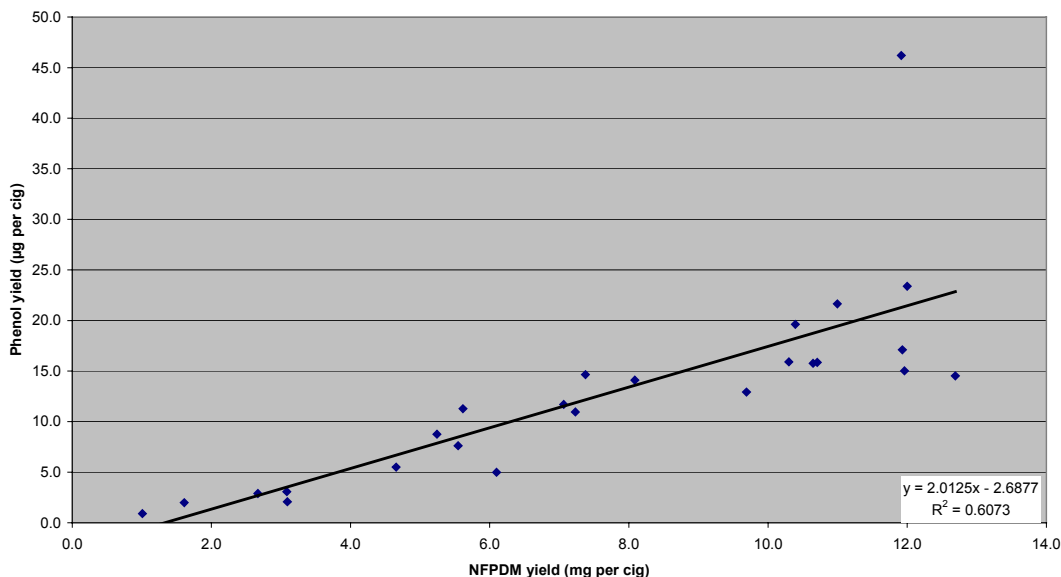
- Low yield 'tar' brands gave low yields for virtually all analytes. Thus, Silk Cut Ultra King Size and Lambert and Butler Ultra Lights were normally to be found at the bottom of the yield table, whatever the analyte that was being determined.
- For most analytes there is evidence of a linear relationship between 'tar' & carbon monoxide yields and the yield of the analyte being measured. For several analytes, regression analysis gave an R^2 value of >0.90 .
- Volatile analytes tended to have a better correlation with carbon monoxide than with 'tar' – the reverse may also be true but the evidence is less clear. For example, low molecular weight carbonyls (e.g. acetaldehyde) and volatile organic compounds (e.g. 1,3-butadiene) gave an R^2 value of 0.97 with carbon monoxide. Hydroquinone and benzo[a]pyrene gave a better fit with 'tar' compared to carbon monoxide (R^2 value of 0.82 against 'tar' compared to an R^2 value of 0.72 against CO for hydroquinone and an R^2 value of 0.82 against 'tar' compared to an R^2 value of 0.79 against CO for benzo[a]pyrene).
- Poor R^2 values are often due to one or two brands giving high/low analyte yields that don't relate to their 'tar' and carbon monoxide yield compared to other brands. This may be due to the particular cigarette design features and/or the materials used in its manufacture (see also "method performance and measurement uncertainty" above). For example:
 - ❖ Nitrosamines in general had poor R^2 values (<0.40) – an examination of the graph for NNN (N-nitrosornicotine) versus NFDPM shows clearly that Gitanes Caporal Filter is an outlier and a better fit would be obtained if the brand was removed from the analysis. One would surmise that the high nitrosamines yields are related to the fact that it is the only brand made with dark air cured tobacco.

Regression analysis of NNN versus NFDPM for 25 cigarette brands



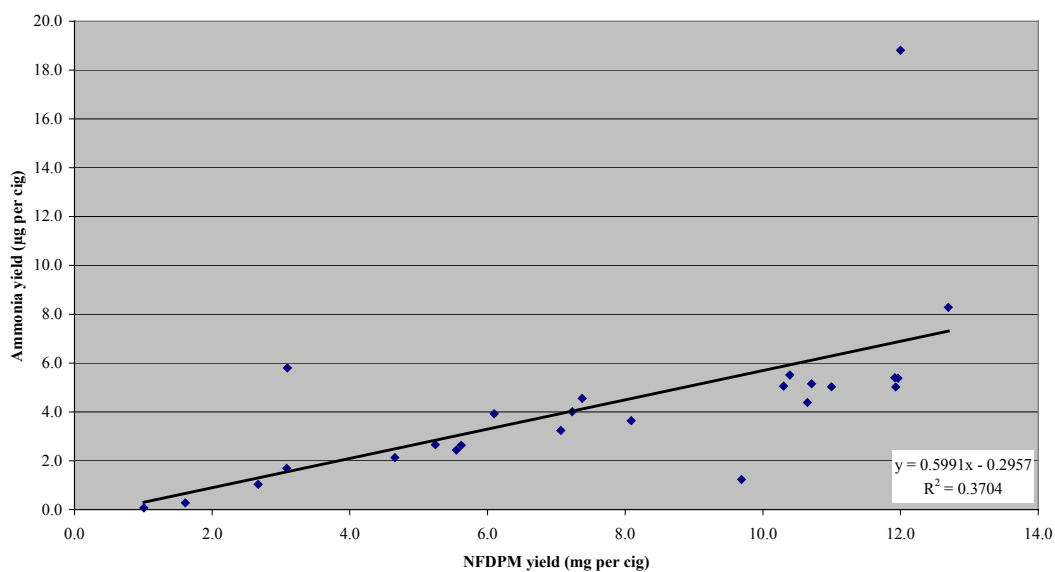
- ❖ Mono hydroxy phenols had a poor correlation coefficient compared to dihydroxy phenols. A visual examination of one of the graphs for mono hydroxy phenols (e.g. phenol) shows that Senior Service is an outlier. This is the only unfiltered brand in the study which may be the reason for the higher yields of mono hydroxy phenols. However, dihydroxy phenol yields are similar to other brands with similar levels of ‘tar’. This brand also had relatively low yields of carbon monoxide and some other volatile compounds because it is also the brand with the highest permeability paper (200 CU).

Regression analysis of phenol versus NFDPM for 25 cigarette brands



- ❖ Ammonia has a poor R^2 value of 0.37. Looking at the graph, Gitanes Caporal Filter is identified as giving a very high ammonia yield for its ‘tar’ value. Removal of this brand then gives the revised R^2 value of 0.56

Regression analysis of ammonia versus NFDPM for 25 cigarette brands



Overall, this study confirms that for many analytes there is good correlation between analyte yields and 'tar' and carbon monoxide yields for cigarette brands. Data from the study shows that cigarette tobacco blend style and the presence or absence of a filter has an effect on the yields of a few smoke constituents. When looking at analyte yields (or when ranking brands), account must be taken of measurement uncertainty, and the likelihood of further variability on repeated testing..

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Appendices, Reports and Annexes

Annex 1 contains the Study Protocol.

Appendix 1 contains a brief glossary of selected abbreviations and terms used in this report

Appendix 2 lists the specific analytes determined in the study.

Appendix 3 contains a list of the brands of cigarettes used in this survey and a summary of their design characteristics ⁶.

There are a series of reports and annexes that accompany this document. For each group of analytes, there is an individual report describing the work undertaken, the yields obtained and regression analysis of the results. In addition there are Annexes to each report containing the analytical method(s) used to measure the yields and a summary of the data obtained in the validation of the procedure.

Report Title	Annexes	Produced by
Part 1 : Determination of NFDPM, Nicotine and Carbon Monoxide Yields in Cigarette Smoke		LGC Limited
Part 2 : Determination of Eight Carbonyl Yields in Cigarette Smoke	Annex A Method Annex B Validation Data	LGC Limited
Part 3 : Determination of Nitrogen Monoxide Yields in Cigarette Smoke	Annex A Method Annex B Validation Data	LGC Limited
Part 4 : Determination of Benzo[a]pyrene Yields in Cigarette Smoke	Annex A Method Annex B Validation Data	LGC Limited
Part 5 : Determination of Ammonia Yields in Cigarette Smoke	Annex A Method Annex B Validation Data	LGC Limited
Part 6 : Determination of Hydrogen Cyanide Yields in Cigarette Smoke	Annex A Method Annex B Validation Data	LGC Limited
Part 7 : Determination of Semi Volatile Compounds Yields in Cigarette Smoke	Annex A Method Annex B Validation Data	Arista Laboratories Europe & LGC Limited
Part 8 Method: Determination of TSNAs yields in mainstream cigarette smoke by LC-MS-MS	Annex A Method Annex B Validation Data	Arista Laboratories Europe
Part 9 Method: Determination of VOCs' yields in mainstream cigarette smoke by GC-MS	Annex A Method Annex B Validation Data	Arista Laboratories Europe
Part 10 : Determination of Mono and Dihydroxy Phenols Yields in Cigarette Smoke	Annex A Method Annex B Validation Data	Arista Laboratories Europe
Part 11 : Determination of Metals Yields in Cigarette Smoke	Annex A Method (metals) Annex B Validation Data Annex C Method (mercury)	Arista Laboratories Europe
Part 12 : Determination of Aromatic Amines Yields in Cigarette Smoke	Annex A Method Annex B Validation Data	Arista Laboratories Europe

⁶ The tobacco manufacturers provided the samples and information about the physical parameters of the cigarettes.

Appendix 1: Selected abbreviations and terms used in this report

Term/Definition	Meaning
TNCO	‘tar’, nicotine and carbon monoxide
Std dev	Sample standard deviation
Run	The smoking run that the cigarette was smoked in
‘tar’	Nicotine Free Dry Particulate Matter (NFDPM)
Yield	The concentration of analyte measured in the smoke (normally per cigarette)
DoH	Department of Health
PMG	Project Management Group
UKAS	United Kingdom Accreditation Service
ISO	International Organization for Standardisation
°C	Degree Celsius
ng	Nanogram
µg	Microgram
mg	Milligram
mL	Millilitre
L	Litre
mm	Millimetre
cig ⁻¹	per cigarette
nd	Not detected
CV(%)	Coefficient of Variation
R ²	“The r-squared value can be interpreted as the proportion of the variance in y attributable to the variance in x”. ⁷
Correlation Coefficient:	“The correlation coefficient, r, measures the degree of association between the two variables The closer r is to 1 the more highly correlated the data values are;” ⁸
NNN	N-nitrosornicotine

⁷ Microsoft Excel

⁸ Practical statistics for the analytical scientist, Trevor Farrant, 1997, ISBN 0 85404 442 6

Appendix 2: Selected smoke constituents for UK study

Type	Specific analyte(s)
	nicotine free dry particulate matter
	nicotine
	carbon monoxide
	ammonia
	hydrogen cyanide
	nitrogen monoxide
Aromatic Amines	1-aminonaphthalene
	2-aminonaphthalene
	3-aminobiphenyl
	4-aminobiphenyl
Aldehydes & Ketones	formaldehyde
	acetaldehyde
	acetone
	acrolein
	propionaldehyde
	crotonaldehyde
	methyl ethyl ketone
	butyraldehyde
Nitrosamines	N-nitrosornicotine (NNN)
	N-nitrosoanatabine (NAT)
	N-nitrosanabasine (NAB)
	4-(N-methyl-N-nitrosamino)-1-(3-pyridinyl)-1-butanone (NNK)
Phenols	phenol
	catechol
	hydroquinone
	resorcinol
	ortho-cresol
	meta/para-cresol
Polycyclic Aromatic Hydrocarbons	benzo[a]pyrene
Semi Volatile Compounds	pyridine
	quinoline
	styrene
Trace Metals	arsenic
	cadmium
	chromium
	lead
	mercury
	nickel
	selenium
Volatile Organic Compounds	benzene
	toluene
	1,3-butadiene
	isoprene
	acrylonitrile
	(styrene)

Appendix 3: Description of brands (sold in the UK - Nov/Dec 2001) used in the benchmark study

Brand	Manufacturer (November 2001)	Description	Filter ventilation %	Paper permeability CU	Circumference mm	Oven dry weight of tobacco mg cig⁻¹	Length mm
Benson & Hedges King Size	Gallaher Limited	filter – typical UK blend	17	29	24.8	0.65	84
Berkeley Superkings	Gallaher Limited	filter – typical UK blend	19	71	24.8	0.73	99
Camel Ultra Lights	Japan Tobacco International Limited	filter – typical American blend	70	50	24.9	0.57	84
Consulate Menthol	British American Tobacco	filter – typical UK blend – menthol	30	50	24.8	0.63	84
Gitanes Caporal Filter	Altadis	filter – dark air cured blend	14	15	26.7	0.68	70
Lambert & Butler King Size	Imperial Tobacco Limited	filter – typical UK blend	0	44	24.6	0.63	84
Lambert & Butler Lights King Size	Imperial Tobacco Limited	filter – typical UK blend	42	44	24.9	0.58	84
Lambert & Butler Ultra Lights	Imperial Tobacco Limited	filter – typical UK blend	76	71	24.9	0.63	84
Marlboro King Size	Philip Morris	filter – typical American blend	19	54	24.8	0.77	84
Marlboro Lights King Size	Philip Morris	filter – typical American blend	45	34	24.8	0.62	84
Mayfair Lights King Size	Gallaher Limited	filter – typical UK blend	30	44	24.8	0.63	84
Mayfair Menthol King Size	Gallaher Limited	filter – typical UK blend – menthol	69	44	24.8	0.58	84
Red Band Lights King Size	Reemtsma	filter – typical UK blend	51	60	24.8	0.61	84
Regal Filter	Imperial Tobacco Limited	filter – typical UK blend	7	44	24.7	0.53	71
Regal King Size	Imperial Tobacco Limited	filter – typical UK blend	0	44	24.7	0.62	84
Rothman Royals 120s	British American Tobacco	filter – typical UK blend	25	75	22.0	0.76	120
Rothman Royals King Size	British American Tobacco	filter – typical UK blend	23	50	24.8	0.67	84
Senior Service	Gallaher Limited	plain - typical UK blend	0	200	25.1	0.74	69
Silk Cut Extra Mild	Gallaher Limited	filter – typical UK blend	69	44	24.8	0.56	84
Silk Cut King Size	Gallaher Limited	filter – typical UK blend	57	71	24.8	0.64	84
Silk Cut Ultra King Size	Gallaher Limited	filter – typical UK blend	82	44	24.8	0.56	84
Superkings	Imperial Tobacco Limited	filter – typical UK blend	0	71	24.7	0.73	99
Superkings Lights	Imperial Tobacco Limited	filter – typical UK blend	31	44	24.7	0.68	99
Superkings Ultra Lights	Imperial Tobacco Limited	filter – typical UK blend	57	71	24.7	0.55	99
Vogue Superslims	British American Tobacco	filter – typical American blend	45	20	17.0	0.38	99