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Polycyclic Aromatic Hydrocarbons in the Mainstream Smoke of Popular U.S. Cigarettes

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Abstract

The mainstream smoke yields of 14 polycyclic aromatic hydrocarbons (PAHs) were determined for 50 commercial U.S. cigarettes using a validated GC/MS method with the International Organization of Standardization (ISO) and Canadian Intense (CI) smoking machine regimens. PAH mainstream smoke deliveries vary widely among the commercial cigarettes with the ISO smoking regimen primarily because of differing filter ventilation. The more abundant, lower molecular weight PAHs such as naphthalene, fluorene, and phenanthrene predominantly comprise the total PAH yields. In contrast, delivery yields of high molecular weight PAHs such as benzo[b]fluoranthene, benzo[e]pyrene, benzo[k]fluoranthene, and benzo[a]pyrene (BaP) are much lower. Comparative analysis of PAHs deliveries shows brand specific differences. Correlation analysis shows strong positive associations between BaP and most of the other PAHs as well as total PAHs. The results suggest that BaP may be a representative marker for other PAH constituents in cigarette smoke generated from similarly blended tobacco, particularly those PAHs with similar molecular weights and chemical structures.

Keywords

Polycyclic aromatic hydrocarbons; benzo[a]pyrene; PAH correlations; mainstream cigarette smoke

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INTRODUCTION

Tobacco use continues to be the leading cause of preventable death, accounting for approximately six million mortalities and more than one-half trillion dollars of economic damage worldwide each year.[1] In the United States, cigarette smoking alone causes nearly one-half million adults to die prematurely each year.[2] Cigarette smoke is an extremely complex chemical composition and contains numerous toxic and carcinogenic substances, including many polycyclic aromatic hydrocarbons (PAHs). PAHs are a class of compounds composed of two or more fused benzenoid rings known for their carcinogenic and mutagenic properties. There are more than five hundred different PAHs in tobacco smoke.[3] According to the International Agency for Research on Cancer (IARC), some of the PAHs are possible or known human carcinogens.[4] The IARC lists benzo[a]pyrene (BaP) as a Group 1 carcinogen, classifying it as the most potent carcinogen among the PAHs.[4] Its induction of lung tumors upon local administration or inhalation is well documented.[5]

PAHs do not naturally occur in the tobacco plant, but are formed primarily by incomplete combustion of tobacco and other organic components during smoking. PAHs are present in some unburned tobacco products, particularly those containing fire-cured tobacco varieties.[6–7] During fire curing, PAHs in combustion fumes generated by smoldering wood are deposited on the tobacco leaves.[8]

In 2012, the U.S. Food and Drug Administration (FDA) identified and published a list of 93 harmful and potentially harmful constituents (HPHCs) in tobacco products and tobacco smoke in the *Federal Register*.[9] Sixteen of these compounds are PAHs. The FDA requires tobacco product manufacturers to test and report the quantities of HPHCs, including BaP, in several tobacco matrices.[10] In this study, we report the levels of 14 PAHs in the mainstream smoke of 50 commercial U.S. cigarette products under non-intense and intense smoking machine regimens using a validated gas chromatography/mass spectrometry (GC/MS) analytical method. We also examined potential correlations between BaP and other individual PAHs to determine if BaP may be an appropriate surrogate for other PAHs in cigarette smoke, including some of those that FDA has listed as HPHCs.

MATERIALS AND METHODS

Materials

The cigarettes selected for this study consisted of 35 top-selling U.S. cigarette brands that represented approximately 54 percent of the total U.S. cigarette market share based on sales volume.[11] An additional 15 cigarettes were randomly selected to include some off-brands with low market share or unique characteristics. The 50 cigarettes consisted of 23 brands with various sub-brands, lengths (king or 100s), sizes (regular, slim, or super slim) and package types (hard pack or soft pack). They were regular, menthol, or Turkish flavored, and all contained a cellulose acetate filter. Most cigarette products (48) were produced by three major tobacco product manufacturers, R. J. Reynolds, Philip Morris, and Lorillard. American Spirit Blue King was manufactured by Natural American Spirit, and USA Gold 100s was manufactured by Commonwealth Brands. All cigarettes were purchased in November 2011 from retail outlets in the greater metropolitan Atlanta area in Georgia, USA.

The cigarette packs were assigned unique identification numbers, and logged into a database. Samples were stored at −80 °C in their original packaging until needed. The 3R4F reference cigarettes were obtained from the University of Kentucky, Kentucky Tobacco Research and Development Center (Lexington, KY).

Neat PAHs used for calibration were obtained from Aldrich Chemical Co. (Milwaukee, WI). A 14-PAH standard (^{13}C, 99%, 5 μg/mL) stock, used as a labeled internal standard, was purchased from Cambridge Isotope Laboratories, Inc. (Andover, MA). All dilutions were prepared in methanol. Cambridge filter pads (CFPs) used to collect mainstream smoke particulate matter were obtained from Whatman (Maidstone, United Kingdom).

Smoke Particulate Matter Collection

Cigarettes and CFPs were conditioned at 22 °C and 60% relative humidity for at least 48 h prior to smoking according to the International Organization of Standardization (ISO) method 3402.[12] Mainstream smoke total particulate matter (TPM) was generated by following the ISO smoking regimen (60-s puff interval, 2-s puff duration, and 35-mL puff volume, unblocked ventilation),[13] or Canadian Intense (CI) smoking regimen (30-s puff interval, 2-s puff duration, and 55-mL puff volume, 100% blocked ventilation)[14] and were collected on individual CFPs using a Cerulean ASM500 16-port smoking machine (Milton Keynes, United Kingdom). The cigarettes were smoked to a butt length of 23 mm or to the length of the filter overwrap plus 3 mm, whichever was longer. Three cigarettes were smoked per CFP for the ISO regimen, and one cigarette was smoked per CFP for the CI regimen. Cigarettes were smoked to obtain the average smoke particulate level for each of the 14 PAHs measured in this study (Figure 1). During each smoking run, 3R4F cigarettes were smoked as quality control (QC) samples. After a group of cigarettes were smoked, each CFP was spiked with 20 μL of the ^{13}C PAH internal standard solution prior to sample preparation and cleanup.

Sample Preparation and GC/MS Analysis

The sample preparation and GC/MS analysis scheme was based on a method previously developed and validated by the Centers for Disease Control and Prevention (CDC),[15] modified to use a Gilson 215 automated solid phase extraction (SPE) system (Middleton, WI) and Varian C-18 SPEC cartridges (Lake Forest, CA).[16] An Agilent GC model 6890 and an Agilent single quadruple MS model 5973 were used for analysis with Chem Station software for data acquisition in selected ion monitoring mode (SIM). Reconstructed ion chromatograms used for quantification were processed using Xcalibur software (Thermo Electron), and results were exported to an Excel spreadsheet. Each quantitation ion peak area was automatically selected and integrated. Integrations were manually inspected for errors and reintegrated if needed. Individual levels of the 14 PAHs were calculated from the means of seven replicates and reported as ng analyte per cigarette (Tables 1–2).

Statistical Analysis

Pearson product-moment correlation coefficients (r) were calculated using Microsoft Excel 2010 software with the correlation data analysis function. P-values, which measure statistical significance of correlation, were calculated using the mathematical formula for correlation critical value t, followed by Excel tdist function. Correlations are considered statistically significant when p-values are less than 0.05. Coefficients of determination (r^2), which measure the goodness of fit between the smoke deliveries of BaP and other PAHs on the regression lines, were calculated using Microsoft Excel 2010 software with the linear regression analysis function.

RESULTS AND DISCUSSION

PAH Yields in Reference Cigarettes

For data quality control, we measured the levels of 14 PAHs in mainstream smoke from 3R4F reference cigarette (University of Kentucky, Lexington, KY) using both ISO and CI smoking regimens. Results are provided in Tables 1–2. The 3R4F cigarettes are constructed to represent typical American blended cigarettes consisting of mainly bright, burley, oriental, and reconstituted tobaccos.[17] As depicted in Figure 2, the levels of 14 PAHs in the mainstream smoke of 3R4F are similar to those of 2R4F reference cigarette measured previously using the same GC/MS method.[15] Moreover, a comparison to the 3R4F PAH data reported previously by Roemer[17] shows comparable levels of pyrene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene and BaP with both smoking regimens (Figure 2).

Figure 3 shows the coefficients of variance (CV) for each PAH yield of the 3R4F cigarette. They are based on 25 analytical determinations and range from 9.5% to 17.1% for ISO smoking and from 10% to 20.2% for CI smoking. As shown, the CI regimen has slightly higher variability than the ISO regimen for most PAH constituents. This is also shown by the overall CV of 13.9% compared to 12.0% for the ISO regimen. The higher CV of the CI regimen may be in part due to the sampling difference between the two smoking regimens (1 cigarette per pad for CI versus 3 cigarettes per pad for ISO).

PAH Levels in U.S. Cigarettes

The yields of 14 PAHs in smoke particulate of 50 U.S. cigarette products measured by both ISO and CI smoking regimens are provided in Tables 1–2 respectively. We also calculated the total PAH yields by adding the amounts of the 14 individual PAHs. All 14 PAHs were detected in the 50 cigarette products ranging from sub-nanogram to microgram levels.

As shown in Figure 4, the PAH yields with the ISO smoking regimen vary widely among the commercial cigarettes with the amount of total mainstream smoke PAHs ranging from 0.139 to 2.6 μg per cigarette. Except for pyrene and benzo[k]fluoranthene, total and individual PAH yields differ more than 10-fold between highest and lowest delivery cigarettes (Table 1). Yield difference for naphthalene is nearly 60-fold.

With the CI smoking regimen, individual PAH levels are higher than those from using the ISO smoking regimen (Table 2). Figure 4 also shows greater total CI PAH levels compared to total ISO PAH levels. However, consistent with previous observation,[15] PAH yield increase is disproportional and is more dramatic for cigarettes with low total ISO PAH smoke yields (Figure 4) because of filter ventilation. The difference in PAH yields between highest and lowest delivery cigarettes from the CI smoking regimen is 2- to 3-fold (Table 2).

The wide range of deliveries under ISO is primarily a function of the wide range of filter ventilation levels for this set of products. Under CI conditions, the filter holes are blocked and the differences observed are more due to tobacco mass, filter length, paper porosity, and possibly filler nitrate content as a source of free radical scavengers[18] that thwart PAH formation.

As shown in Figure 4, American Spirit Blue displays the highest total PAH yields measured by both ISO (2.6 μg/cigarette) and CI (4.9 μg/cigarette) smoking regimens. It also exhibits the highest yields of most of the 14 PAH constituents analyzed (Tables 1 and 2). Moreover, it delivered from 60% to 170% higher PAH yields than the average PAH yields of all 50 cigarettes with the ISO smoking regimen (Table 1). The highest PAH smoke yields of American Spirit Blue are in part attributable to its highest tobacco mass of 881 mg/cig, which is 216 mg more than the average tobacco mass of the other 49 cigarettes (665 mg/cig). Moreover, American Spirit cigarettes have been indicated to contain 100% Virginia tobacco which is flue-cured.[19] Flue-cured tobaccos are known to generate higher levels of PAHs than other tobacco types, particularly those PAHs with high molecular weight.[15–16,20] Along with American Spirit Blue, Winston Red and Winston Red 100s are among the top five products with highest total PAH yields measured by both ISO and CI smoking regimens (Tables 1 and 2).

In contrast, among the test cigarettes, Carlton White 100s had the lowest total (139 ng/cigarette) and individual PAH yields with the ISO regimen (Figure 4), whereas Marlboro Silver had the lowest total PAH yields with the CI smoking regimen (1.6 μg/cigarette). The lower PAH smoke yields of Carlton White 100s and Marlboro Silver are in part attributable to their very low tobacco mass of 585 mg/cig. Moreover, Carlton White 100s has a high filter ventilation (62.3%) which also contributes to its lower ISO PAH deliveries.

As depicted in Figure 5, the average yields of individual PAHs for all 50 commercial cigarettes measured for ISO and CI smoking regimens are similar to those of 3R4F reference cigarette. Low molecular weight PAHs such as naphthalene, fluorene, and phenanthrene dominate the total PAH yields. Naphthalene is the most abundant PAH. In contrast, yields of high molecular weight PAHs such as benzo[b]fluoranthene, benzo[e]pyrene, benzo[k]fluoranthene and benzo[a]pyrene are much lower. These trends are consistent with previous studies.[15–16] With exception of a few PAHs, there is an overall inverse trend between PAH yield and molecular weight. Yield of benzo[k]fluoranthene was lowest among the PAH constituents tested.

We also examined correlations among PAH yields. Pearson correlation coefficients (r) and p-values were calculated using Microsoft Excel 2010 software and are provided in Tables 3–4. For the ISO smoking regimen (Table 3), except for the association between acenaphthene and benzo[e]pyrene, correlations among the 14 PAHs and total PAH range from moderate ($r > 0.61$) to strongly positive linear relationships ($r > 0.95$). All show high statistical significance with p-values below 0.001. Strongest associations exist for benz[a]anthracene, chrysene, and BaP with many r values greater than 0.9, whereas weaker correlations appear among naphthalene, acenaphthene, and benzo[e]pyrene. For the CI smoking regimen, correlations between the PAH constitutents are generally weaker than the ISO regimen

(Table 4). However, strong associations remain with benz[a]anthracene, chrysene, and BaP with many r values greater than 0.9. In contrast, very weak correlations are observed among naphthalene, acenaphthene, and benzo[e]pyrene with a number of r values below 0.5. Notably, no correlation exists between acenaphthene and benzo[e]pyrene with the CI smoking regimen.

As stated, BaP has been extensively studied among the PAHs because of its efficacy in inducing lung tumors.[5] In analytical studies, BaP has often been used as a surrogate for other PAHs.[5] In effect, many studies reported only BaP levels in cigarette smoke.[21–23] Accordingly, part of this study focused on the correlations of BaP to determine if it can be a surrogate to estimate the levels of other PAHs in smoke particulate. As shown in Figure 6, BaP displays moderate linear relationships with small PAHs such as naphthalene and acenaphthene ($r = 0.79$) for the ISO smoking regimen. However, it correlates well with most other PAHs and total PAHs ($r \geq 0.9$). Correlations appear strengthened as the size of PAHs increases. Significant correlations exist for pyrene and benzo[b]fluoranthene with r values greater than 0.95. In particular, BaP strongly correlates to benz[a]anthracene and chrysene with r values ≥ 0.98. Note that the chemical structures of benz[a]anthracene and chrysene resemble that of BaP (Figure 1). Surprisingly, correlation with larger benzo[e]pyrene is lower ($r = 0.83$). As shown in Figure 1, although having the same molecular weight, the backbone structure of BaP differs from that of benzo[e]pyrene, suggesting there may be different precursors or pyrosynthetic pathways to high molecular weight PAHs with different chemical structures. Correlations between BaP and other PAHs weaken under the CI smoking regimen (Figure 6) which may be attributable to its higher coefficients of variance (Figure 3).

To evaluate the utility of using BaP levels to estimate smoke yields of other PAHs from the ISO smoking regimen, we plotted yields of other PAHs with high correlation coefficients ($r \geq 0.9$) versus BaP yields, and performed simple linear regression analysis. As shown in Figure 7, the data fit regression lines without outliers, thus confirming proportional linear relationships of BaP with total and other PAHs. In particular, the high coefficients of determination for pyrene and benzo[b]fluoranthene ($r^2 > 0.91$) show low variability for estimating their smoke deliveries using BaP yields (Figure 7b–c). Moreover, the very high r^2 values ($r^2 \geq 0.97$) for benz[a]anthracene and chrysene (Figure 7c) indicate an excellent prediction of benz[a]anthracene and chrysene levels using BaP.

We also plotted the yields of several high molecular weight PAHs versus BaP yields measured under the CI smoking regimen. As shown in Figure 8, while linear regression lines show excellent correlation between BaP and benz[a]anthracene and chrysene ($r^2 > 0.96$), linear relationships with benzo[b]fluoranthene and benzo[k]fluoranthene are weaker, indicating lower prediction reliability under the CI smoking regimen.

The results of the correlation and linear regression analyses demonstrate possible quantitative relationships between BaP and other specific PAH compounds in cigarette smoke measured for both ISO and CI smoking regimens. In particular, very strong correlations exist between BaP and those with similar molecular weight and chemical structures.

In summary, this study provides a survey of PAH mainstream smoke yields for popular U.S. cigarettes having a wide range of machine generated smoke deliveries. The results serve as a useful reference for comparing relative smoke PAH deliveries among different cigarettes as well as a baseline to determine if changes occur with time. The study identifies substantial differences in PAH levels in the mainstream smoke of different commercial cigarettes. Highest PAH levels were found in Virgina blended American Spirit Blue. Correlation analysis reveals strong associations between BaP and most of the other PAHs under the ISO smoking regimen. Correlations from the CI smoking regimen are generally weaker, but remain significant. Linear regression analysis suggests that BaP has potential as a surrogate marker for other PAHs in cigarette smoke, particularly those with similar molecular weights and chemical structures. Further studies are necessary to extend BaP correlation to other PAHs, particularly those of tetracyclic and higher PAHs on IARC's carcinogen list and FDA's HPHC list that were not included in this study.

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ABBREVIATIONS

ACL	acenaphthylene
ACT	acenaphthene
ANT	anthracene
BAA	benz[a]anthracene
BAP	benzo[a]pyrene
BBF	benzo[b]fluoranthene
BEP	benzo[e]pyrene
BKF	benzo[k]fluoranthene
CDC	Centers for Disease Control and Prevention
CHR	chrysene
FLR	fluoranthene
FLU	fluorene
GC/MS	gas chromatography/mass spectrometry
NAP	naphthalene
PHE	phenanthrene
PYR	pyrene

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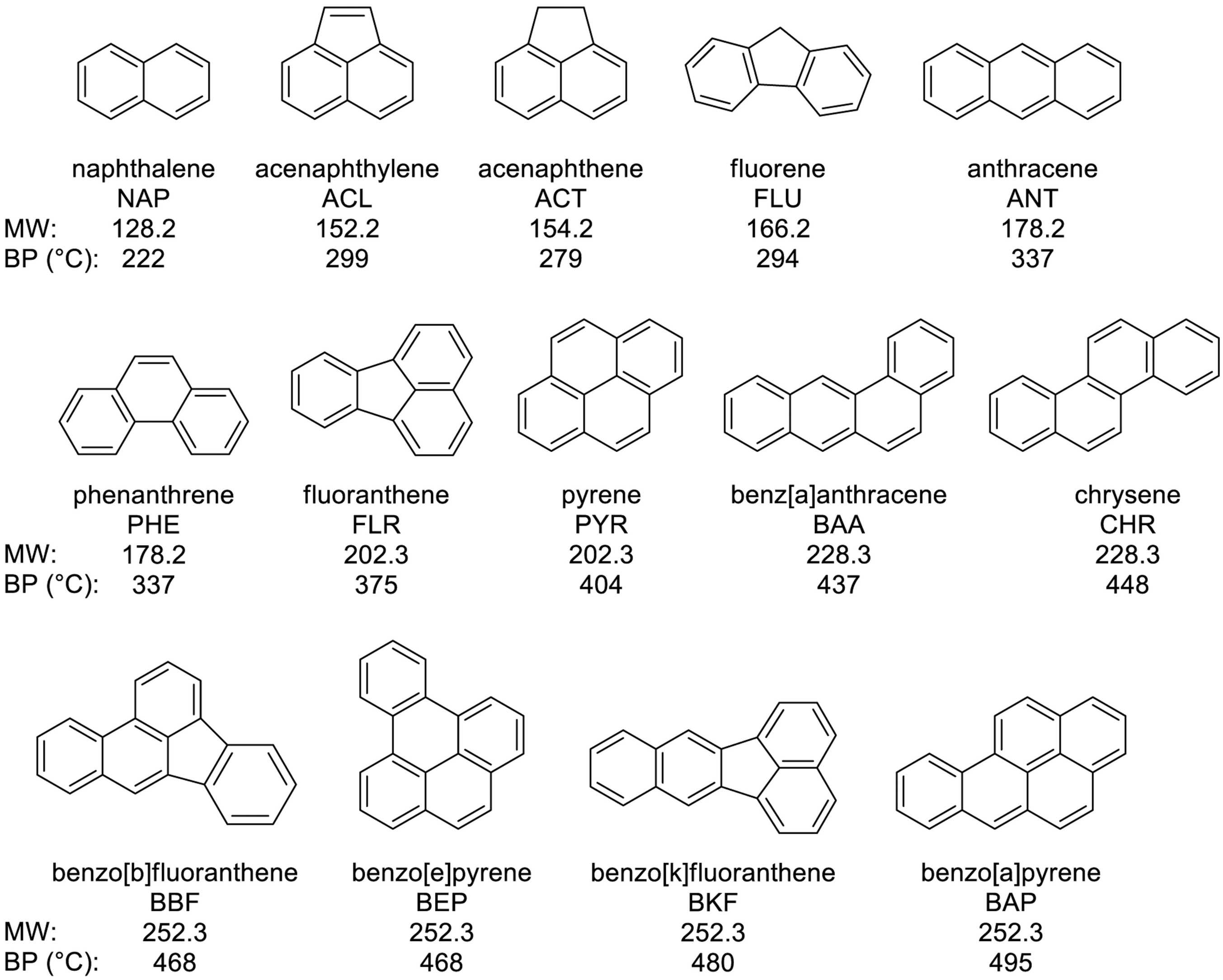

Figure 1.

Chemical structure, molecular weight, and boiling point of 14 polycyclic aromatic hydrocarbon analytes.

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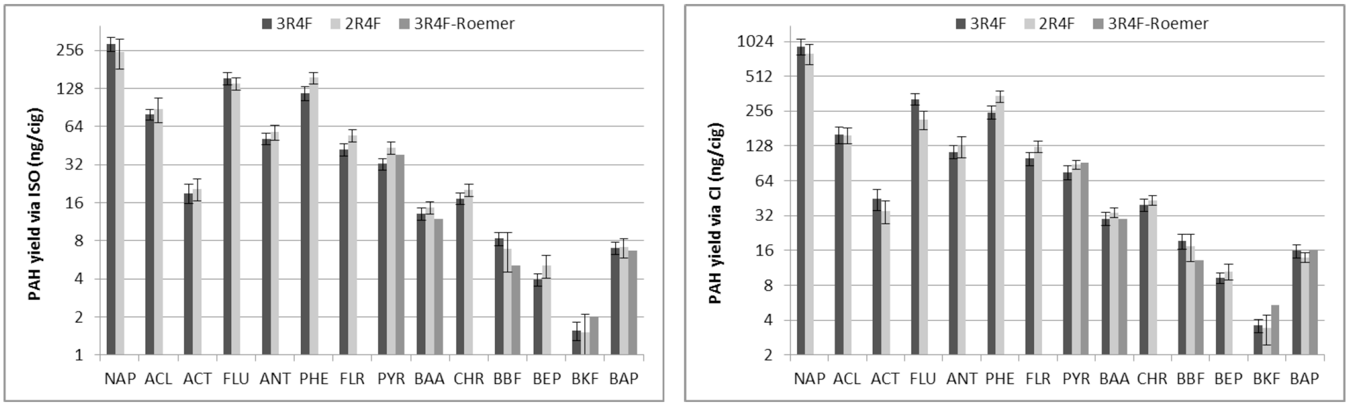

Figure 2.

PAH Levels in 3R4F and 2R4F reference cigarettes. PAHs are arranged by ascending molecular weight and boiling point. Y-axis depicts PAH yield on a log-2 scale.

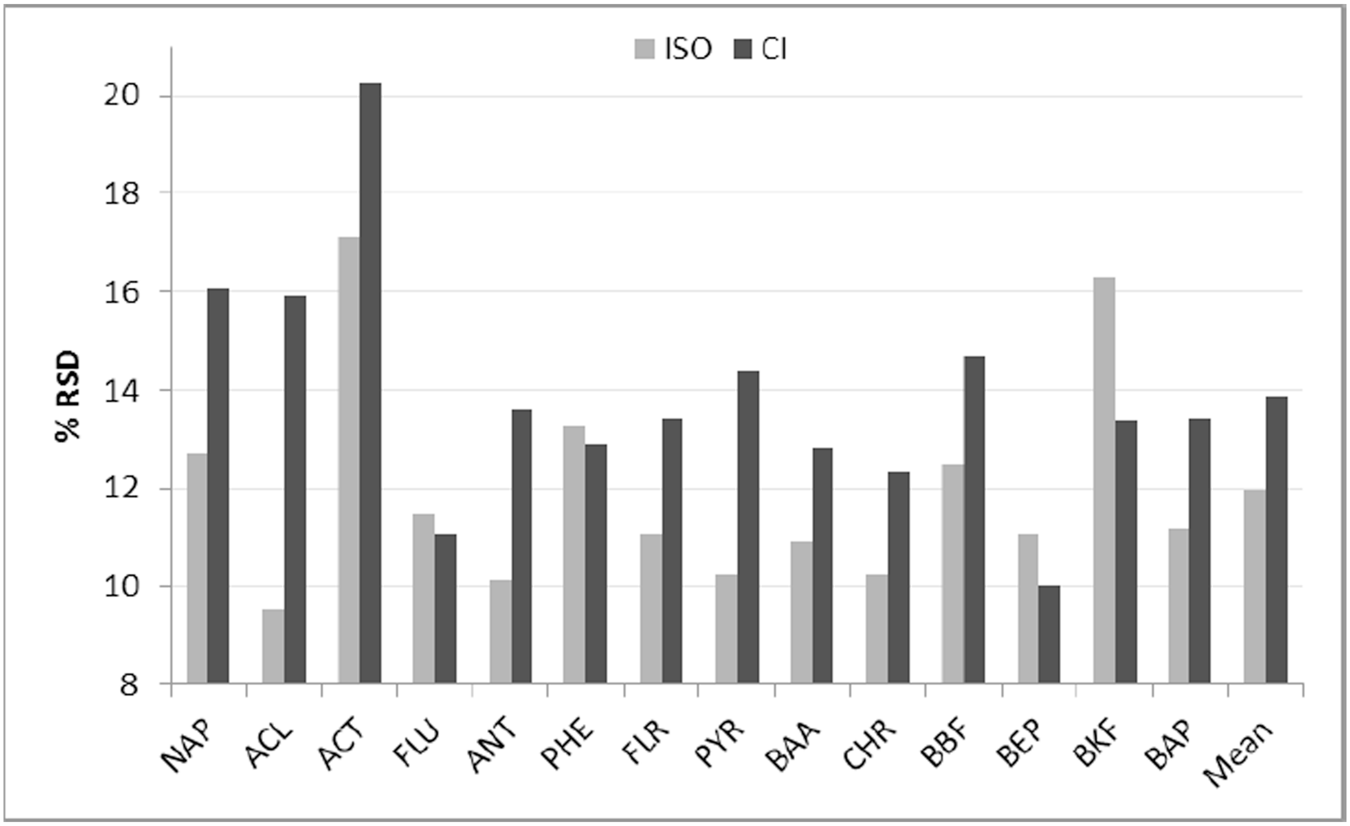

Figure 3.

Coefficients of variance of 3R4F PAH yields.

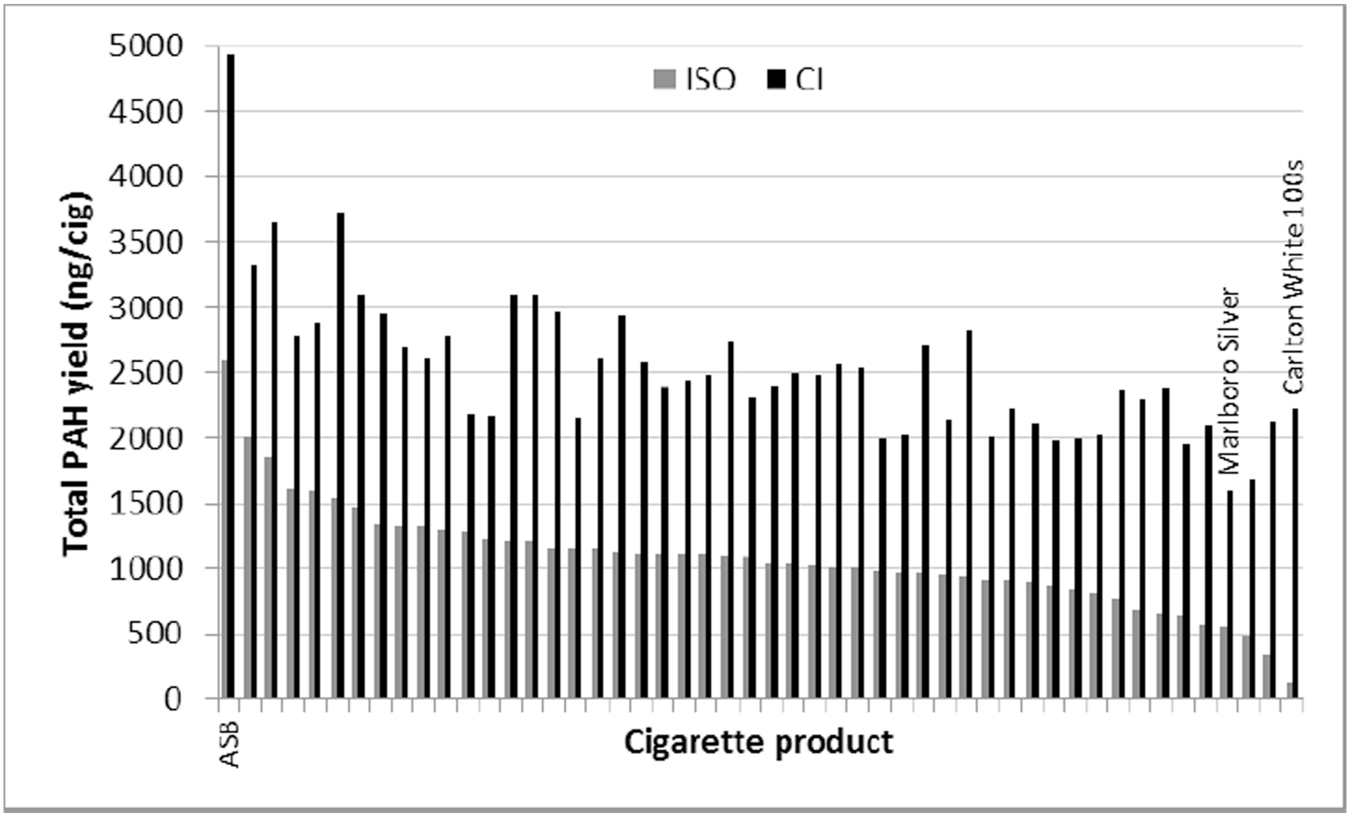

Figure 4.

Total PAH yields measured under ISO and CI smoking regimens. Cigarette abbreviation: ASB, American Spirit Blue.

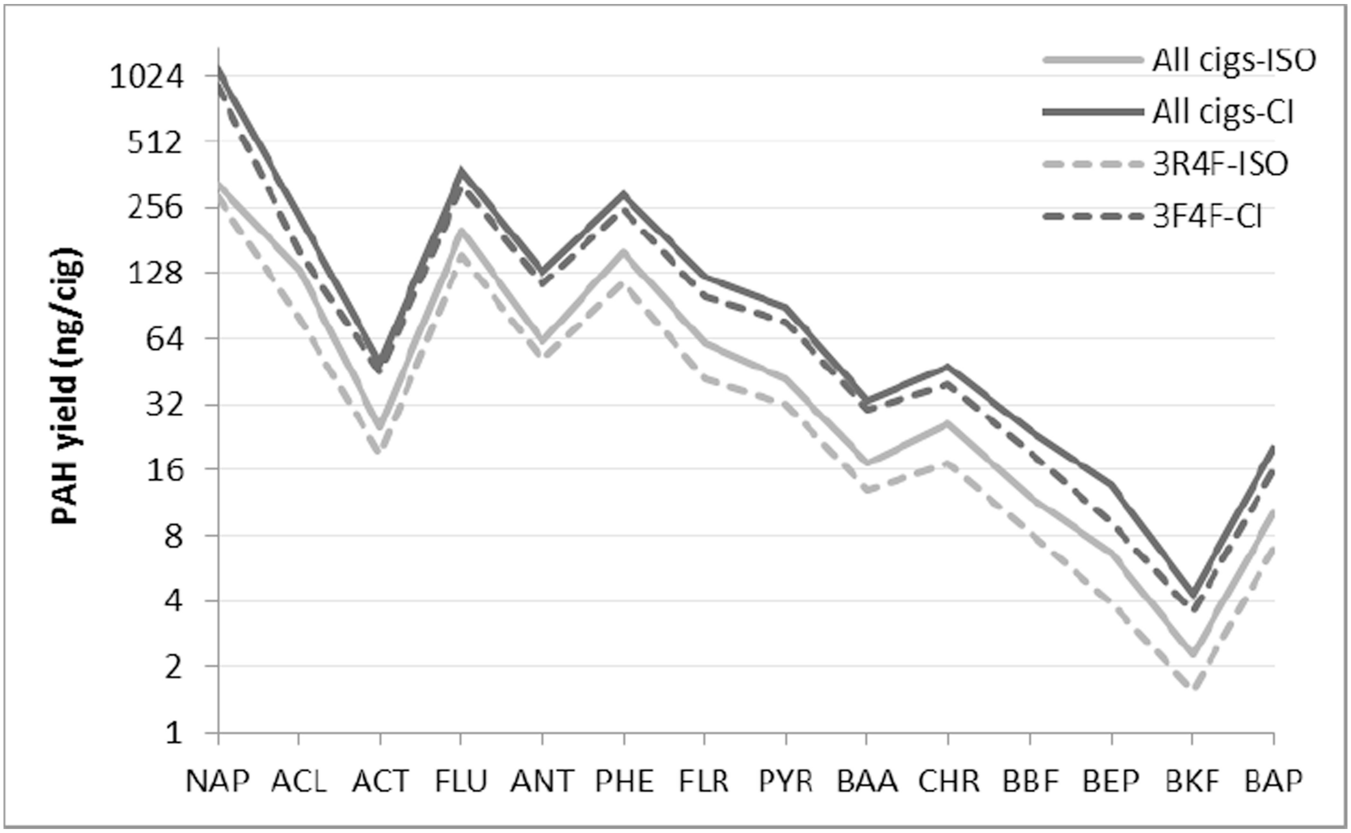

Figure 5.

Average yields of individual PAHs for all 50 commercial cigarettes. Y-axis depicts PAH yield on a log-2 scale.

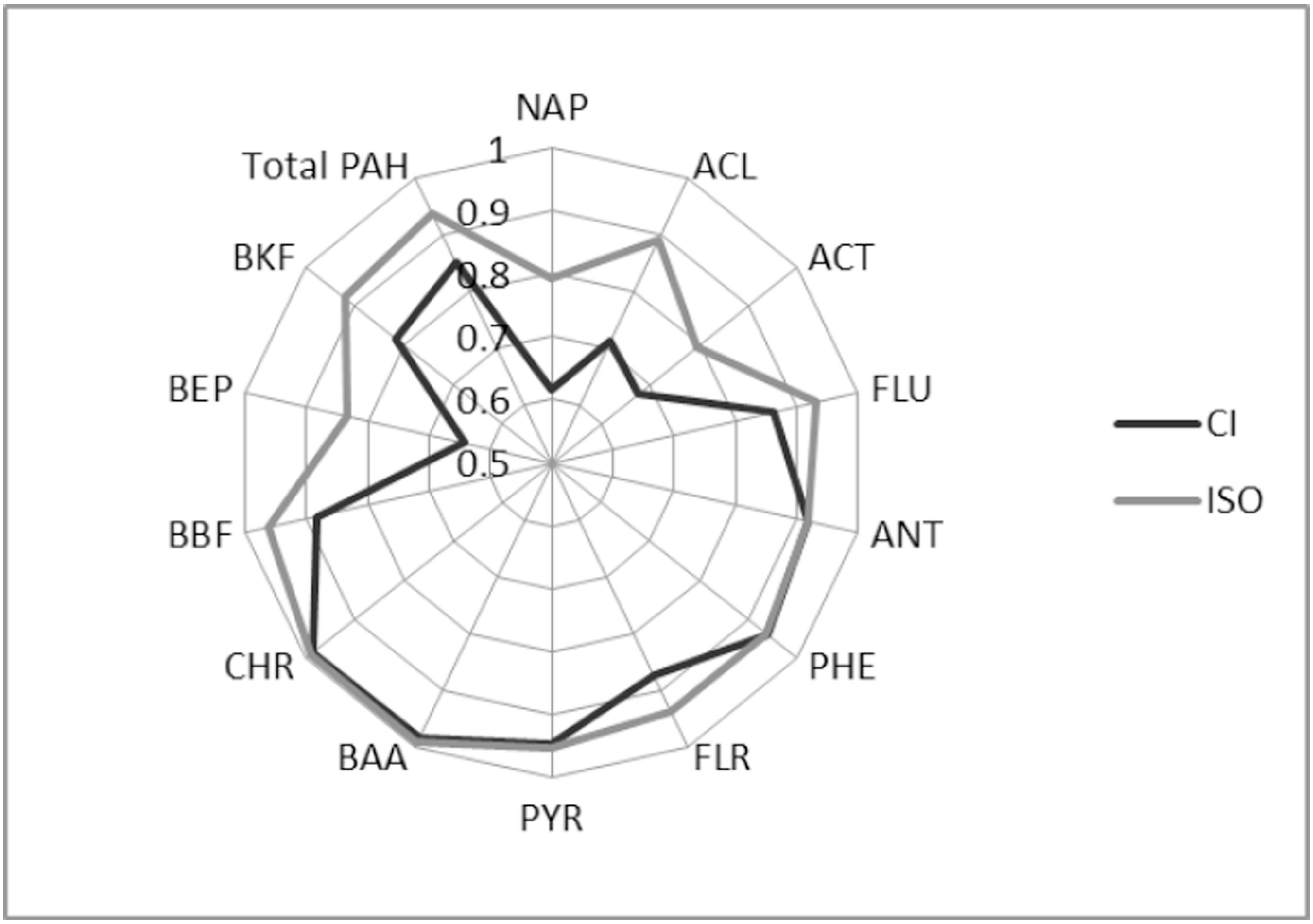

Figure 6.

Spider-chart showing BaP correlation with individual and total PAHs. Individual PAHs are arranged clockwise by ascending molecular weight and boiling point.

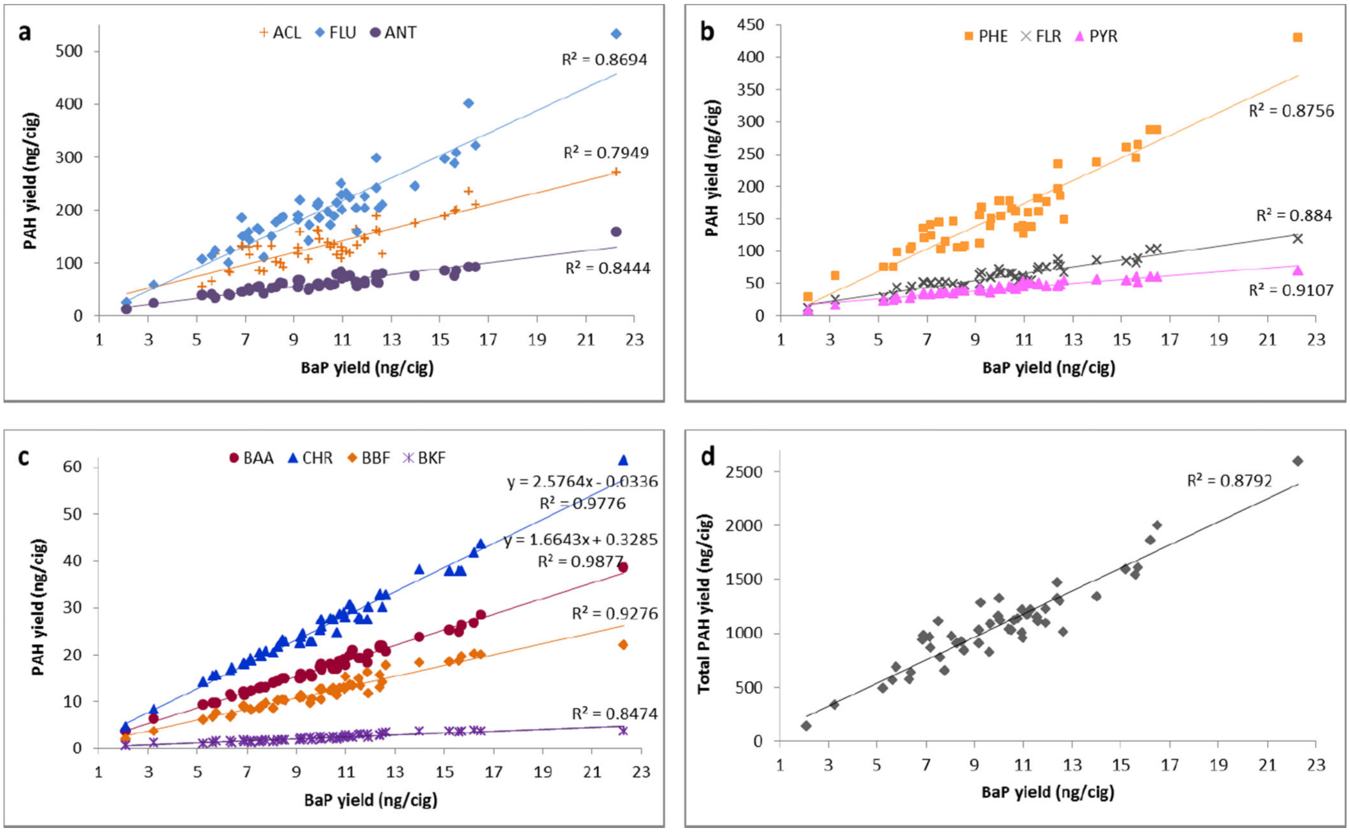

Figure 7.

Linear relationships between BaP yields with other PAHs using the ISO smoking regimen.

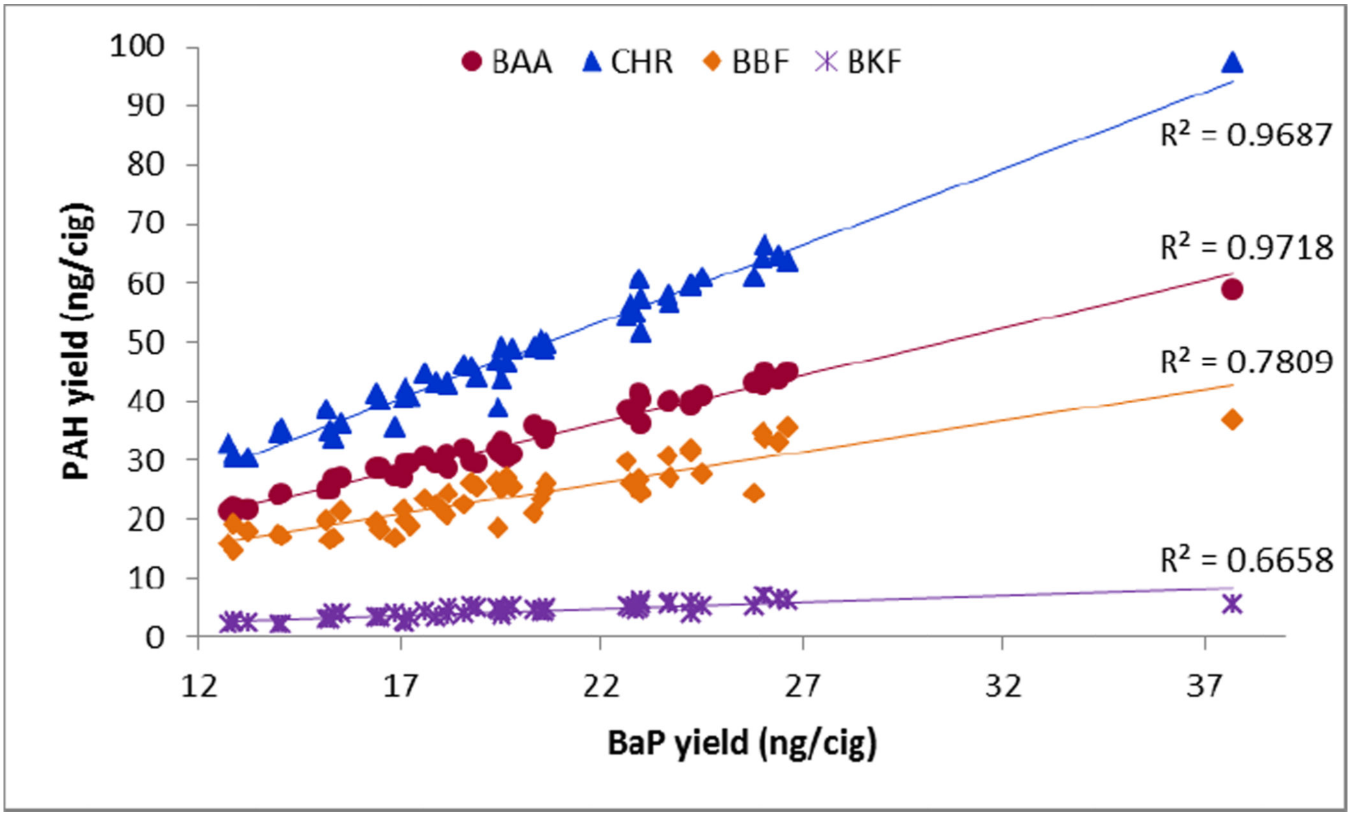

Figure 8.

Linear relationships between BaP yields and other high molecular weight PAHs using the CI smoking regimen.

Table 1

PAH Levels in Mainstream Smoke of 50 Commercial U.S. Cigarette Products Measured by ISO Smoking Regimen

cigarette product[a]	PAH[b] (ng/cigarette)														
	NAP	ACL	ACT	FLU	ANT	PHE	FLR	PYR	BAA	CHR	BBF	BEP	BKF	BAP	total PAH[c]
American Spirit Blue King HP	804 ± 186	272 ± 88	52 ± 5.4	534 ± 66	158 ± 37	431 ± 39	119 ± 15	70 ± 13	39 ± 4.4	61 ± 6.8	22 ± 1.3	11 ± 1.2	3.7 ± 0.3	22 ± 0.8	2599 ± 224
Winston Red 100s HP	774 ± 60	210 ± 36	34 ± 11	321 ± 54	91 ± 20	288 ± 45	103 ± 23	60 ± 14	29 ± 1.4	44 ± 3.2	20 ± 1.3	13 ± 1.1	3.6 ± 0.3	17 ± 0.9	2006 ± 105
Winston Red King HP	518 ± 41	235 ± 28	48 ± 6.3	401 ± 33	92 ± 16	288 ± 18	102 ± 25	60 ± 9.4	27 ± 1.0	42 ± 2.6	20 ± 1.6	10 ± 0.9	3.8 ± 0.5	16 ± 1.0	1862 ± 70
Kool Green King Menthol SP	467 ± 51	201 ± 33	35 ± 5.7	308 ± 26	85 ± 17	265 ± 19	89 ± 16	52 ± 3.7	26 ± 2.9	38 ± 5.5	20 ± 1.4	10 ± 1.5	3.6 ± 0.5	16 ± 1.6	1615 ± 73
Kool Green King Menthol HP	474 ± 61	188 ± 19	39 ± 5.0	297 ± 29	85 ± 16	260 ± 22	85 ± 11	54 ± 10	25 ± 1.7	38 ± 2.4	19 ± 1.3	8.6 ± 0.6	3.6 ± 0.3	15 ± 0.6	1591 ± 77
Camel Filters King Turkish HP	443 ± 62	198 ± 42	40 ± 6.2	289 ± 26	75 ± 12	244 ± 32	82 ± 6.4	60 ± 6.3	25 ± 2.1	38 ± 3.7	19 ± 1.8	8.9 ± 1.3	3.5 ± 0.6	16 ± 1.6	1540 ± 88
Winston Gold King HP	398 ± 34	189 ± 40	43 ± 5.0	298 ± 32	77 ± 20	235 ± 22	87 ± 12	47 ± 5.8	22 ± 1.4	33 ± 1.6	16 ± 0.8	7.6 ± 0.4	2.8 ± 0.1	12 ± 0.6	1468 ± 70
Pall Mall Blue King HP	320 ± 31	176 ± 21	40 ± 5.3	245 ± 23	76 ± 11	237 ± 21	87 ± 12	56 ± 8.9	24 ± 1.8	38 ± 2.9	18 ± 1.4	8.7 ± 0.7	3.7 ± 0.3	14 ± 0.8	1343 ± 53
Marlboro Gold 100s HP	509 ± 87	159 ± 26	24 ± 6.4	212 ± 36	59 ± 11	178 ± 24	67 ± 7.4	42 ± 6.6	18 ± 1.3	28 ± 3.7	11 ± 0.8	6.6 ± 0.8	1.9 ± 0.4	10 ± 0.7	1325 ± 102
Salem Green King Menthol HP	420 ± 50	161 ± 20	21 ± 2.6	242 ± 22	65 ± 7.9	196 ± 19	79 ± 7.8	45 ± 3.8	22 ± 2.2	33 ± 4.6	13 ± 1.5	11 ± 2.6	2.8 ± 0.7	12 ± 2.0	1322 ± 63
Vantage Multi Color King SP	448 ± 41	159 ± 25	20 ± 2.6	204 ± 19	63 ± 7.8	186 ± 16	76 ± 12	48 ± 3.9	22 ± 2.9	30 ± 4.4	14 ± 2.0	12 ± 2.0	3.2 ± 0.5	13 ± 2.5	1297 ± 57
USA Gold 100s Menthol SP	474 ± 124	159 ± 30	26 ± 8.9	218 ± 49	68 ± 15	168 ± 23	67 ± 6.2	39 ± 5.0	15 ± 1.8	24 ± 2.6	11 ± 0.8	7.3 ± 0.5	1.9 ± 0.4	9.3 ± 1.0	1287 ± 140
Newport Green King Menthol SP	374 ± 63	147 ± 11	29 ± 5.0	225 ± 21	66 ± 9.0	175 ± 13	74 ± 5.3	47 ± 4.4	18 ± 1.5	28 ± 2.8	16 ± 1.1	7.9 ± 0.9	3.2 ± 0.3	12 ± 1.0	1222 ± 70
Marlboro Red King HP	444 ± 91	119 ± 24	29 ± 5.7	223 ± 49	75 ± 13	138 ± 34	55 ± 7.6	49 ± 10	21 ± 2.8	30 ± 3.3	13 ± 1.7	6.2 ± 0.8	2.4 ± 0.3	11 ± 1.2	1216 ± 113
Marlboro Red 100s SP	396 ± 39	130 ± 19	26 ± 5.6	249 ± 25	84 ± 10	137 ± 35	61 ± 7.7	53 ± 16	19 ± 0.8	29 ± 1.9	13 ± 0.9	5.8 ± 0.3	2.3 ± 0.2	11 ± 0.7	1216 ± 64
Marlboro Red 100s HP	365 ± 38	121 ± 16	25 ± 3.2	232 ± 32	74 ± 14	159 ± 38	55 ± 8.7	50 ± 8.0	20 ± 1.5	31 ± 3.4	14 ± 1.0	6.1 ± 1.0	2.4 ± 0.2	11 ± 1.8	1164 ± 67
Salem Gold King Menthol HP	329 ± 60	161 ± 33	35 ± 1.3	208 ± 12	59 ± 7.3	177 ± 15	73 ± 8.7	45 ± 8.8	17 ± 1.7	25 ± 1.8	13 ± 1.4	5.9 ± 0.8	2.4 ± 0.2	10 ± 1.0	1160 ± 73

cigarette product[a]	PAH[b] (ng/cigarette)														
	NAP	ACL	ACT	FLU	ANT	PHE	FLR	PYR	BAA	CHR	BBF	BEP	BKF	BAP	total PAH[c]
Camel Blue King Turkish HP	306 ± 59	163 ± 23	34 ± 2.4	203 ± 22	64 ± 8.2	181 ± 17	70 ± 7.6	48 ± 8.2	19 ± 2.5	28 ± 3.3	15 ± 1.8	7.0 ± 1.1	2.8 ± 0.5	12 ± 1.5	1152 ± 71
Marlboro Red King SP	391 ± 71	115 ± 18	26 ± 3.7	214 ± 23	79 ± 9.2	136 ± 32	53 ± 2.7	45 ± 10	19 ± 1.1	29 ± 1.7	13 ± 0.8	5.6 ± 0.4	2.2 ± 0.1	11 ± 0.9	1137 ± 85
Maverick Gold 100s HP	378 ± 63	145 ± 18	21 ± 6.1	185 ± 43	55 ± 6.4	154 ± 20	66 ± 4.6	41 ± 6.8	17 ± 2.2	26 ± 4.2	13 ± 1.5	8.4 ± 0.7	2.0 ± 0.3	10 ± 1.6	1121 ± 82
Basic Gold 100s SP	383 ± 57	135 ± 18	21 ± 5.0	187 ± 36	58 ± 11	161 ± 21	60 ± 7.4	41 ± 3.5	17 ± 0.9	25 ± 2.0	11 ± 0.8	7.5 ± 0.7	2.0 ± 0.2	11 ± 0.8	1120 ± 74
Doral Gold King HP	375 ± 44	133 ± 12	17 ± 1.4	159 ± 12	56 ± 6.4	161 ± 12	75 ± 7.7	50 ± 7.0	19 ± 0.8	28 ± 1.6	14 ± 0.8	12 ± 0.8	3.2 ± 0.5	12 ± 0.9	1113 ± 50
Parliament Blue King HP	458 ± 55	132 ± 17	19 ± 4.4	165 ± 26	53 ± 12	144 ± 28	51 ± 6.4	35 ± 5.1	13 ± 1.5	20 ± 3.1	8.5 ± 1.5	5.5 ± 1.1	1.3 ± 0.4	7.5 ± 1.3	1113 ± 70
Benson & Hedges Green 100s Menthol HP	288 ± 61	146 ± 25	19 ± 2.8	204 ± 24	60 ± 11	175 ± 21	74 ± 10	45 ± 4.9	20 ± 2.3	30 ± 2.6	12 ± 1.4	10 ± 1.5	2.4 ± 0.5	12 ± 1.3	1098 ± 75
Basic Gold 100s HP	389 ± 66	141 ± 23	19 ± 4.9	172 ± 20	51 ± 7.1	150 ± 23	58 ± 6.5	41 ± 3.8	15 ± 1.4	23 ± 2.9	11 ± 1.1	7.2 ± 0.6	1.9 ± 0.3	10 ± 0.8	1089 ± 77
Benson & Hedges Luxury Gold 100s SP	245 ± 57	138 ± 18	29 ± 3.9	197 ± 14	61 ± 11	177 ± 16	66 ± 6.7	45 ± 5.6	18 ± 1.4	28 ± 1.8	12 ± 0.9	5.9 ± 0.8	2.2 ± 0.3	10 ± 1.2	1035 ± 65
Marlboro Red Label King HP	358 ± 40	129 ± 32	22 ± 4.0	189 ± 23	66 ± 10	112 ± 28	49 ± 4.4	43 ± 9.4	15 ± 2.0	23 ± 3.1	11 ± 1.4	4.8 ± 0.6	1.9 ± 0.3	9.2 ± 1.4	1032 ± 65
Misty Blue Slims HP	298 ± 67	130 ± 26	19 ± 6.4	171 ± 26	56 ± 5.2	165 ± 22	66 ± 6.3	44 ± 6.0	17 ± 2.5	28 ± 4.0	13 ± 1.7	8.5 ± 2.0	2.5 ± 0.9	11 ± 2.0	1027 ± 80
Newport Green 100s Menthol HP	210 ± 36	117 ± 13	28 ± 3.8	210 ± 37	80 ± 7.4	148 ± 36	66 ± 6.3	55 ± 14	21 ± 0.9	33 ± 1.2	18 ± 0.4	7.9 ± 0.3	3.5 ± 0.1	13 ± 0.7	1010 ± 66
Marlboro Green King Menthol HP	240 ± 32	108 ± 12	28 ± 6.1	229 ± 45	80 ± 10	139 ± 23	54 ± 7.6	49 ± 6.3	19 ± 1.2	28 ± 2.4	13 ± 1.1	5.7 ± 0.7	2.5 ± 0.5	11 ± 1.0	1005 ± 63
Kent Golden King SP	382 ± 66	130 ± 18	19 ± 3.9	150 ± 26	45 ± 7.4	120 ± 22	51 ± 2.8	33 ± 5.1	11 ± 1.6	18 ± 2.8	8.8 ± 1.2	6.0 ± 0.6	1.5 ± 0.2	6.9 ± 0.8	981 ± 77
Merit Gold King SP	337 ± 65	131 ± 17	17 ± 5.7	150 ± 25	52 ± 7.5	145 ± 25	49 ± 6.4	34 ± 6.0	14 ± 2.7	20 ± 4.0	8.6 ± 1.3	5.4 ± 1.0	1.4 ± 0.4	8.1 ± 2.2	974 ± 77
Winston White 100s HP	328 ± 79	130 ± 32	19 ± 5.1	159 ± 29	51 ± 8.7	140 ± 28	49 ± 5.7	33 ± 4.0	12 ± 1.9	19 ± 3.8	8.3 ± 1.5	5.5 ± 1.0	1.6 ± 0.4	7.2 ± 1.1	963 ± 95
Newport Green King Menthol HP	226 ± 40	121 ± 14	29 ± 7.1	199 ± 31	71 ± 8.8	127 ± 19	58 ± 4.0	45 ± 4.6	18 ± 1.7	28 ± 3.1	15 ± 1.7	6.6 ± 0.7	3.0 ± 0.3	11 ± 1.5	958 ± 57
Capri Magenta Super Slims HP	275 ± 42	133 ± 21	31 ± 4.1	186 ± 13	46 ± 8.2	135 ± 17	52 ± 4.4	34 ± 5.4	12 ± 0.9	18 ± 1.7	9.2 ± 0.8	4.4 ± 0.7	1.7 ± 0.2	6.9 ± 0.5	944 ± 53

cigarette product[a]	PAH[b] (ng/cigarette)													
	NAP	ACL	ACT	FLU	ANT	PHE	FLR	PYR	BAA	CHR	BBF	BEP	BKF	BAP	total PAH[c]
Marlboro Gold King HP	304 ± 34	101 ± 15	24 ± 4.2	177 ± 14	53 ± 6.2	105 ± 18	43 ± 2.0	39 ± 5.9	14 ± 1.2	22 ± 2.1	10 ± 1.0	4.4 ± 0.5	1.8 ± 0.2	8.3 ± 0.8	920 ± 60
Salem Gold 100s Menthol HP	200 ± 21	117 ± 17	34 ± 2.6	181 ± 17	53 ± 9.3	155 ± 14	63 ± 4.4	40 ± 6.3	16 ± 0.9	24 ± 1.6	11 ± 0.9	5.7 ± 0.7	2.1 ± 0.3	9.2 ± 0.9	910 ± 37
Marlboro Gold King SP	297 ± 54	101 ± 12	25 ± 2.4	183 ± 13	62 ± 6.6	106 ± 16	45 ± 4.4	38 ± 6.7	15 ± 0.9	23 ± 2.0	10 ± 0.8	4.5 ± 0.3	1.8 ± 0.2	8.5 ± 0.5	905 ± 45
Virginia Slims Gold HP	281 ± 53	116 ± 18	18 ± 4.9	144 ± 19	47 ± 7.3	124 ± 22	50 ± 6.2	34 ± 2.3	12 ± 2.5	19 ± 3.6	8.1 ± 1.4	5.6 ± 1.3	1.3 ± 0.3	7.2 ± 1.2	866 ± 64
Marlboro Gold King Menthol HP	221 ± 74	92 ± 13	25 ± 2.1	187 ± 33	59 ± 8.8	108 ± 26	46 ± 4.6	38 ± 8.2	15 ± 0.8	23 ± 2.3	10 ± 0.7	4.7 ± 0.5	1.8 ± 0.1	8.6 ± 0.6	839 ± 87
Basic Green 100s Menthol HP	207 ± 21	106 ± 11	15 ± 1.6	142 ± 8.0	49 ± 6.2	139 ± 12	60 ± 6.0	35 ± 4.6	16 ± 1.1	23 ± 3.2	10 ± 0.3	8.4 ± 0.4	2.3 ± 0.4	10 ± 0.9	822 ± 30
Marlboro Gold 100s SP	220 ± 23	84 ± 11	23 ± 1.9	162 ± 24	55 ± 9.0	102 ± 24	39 ± 3.2	36 ± 4.9	13 ± 0.5	20 ± 1.1	8.8 ± 0.3	3.9 ± 0.1	1.6 ± 0.04	7.6 ± 0.4	776 ± 44
True Silver King SP	173 ± 21	116 ± 22	27 ± 3.0	124 ± 18	34 ± 4.6	98 ± 12	44 ± 6.7	28 ± 4.5	10 ± 1.4	16 ± 2.4	7.6 ± 0.9	3.6 ± 0.5	1.6 ± 0.2	5.8 ± 0.8	687 ± 39
Doral Silver 100s HP	142 ± 18	83 ± 16	12 ± 4.1	110 ± 12	42 ± 6.1	114 ± 17	52 ± 6.3	36 ± 5.9	13 ± 1.5	21 ± 2.6	10 ± 1.1	6.2 ± 0.7	1.8 ± 0.2	7.8 ± 1.9	650 ± 34
Salem Silver 100s Menthol HP	147 ± 54	83 ± 20	14 ± 3.2	123 ± 14	38 ± 4.7	106 ± 14	46 ± 5.6	33 ± 5.6	11 ± 1.8	17 ± 3.0	7.3 ± 0.7	4.8 ± 0.8	1.3 ± 0.3	6.4 ± 1.3	638 ± 62
Basic Blue 100s HP	117 ± 12	84 ± 13	12 ± 1.7	101 ± 10	41 ± 4.3	102 ± 8.1	40 ± 4.5	28 ± 3.8	12 ± 1.6	17 ± 2.6	6.7 ± 0.7	5.7 ± 0.8	1.6 ± 0.1	6.3 ± 1.3	572 ± 23
Marlboro Silver King HP	153 ± 25	64 ± 8.6	19 ± 2.3	114 ± 9.3	40 ± 4.6	74 ± 8.3	32 ± 2.7	25 ± 2.8	10 ± 0.7	15 ± 1.2	6.7 ± 0.5	3.0 ± 0.3	1.2 ± 0.1	5.6 ± 0.5	563 ± 30
Marlboro Silver 100s HP	108 ± 27	56 ± 7.8	17 ± 1.8	107 ± 10	39 ± 5.9	75 ± 13	28 ± 2.8	24 ± 2.3	9.2 ± 0.6	14 ± 0.9	6.0 ± 0.3	2.8 ± 0.2	1.1 ± 0.1	5.2 ± 0.4	492 ± 33
NOW Gold 100s SP	62 ± 20	57 ± 13	8.0 ± 1.3	58 ± 9.2	24 ± 2.8	61 ± 7.9	25 ± 5.0	17 ± 2.3	6.2 ± 1.3	8.4 ± 1.0	3.7 ± 0.4	2.4 ± 0.9	1.2 ± 0.1	3.3 ± 1.3	336 ± 27
Carlton White 100s HP	14 ± 1.9	23 ± 2.4	3.8 ± 0.4	24 ± 3.3	12 ± 1.0	28 ± 2.2	12 ± 1.3	8.1 ± 0.9	3.7 ± 0.1	4.5 ± 0.3	1.9 ± 0.3	1.2 ± 0.5	0.7 ± 0.2	2.1 ± 1.0	139 ± 5
Mean	329 ± 59	133 ± 25	25 ± 4.6	199 ± 28	62 ± 11	159 ± 23	61 ± 8.6	42 ± 7.1	17 ± 1.8	26 ± 3.0	12 ± 1.2	6.7 ± 1.0	2.3 ± 0.3	10 ± 1.2	1084 ± 76
3R4F[d]	287 ± 36	80 ± 7.6	19 ± 3.3	153 ± 18	51 ± 5.2	117 ± 15	42 ± 4.7	32 ± 3.3	13 ± 1.4	17 ± 1.8	8.3 ± 1.0	4.0 ± 0.4	1.6 ± 0.3	7.0 ± 0.8	833 ± 45

[a]Cigarettes are sorted by total PAH quantity. Cigarette description abbreviations: HP, hard pack; SP, soft pack; King, king size (approximately 84 mm cigarette length); 100s, 100mm cigarette length.

[b]See Figure 1 for PAH abbreviations. PAH constituents are sorted by molecular weight followed by boiling point. Individual PAH quantities were determined from 7 replicates.

[c]Sum of quantities of the 14 individual PAHs.

[d] PAH values are average of 25 replicates.

Table 2

PAH Levels in Mainstream Smoke of 50 Commercial U.S. Cigarette Products Measured by CI Smoking Regimen

cigarette products[a]	PAH[b] (ng/cigarette)														
	NAP	ACL	ACT	FLU	ANT	PHE	FLR	PYR	BAA	CHR	BBF	BEP	BKF	BAP	total PAH[c]
American Spirit Blue King HP	2120 ± 174	428 ± 39	74 ± 19	792 ± 124	288 ± 29	611 ± 92	189 ± 32	172 ± 25	59 ± 3.4	97 ± 6.4	37 ± 2.0	19 ± 1.5	5.6 ± 0.5	38 ± 2.3	4929 ± 242
Camel Filters King Turkish HP	1790 ± 346	339 ± 34	68 ± 8.1	529 ± 69	178 ± 22	377 ± 34	152 ± 17	106 ± 21	44 ± 2.4	65 ± 4.1	33 ± 1.6	16 ± 0.4	6.3 ± 0.5	26 ± 1.8	3728 ± 358
Winston Red King HP	1550 ± 173	350 ± 89	74 ± 15	593 ± 85	180 ± 25	428 ± 78	167 ± 29	115 ± 26	45 ± 5.9	64 ± 7.7	35 ± 4.3	17 ± 2.1	6.2 ± 0.7	27 ± 3.6	3651 ± 232
Winston Red 100s HP	1510 ± 206	308 ± 31	54 ± 12	461 ± 81	144 ± 15	378 ± 63	173 ± 31	104 ± 31	39 ± 6.8	60 ± 8.9	31 ± 4.8	21 ± 3.1	4.1 ± 1.1	24 ± 3.6	3312 ± 237
Winston Gold King HP	1340 ± 191	304 ± 34	66 ± 18	492 ± 33	152 ± 9.0	350 ± 33	148 ± 20	92 ± 13	38 ± 5.0	54 ± 7.0	30 ± 3.4	14 ± 1.9	5.2 ± 0.7	23 ± 3.0	3108 ± 202
Marlboro Red 100s SP	1360 ± 187	254 ± 64	66 ± 15	489 ± 59	173 ± 32	366 ± 52	132 ± 19	109 ± 16	39 ± 2.0	55 ± 4.9	26 ± 2.1	12 ± 0.8	4.5 ± 0.4	23 ± 2.6	3108 ± 217
Marlboro Red King HP	1560 ± 377	204 ± 34	61 ± 10	422 ± 69	153 ± 22	321 ± 35	121 ± 24	99 ± 16	38 ± 5.8	56 ± 10	26 ± 4.6	12 ± 1.9	4.8 ± 1.0	23 ± 3.7	3100 ± 388
Marlboro Red 100s HP	1290 ± 238	236 ± 55	62 ± 11	476 ± 104	176 ± 25	314 ± 69	132 ± 21	113 ± 18	41 ± 4.7	61 ± 7.9	28 ± 3.7	12 ± 1.5	5.1 ± 0.9	25 ± 2.9	2970 ± 277
Pall Mall Blue King HP	1260 ± 202	275 ± 45	59 ± 6.8	422 ± 32	151 ± 10	346 ± 36	138 ± 12	104 ± 13	45 ± 2.9	66 ± 6.4	34 ± 2.7	17 ± 1.9	6.9 ± 0.8	26 ± 2.2	2950 ± 214
Marlboro Red King SP	1430 ± 363	191 ± 31	54 ± 7.5	389 ± 102	159 ± 23	311 ± 34	130 ± 23	104 ± 27	41 ± 8.1	61 ± 8.1	27 ± 3.6	12 ± 1.8	4.8 ± 1.0	23 ± 2.6	2937 ± 382
Kool Green King Menthol HP	1120 ± 327	293 ± 69	64 ± 19	478 ± 70	158 ± 23	352 ± 56	139 ± 25	100 ± 19	40 ± 4.6	59 ± 8.3	32 ± 4.0	15 ± 1.1	5.9 ± 0.8	24 ± 2.3	2881 ± 349
Capri Magenta Super Slims HP	1410 ± 194	272 ± 36	64 ± 8.7	406 ± 59	119 ± 24	271 ± 41	100 ± 18	67 ± 5.7	27 ± 3.0	36 ± 5.2	21 ± 1.9	10 ± 1.0	4.0 ± 0.4	16 ± 1.5	2822 ± 212
Kool Green King Menthol SP	1110 ± 347	289 ± 58	57 ± 9.4	455 ± 42	140 ± 15	340 ± 32	140 ± 15	89 ± 6.2	40 ± 3.1	58 ± 5.2	31 ± 2.8	15 ± 1.4	5.6 ± 0.6	24 ± 2.2	2792 ± 357
Vantage Multi Color King SP	1230 ± 319	251 ± 17	40 ± 8.1	327 ± 25	140 ± 10	360 ± 10	160 ± 21	106 ± 12	40 ± 3.8	57 ± 10	27 ± 2.7	23 ± 2.7	5.9 ± 0.6	24 ± 4.8	2790 ± 322
Benson & Hedges Green 100s Menthol HP	870 ± 431	308 ± 42	46 ± 7.1	443 ± 51	172 ± 27	441 ± 87	174 ± 19	114 ± 15	43 ± 4.7	61 ± 5.6	24 ± 2.5	20 ± 3.4	5.3 ± 0.7	26 ± 3.3	2748 ± 446
Winston White 100s HP	1230 ± 209	283 ± 40	46 ± 10	370 ± 85	123 ± 24	302 ± 43	130 ± 14	85 ± 14	31 ± 3.8	44 ± 7.3	25 ± 1.1	16 ± 1.6	3.6 ± 0.8	20 ± 1.2	2708 ± 235

cigarette products[a]	PAH[b] (ng/cigarette)														
	NAP	ACL	ACT	FLU	ANT	PHE	FLR	PYR	BAA	CHR	BBF	BEP	BKF	BAP	total PAH[c]
Marlboro Gold 100s HP	1310 ± 292	269 ± 56	48 ± 7.1	328 ± 27	118 ± 13	279 ± 53	124 ± 18	85 ± 16	29 ± 4.1	42 ± 5.8	20 ± 2.4	13 ± 1.6	2.6 ± 0.9	17 ± 1.6	2685 ± 305
Camel Blue King Turkish HP	1190 ± 396	246 ± 48	56 ± 5.1	358 ± 53	129 ± 20	287 ± 59	114 ± 8.6	81 ± 6.9	35 ± 6.0	50 ± 8.2	26 ± 3.2	13 ± 1.7	4.7 ± 0.4	21 ± 2.6	2610 ± 408
Salem Green King Menthol HP	981 ± 710	278 ± 53	47 ± 11	392 ± 32	142 ± 10	340 ± 50	154 ± 25	104 ± 14	40 ± 6.2	57 ± 10	25 ± 3.3	21 ± 4.6	5.6 ± 0.9	23 ± 4.0	2610 ± 715
Maverick Gold 100s HP	1200 ± 168	241 ± 20	48 ± 12	362 ± 55	107 ± 12	259 ± 43	135 ± 22	90 ± 12	30 ± 2.3	47 ± 3.4	27 ± 2.8	17 ± 1.2	4.6 ± 1.7	20 ± 1.6	2586 ± 185
Newport Green 100s Menthol HP	935 ± 324	212 ± 38	55 ± 11	437 ± 86	156 ± 27	330 ± 50	139 ± 15	107 ± 15	43 ± 3.1	64 ± 3.8	35 ± 3.7	16 ± 1.6	7.0 ± 0.9	26 ± 2.8	2562 ± 343
Marlboro Green King Menthol HP	1020 ± 309	213 ± 59	57 ± 16	436 ± 84	156 ± 22	306 ± 54	122 ± 10	94 ± 15	35 ± 2.8	50 ± 4.4	23 ± 2.3	11 ± 1.3	4.2 ± 0.5	21 ± 3.2	2547 ± 332
Marlboro Red Label King HP	1190 ± 313	189 ± 23	52 ± 10	335 ± 66	132 ± 12	269 ± 43	111 ± 11	91 ± 19	32 ± 4.1	46 ± 5.8	23 ± 3.1	10 ± 1.3	4.0 ± 0.6	19 ± 2.5	2502 ± 325
Parliament Blue King HP	1380 ± 111	221 ± 19	37 ± 5.1	266 ± 37	92 ± 8.8	221 ± 13	94 ± 18	74 ± 13	24 ± 2.0	35 ± 4.5	17 ± 1.7	11 ± 2.0	2.0 ± 0.6	14 ± 1.5	2489 ± 122
Misty Blue Slims HP	1150 ± 191	249 ± 51	43 ± 5.2	307 ± 45	110 ± 22	261 ± 31	136 ± 14	93 ± 18	30 ± 3.9	44 ± 5.6	26 ± 2.0	16 ± 2.1	4.8 ± 1.1	19 ± 1.8	2488 ± 208
Doral Gold King HP	1100 ± 226	209 ± 18	34 ± 7.8	273 ± 38	116 ± 32	306 ± 64	141 ± 24	100 ± 19	36 ± 7.9	52 ± 9.0	24 ± 5.5	21 ± 4.6	6.0 ± 1.3	23 ± 7.1	2441 ± 243
Benson & Hedges Luxury Gold 100s SP	969 ± 101	228 ± 27	55 ± 5.8	400 ± 32	135 ± 15	279 ± 30	113 ± 15	84 ± 8.0	34 ± 2.8	49 ± 5.2	25 ± 2.0	12 ± 1.2	4.4 ± 0.5	21 ± 1.8	2407 ± 116
Basic Gold 100s SP	1140 ± 238	239 ± 36	38 ± 5.6	312 ± 34	108 ± 6.2	240 ± 27	108 ± 23	76 ± 14	29 ± 3.5	43 ± 4.8	22 ± 3.0	15 ± 1.8	3.5 ± 0.6	18 ± 2.6	2392 ± 246
Doral Silver 100s HP	1090 ± 195	218 ± 18	36 ± 4.7	294 ± 36	108 ± 9.0	259 ± 25	132 ± 25	89 ± 14	32 ± 3.1	47 ± 1.9	26 ± 3.1	17 ± 2.9	4.9 ± 1.5	19 ± 1.6	2373 ± 203
Marlboro Gold 100s SP	984 ± 139	204 ± 39	53 ± 9.2	367 ± 26	133 ± 10	292 ± 36	112 ± 14	89 ± 13	31 ± 1.3	43 ± 2.7	21 ± 1.0	9.3 ± 0.6	3.7 ± 0.3	18 ± 1.8	2359 ± 153
True Silver King SP	1020 ± 197	222 ± 31	52 ± 5.9	353 ± 21	113 ± 18	225 ± 14	111 ± 12	79 ± 12	28 ± 2.6	43 ± 2.8	24 ± 2.2	12 ± 1.3	4.9 ± 0.9	18 ± 2.0	2305 ± 203
Basic Gold 100s HP	1090 ± 198	223 ± 48	42 ± 6.2	311 ± 49	108 ± 6.5	234 ± 25	100 ± 14	72 ± 13	27 ± 3.0	40 ± 5.9	22 ± 3.1	13 ± 0.8	2.8 ± 0.9	17 ± 2.1	2302 ± 212
Carlton White 100s HP	1080 ± 605	218 ± 56	33 ± 6.6	251 ± 45	98 ± 18	251 ± 73	116 ± 19	72 ± 7.3	27 ± 8.5	35 ± 8.0	17 ± 4.2	13 ± 5.5	3.9 ± 0.9	17 ± 6.3	2232 ± 614
Salem Gold 100s Menthol HP	772 ± 172	202 ± 43	56 ± 10	418 ± 55	138 ± 20	297 ± 45	118 ± 13	83 ± 11	33 ± 3.2	49 ± 4.2	25 ± 2.6	12 ± 1.2	4.3 ± 0.5	20 ± 2.2	2227 ± 193
USA Gold 100s Menthol SP	975 ± 119	238 ± 30	40 ± 5.6	334 ± 55	104 ± 8.2	220 ± 31	107 ± 18	72 ± 13	21 ± 2.6	30 ± 5.1	18 ± 1.2	11 ± 1.1	2.5 ± 0.5	13 ± 1.6	2187 ± 140

cigarette products[a]	PAH[b] (ng/cigarette)													
	NAP	ACL	ACT	FLU	ANT	PHE	FLR	PYR	BAA	CHR	BBF	BEP	BKF	BAP	total PAH[c]
Newport Green King Menthol SP	847 ± 80	216 ± 24	55 ± 7.0	357 ± 55	117 ± 13	244 ± 25	117 ± 18	86 ± 14	30 ± 3.6	46 ± 7.6	26 ± 3.7	12 ± 1.7	5.3 ± 0.7	19 ± 3.0	2176 ± 107
Salem Gold King Menthol HP	852 ± 179	224 ± 42	54 ± 7.0	343 ± 24	112 ± 11	257 ± 18	101 ± 13	84 ± 5.4	31 ± 1.7	45 ± 3.1	23 ± 2.6	11 ± 1.5	4.3 ± 0.6	18 ± 1.6	2158 ± 187
Newport Green King Menthol HP	806 ± 134	179 ± 14	49 ± 9.1	366 ± 74	129 ± 20	263 ± 47	120 ± 12	90 ± 11	31 ± 2.7	49 ± 6.3	25 ± 2.9	12 ± 1.2	5.1 ± 0.7	20 ± 3.3	2143 ± 163
NOW Gold 100s SP	978 ± 239	215 ± 37	32 ± 4.9	269 ± 35	97 ± 12	249 ± 40	115 ± 16	72 ± 8.5	27 ± 5.4	34 ± 6.6	17 ± 3.2	12 ± 3.0	3.9 ± 1.0	15 ± 2.9	2135 ± 249
Marlboro Gold King SP	956 ± 153	159 ± 13	47 ± 7.9	316 ± 63	116 ± 13	243 ± 35	90 ± 8.7	76 ± 7.4	29 ± 3.8	41 ± 4.7	19 ± 2.5	8.6 ± 1.2	3.4 ± 0.6	16 ± 3.1	2120 ± 171
Basic Blue 100s HP	896 ± 144	207 ± 24	35 ± 3.1	277 ± 39	106 ± 10	258 ± 25	119 ± 15	81 ± 8.8	31 ± 2.8	39 ± 4.3	19 ± 2.0	16 ± 2.1	4.5 ± 0.6	19 ± 3.1	2107 ± 155
Basic Green 100s Menthol HP	612 ± 269	226 ± 26	38 ± 2.6	333 ± 28	127 ± 11	306 ± 20	142 ± 7.6	92 ± 14	36 ± 4.3	49 ± 6.5	21 ± 1.8	18 ± 3.1	4.7 ± 0.4	20 ± 2.7	2024 ± 273
Merit Gold King SP	977 ± 386	198 ± 46	37 ± 6.5	245 ± 41	92 ± 18	206 ± 50	99 ± 13	63 ± 5.2	24 ± 6.7	35 ± 7.6	17 ± 4.0	11 ± 2.3	2.1 ± 0.7	14 ± 3.8	2020 ± 395
Marlboro Gold King HP	858 ± 192	152 ± 26	44 ± 8.9	296 ± 39	116 ± 17	246 ± 37	93 ± 5.8	83 ± 12	29 ± 3.0	40 ± 4.6	18 ± 3.2	8.6 ± 0.8	3.5 ± 0.3	17 ± 2.0	2004 ± 203
Marlboro Gold King Menthol HP	760 ± 205	164 ± 31	50 ± 11	334 ± 38	128 ± 9.4	259 ± 40	108 ± 16	79 ± 9.0	29 ± 1.8	40 ± 2.7	19 ± 0.3	8.7 ± 0.8	3.3 ± 0.2	17 ± 3.5	2000 ± 216
Kent Golden King SP	989 ± 199	202 ± 15	36 ± 5.7	250 ± 23	81 ± 4.9	174 ± 24	96 ± 24	72 ± 10	21 ± 2.7	31 ± 4.2	19 ± 2.2	12 ± 1.7	2.8 ± 0.9	13 ± 1.3	1998 ± 204
Virginia Slims Gold HP	909 ± 84	221 ± 15	35 ± 3.2	267 ± 25	91 ± 16	201 ± 30	97 ± 16	65 ± 11	21 ± 3.2	33 ± 7.6	16 ± 1.0	11 ± 2.4	2.3 ± 0.7	13 ± 1.1	1983 ± 97
Salem Silver 100s Menthol HP	766 ± 79	218 ± 25	38 ± 5.1	289 ± 13	107 ± 11	242 ± 22	106 ± 14	77 ± 7.9	25 ± 2.9	38 ± 4.9	20 ± 2.4	12 ± 1.4	2.9 ± 0.7	15 ± 2.5	1956 ± 89
Marlboro Silver 100s HP	608 ± 201	143 ± 15	45 ± 6.1	285 ± 26	101 ± 18	233 ± 30	86 ± 8.1	71 ± 13	25 ± 2.6	35 ± 4.9	16 ± 2.6	8.3 ± 1.4	2.9 ± 0.4	15 ± 2.5	1675 ± 207
Marlboro Silver King HP	678 ± 129	141 ± 16	36 ± 6.2	236 ± 21	88 ± 9.3	187 ± 25	74 ± 7.6	60 ± 7.0	22 ± 1.6	30 ± 3.0	15 ± 1.1	6.8 ± 0.6	2.5 ± 0.3	13 ± 2.1	1590 ± 135
Mean	1105 ± 269	235 ± 39	49 ± 9.4	371 ± 56	130 ± 18	292 ± 44	123 ± 18	89 ± 15	33 ± 4.2	48 ± 6.2	24 ± 2.9	14 ± 2.1	4.3 ± 0.8	20 ± 2.9	2538 ± 283
3R4F[d]	926 ± 149	160 ± 25	45 ± 9.1	324 ± 36	114 ± 15	251 ± 32	100 ± 13	76 ± 11	30 ± 3.9	39 ± 4.9	19 ± 2.8	9.2 ± 0.9	3.6 ± 0.5	16 ± 2.1	2112 ± 160

[a]Cigarettes products are sorted by total PAH quantity. Cigarette description abbreviations: HP, hard pack; SP, soft pack; King, king size (approximately 84 mm cigarette length); 100s, 100mm cigarette length.

[b]See Figure 1 for PAH abbreviations. PAH constituents are sorted by molecular weight followed by boiling point. Individual PAH quantities were determined from 7 replicates.

[c]Sum of quantities of the 14 individual PAHs.

[d]PAH values are average of 25 replicates.

Table 3

Pearson Coefficients and P-Values for Correlations between PAH levels in Mainstream Smoke of 50 Commercial U.S. Cigarette Products Measured by ISO Smoking Regimen

	NAP	**ACL**	**ACT**	**FLU**	**ANT**	**PHE**	**FLR**	**PYR**	**BAA**	**CHR**	**BBF**	**BEP**	**BKF**	**BAP**
ACL	0.867 <0.001													
ACT	0.616 <0.001	0.811 <0.001												
FLU	0.828 <0.001	0.903 <0.001	0.877 <0.001											
ANT	0.783 <0.001	0.800 <0.001	0.800 <0.001	0.952 <0.001										
PHE	0.826 <0.001	0.953 <0.001	0.806 <0.001	0.931 <0.001	0.858 <0.001									
FLR	0.799 <0.001	0.950 <0.001	0.777 <0.001	0.883 <0.001	0.807 <0.001	0.955 <0.001								
PYR	0.753 <0.001	0.838 <0.001	0.789 <0.001	0.885 <0.001	0.895 <0.001	0.843 <0.001	0.890 <0.001							
BAA	0.804 <0.001	0.883 <0.001	0.794 <0.001	0.940 <0.001	0.930 <0.001	0.936 <0.001	0.932 <0.001	0.948 <0.001						
CHR	0.804 <0.001	0.885 <0.001	0.810 <0.001	0.951 <0.001	0.945 <0.001	0.941 <0.001	0.929 <0.001	0.947 <0.001	0.993 <0.001					
BBF	0.721 <0.001	0.856 <0.001	0.835 <0.001	0.886 <0.001	0.869 <0.001	0.873 <0.001	0.912 <0.001	0.956 <0.001	0.947 <0.001	0.945 <0.001				
BEP	0.718 <0.001	0.783 <0.001	0.453 <0.001	0.669 <0.001	0.629 <0.001	0.790 <0.001	0.886 <0.001	0.777 <0.001	0.821 <0.001	0.797 <0.001	0.782 <0.001			
BKF	0.613 <0.001	0.791 <0.001	0.745 <0.001	0.792 <0.001	0.770 <0.001	0.816 <0.001	0.886 <0.001	0.903 <0.001	0.901 <0.001	0.886 <0.001	0.960 <0.001	0.826 <0.001		
BAP	0.794 <0.001	0.892 <0.001	0.794 <0.001	0.932 <0.001	0.919 <0.001	0.936 <0.001	0.940 <0.001	0.954 <0.001	0.994 <0.001	0.989 <0.001	0.963 <0.001	0.834 <0.001	0.921 <0.001	
Total PAH	0.936 <0.001	0.958 <0.001	0.803 <0.001	0.959 <0.001	0.906 <0.001	0.957 <0.001	0.931 <0.001	0.887 <0.001	0.942 <0.001	0.946 <0.001	0.882 <0.001	0.780 <0.001	0.794 <0.001	0.938 <0.001

Pearson coefficients are shown in larger font and p-values in smaller font

Table 4

Pearson Coefficients and P-Values for Correlations between PAH levels in Mainstream Smoke of 50 Commercial U.S. Cigarette Products Measured by CI Smoking Regimen

	NAP	ACL	ACT	FLU	ANT	PHE	FLR	PYR	BAA	CHR	BBF	BEP	BKF	BAP
ACL	0.720 <0.001													
ACT	0.586 <0.001	0.565 <0.001												
FLU	0.670 <0.001	0.778 <0.001	0.882 <0.001											
ANT	0.643 <0.001	0.687 <0.001	0.783 <0.001	0.945 <0.001										
PHE	0.636 <0.001	0.799 <0.001	0.671 <0.001	0.894 <0.001	0.937 <0.001									
FLR	0.548 <0.001	0.797 <0.001	0.463 <0.001	0.722 <0.001	0.743 <0.001	0.880 <0.001								
PYR	0.622 <0.001	0.679 <0.001	0.619 <0.001	0.842 <0.001	0.929 <0.001	0.928 <0.001	0.850 <0.001							
BAA	0.599 <0.001	0.687 <0.001	0.694 <0.001	0.853 <0.001	0.918 <0.001	0.936 <0.001	0.859 <0.001	0.930 <0.001						
CHR	0.623 <0.001	0.695 <0.001	0.706 <0.001	0.877 <0.001	0.933 <0.001	0.925 <0.001	0.837 <0.001	0.949 <0.001	0.980 <0.001					
BBF	0.604 <0.001	0.699 <0.001	0.748 <0.001	0.817 <0.001	0.762 <0.001	0.770 <0.001	0.786 <0.001	0.788 <0.001	0.864 <0.001	0.888 <0.001				
BEP	0.353 0.012	0.641 <0.001	0.060 0.678	0.347 0.013	0.377 0.007	0.600 <0.001	0.847 <0.001	0.592 <0.001	0.608 <0.001	0.586 <0.001	0.591 <0.001			
BKF	0.331 0.019	0.481 <0.001	0.547 <0.001	0.599 <0.001	0.618 <0.001	0.660 <0.001	0.732 <0.001	0.697 <0.001	0.816 <0.001	0.778 <0.001	0.842 <0.001	0.614 <0.001		
BAP	0.614 <0.001	0.714 <0.001	0.675 <0.001	0.863 <0.001	0.918 <0.001	0.939 <0.001	0.875 <0.001	0.947 <0.001	0.986 <0.001	0.984 <0.001	0.884 <0.001	0.642 <0.001	0.816 <0.001	
Total PAH	0.913 <0.001	0.858 <0.001	0.744 <0.001	0.893 <0.001	0.873 <0.001	0.882 <0.001	0.776 <0.001	0.845 <0.001	0.839 <0.001	0.856 <0.001	0.795 <0.001	0.501 <0.001	0.558 <0.001	0.852 <0.001

Pearson coefficients are shown in larger font and p-values in smaller font