Volatile organic compounds from the combustion of human and animal tissue

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The volatile by-products of the combustion of ordinary fuels such as wood, polystyrene, polyethylene, urethane foam, PVC and the like are well known to the forensic fire debris examiner. When a fire involves a human body, volatile species are produced that are not so well known, including various alkenes and aldehydes. These have sometimes been mistaken for the residues of unusual accelerants. In an attempt to document what volatiles are produced by the combustion of animal fat and human fat, the authors have used an open-tube pyrolysis probe as a micro-furnace to burn small samples of unembalmed subcutaneous fat from human, avian and porcine sources, and collect volatiles by charcoal strip adsorption. The volatile products were analyzed by GC/MS. Predominant species included aldehydes in the C_6–C_{10} range, homologous series of alkenes and alkanes, and other hydrocarbon products. These results were compared to those obtained by free-burning (open flame in air) of similar specimens and to the volatiles detected in debris from beneath a human cadaver in a test fire. Differences between the volatile profiles produced by human fat as compared to pork and chicken fat and adventitious sources of such volatiles are discussed.

Les dérivés volatiles provenant de la combustion de combustibles ordinaires tels que le bois, le polystyrène, le polyéthylène, les mousses uréthanes, le PVC et autres sont biens connus des spécialistes de l'étude des débris provenant d'incendies. Lorsqu'un feu implique un corps humain, les espèces volatiles produites qui comprennent divers alcènes et aldéhydes ne sont pas si bien connues. Ceux-ci ont parfois été confondus pour des résidus d'accélérants inhabituels. Afin de documenter les produits volatiles provenant de la combustion de graisses animales et humaines, les auteurs on utilisé une sonde pyrolytique à tube ouvert comme un micro four pour brûler de petits échantillons de graisse sous-cutanées non embaumées provenant de sources humaines aviaires et porcines, et collecter les produits volatiles par adsorption sur bande de charbon. Les produits volatiles on été analysés par GC/MS. Les espèces prédominantes incluaient des aldéhydes dans le domaine allant de C6 à C10 des séries homologues d'alcènes et d'alcanes et d'autres hydrocarbures. Ces résultats ont été comparés avec ceux obtenus en brûlant à feu ouvert des spécimens similaires et au produit volatile détectés dans les débris provenant d'en dessous d'un cadavre humain dans un test de feu. Les différences entre les profils des volatiles produits par la graisse humaine comparée à la graisse de cochon et de poulet ainsi que de sources adventives de tels produits volatiles sont discutés.

Key words Forensic science, fire investigation, combustion, pyrolysis, human, GC-MS, volatile

Die bei Verbrennung normaler Brennstoffe wie Holz, Polystyrol, Polyethylen, Urethanschaum, Polyvinylchlorid u. ä. auftretenden flüchtigen Nebenprodukte sind dem kriminaltechnischen Brandrückstandsanalytiker wohl bekannt. Wenn in einem Feuer auch ein menschlicher Körper verbrennt, entstehen weniger geläufige flüchtige Substanzen, unter anderem verschiedene Alkene und Aldehyde, die in einzelnen Fällen schon irrtümlich als Rückstände ungewöhnlicher Brandbeschleunigungsmittel gedeutet wurden. Um nachzustellen, welche flüchtigen Stoffe bei der Verbrennung von tierischem und menschlichem Fett gebildet werden, benutzten die Autoren ein offenes Schraubdeckelglas auf einem Heizdraht als Mikro-Ofen zur Verbrennung kleiner Proben von nicht konserviertem, subcutanem Fettgewebe von Menschen, Vögeln und Schweinen. Die flüchtigen Produkte wurden auf Aktivkohlestreifen absorbiert und mittels GC/MS analysiert. Überwiegend wurden C6-C10-Aldehyde, homologe Reihen von Alkenen und Alkanen sowie andere Kohlenwasserstoffprodukte festgestellt. Diese wurden mit flüchtigen Verbindungen verglichen, welche bei offener Verbrennung ähnlicher Proben und nach einem Brandversuch unter einer Leiche im Schutt festgestellt worden waren. Die in Bezug auf das Muster der flüchtigen Verbrennungsprodukte bestehenden Unterschiede zwischen Menschenfett einerseits und Schweine- bzw. Vogelfett und zusätzlichen Quellen dieser flüchtigen Verbindungen andererseits werden diskutiert.

Los subproductos volátiles de la combustión de materiales tales como madera, poliestireno, polietileno, espuma de uretano, PVC y similares son bien conocidos por el perito forense experto en restos de incendios. Cuando en el incendio hay algún cuerpo humano las especies volátiles producidas, entre las que se incluyen varios alquenos y aldehidos, no son tan conocidas. A veces se han confundido con los residuos de acelerantes poco habituales. En un intento de demostrar que estos volátiles se producen por la combustión de grasas animales y humanas, los autores utilizan una sonda de pirólisis abierta como un microhorno para quemar muestras pequeñas de grasas subcutáneas no embalsamadas de origen humano, aviar y porcino recogiendo los productos volátiles por absorción en tiras de carbón. Los productos volátiles fueron analizados por CG/EM. Las especies predominantes incluían aldehídos en el rango C6–C10, series homólogas de alquenos y alcanos y otros productos hidrocarbonados. Estos resultados se compararon con los obtenidos en combustiones al aire libre de especímenes similares y con los productos volátiles detectados en restos de un cadáver humano en un test de incendio. Se discuten las diferencias entre los perfiles de productos volátiles producidos por grasa humanas y los producidos por grasas de pollo y cerdo así como los posibles orígenes de dichos productos.

Introduction

This enquiry was prompted by questions that arose during a recent homicide investigation in which the volatile constituents in a fire environment were apparently transferred to the clothing and hair of an individual who was thought to have had prolonged contact with the smoky fire. Sometimes the odour of smoke adheres to hair or clothing, and it was suggested that these odours might be identifiable by sensitive GC/MS methods and that they might be linked to the combination of fuels involved in the fire. Those enquiries may form another paper. This paper addresses the question of whether if fire involved a human body, would there be anything distinctive about the volatiles produced in its partial combustion that could be identified by ordinary GC/MS/carbon-strip methodology.

Work done by McLellan examined the volatiles produced by uncooked and burned (by various exposures) pork prior to and during decomposition [1]. Her results had shown that n-aldehydes, particularly n-pentanal, n-hexanal and 3-methyl butanal (as well as toluene and ethylbenzene), were produced by fresh, burned pork tissue (various methyl sulfides dominated the decomposing tissue samples, whether burned or not).

Additional work has been done by DeHaan and Brien using limited quantities of subcutaneous fat of both porcine and human origin in small open-burning flames (personal communication). Volatiles were captured directly on carbon-strips and on polyester and wool, followed by carbon-strip adsorption-elution. This work showed that volatile products including a homologous series of n-aldehydes from C_5 to C_{10} were present as major constituents, as well as other unsaturated, aromatic and cyclic hydrocarbons. These initial tests suggested that pork and human fat produced slightly different profiles of pyrolysis and combustion products, but time and specimen limitations precluded further work at that time.

Several options were evaluated to produce a more reproducible test method. Normal pyrolysis GC was contemplated, but the non-oxygenated environment of a typical solid-probe pyrolysis system would not produce the oxygenated species more typical of a free-burning, flaming fire. It was known from previous work (by DeHaan) that animal fats melt at relatively low temperatures and usually burn as a diffusion flame supported by evaporation of the fat from a rigid, porous wick such as charred cloth or wood [2]. This process would produce fuel surface temperatures typical of most solid fuels (400–500°C) [3]. The reported auto-ignition temperature for animal lard is 355°C [4]. It was decided that a platinum-ribbon micro-furnace such as the CDS Pyrolysis Probe 1000 operating in air could produce such temperatures (350–500°C) with excellent reproducibility, and the volatiles could be retained within a 4 ml sampling vial placed over the ribbon heater. A carbon strip could be placed in the vial to concentrate the volatiles for GC/MS analysis in the same manner as for fire debris analysis [5].

Experimental Method

A CDS Pyrolysis Probe 1000 (Figure 1) was used for the majority of the tests reported here. It was ramped at 5°C/ms from ambient to a pre-set temperature limit (300/500/700°C) and held there for 10s. A new 4 ml, screw-top, glass vial was placed over the ribbon heater for each test, open to the air (as in Figure 2). A new 8 mm × 8 mm carbon strip (Albrayco, CT) was placed in each vial prior to firing. A sample of fat (5–12 mg in mass) was placed directly on the heating element. The ribbon heater was fired between runs to eliminate carry-over. After cooling, the carbon strip was extracted for 15 minutes with 50–100 µl of diethyl ether with a diphenylmethane internal standard. Each eluate was injected onto a Varian CP-3800 Gas Chromatograph with a Saturn 2000 Ion Trap Mass Spectrometer using a J&W DB-5 capillary column (30 m x 0.25 µ ID, 0.1 µm film). The chromatograph oven was programmed using a standard ignitable liquid analysis program (40–260°C at 15°/minute, 40°C for four minutes, five minutes at 260°C). The GC/MS results were processed using the usual ions for alkanes (57, 71, 85), aromatics (91, 105, 119), and unsaturated hydrocarbons (55, 69, 83), plus 44 for aldehydes [6].

Samples of chicken fat (solidified from boiled fresh chicken), fresh pork fat (from a local butcher) and subcutaneous fat from an adult human cadaver (unembalmed) (from the University of California Dept of Human Anatomy) were used. Each type of fat was analyzed three times at each of three furnace temperatures. Additional testing used strips of low-density polyethylene and cotton cloth tested in the same manner. It was deemed desirable to compare the chromatographic peak pattern of volatiles from a

Figure 1 CDS Pyroprobe system with temperature controller (bottom left), plotter (top left), and probe (right).

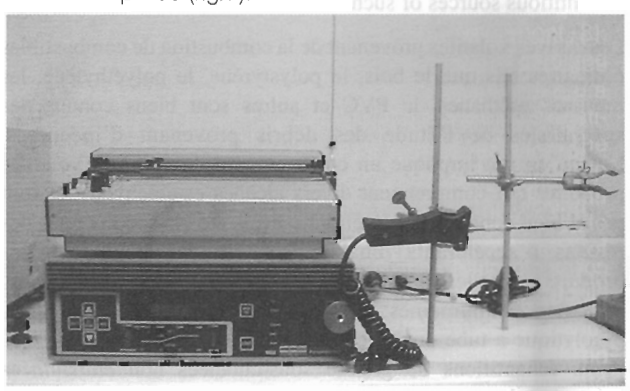


Figure 2 Close-up of platinum ribbon micro-furnace at end of probe. Two ml glass vial placed over micro-furnace with 8 mm x 8 mm carbon strip in vial.

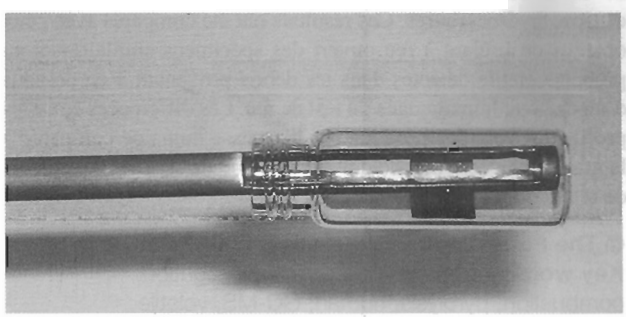
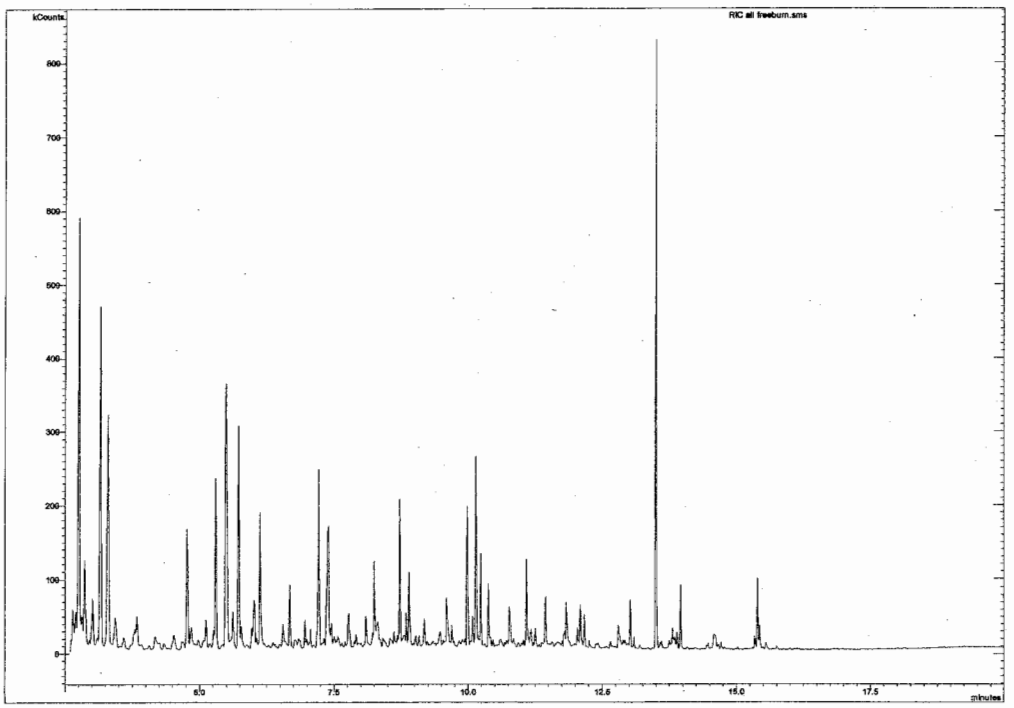


Figure 3 Typical total ion chromatogram of human fat burned in air (sampled using carbon strip). Detector off until 2.5 minutes, internal standard (diphenylmethane) at 13.5 minutes.



"bulk sample" of human fat free-burning in air to those from the micro-furnace tests. To accomplish this, one test was carried out using approximately 12 g of human fat wrapped in cotton cloth and burned as a fat-fueled, wick-fed flame in open air. A clean, metal, friction-lid can was inverted over the sample to extinguish the sustained flame. An 8 mm × 8 mm carbon strip inside the can was removed after cooling and eluted in the same manner as above.

In addition, a complete, unembalmed human cadaver was placed in a house being burned for firefighter training. The cadaver was in a polyethylene bag and was placed on a bed of wood scrap on a carpeted concrete floor. The building was set afire and burned to completion and collapse (burn time of 59 minutes). Samples of charred wood and carpet were collected from beneath the torso the following day and were secured in sealed metal friction-lid cans until tested. They were tested using the same carbon-strip adsorption-elution method used for the "free-burn" test above (leaving the strip in the can for two hours at 80°C).

Results

The combustion of human and animal fat produced a variety of n-alkanes, n-aldehydes, alkenes, and light aromatics. A representative GC/MS chromatogram is shown in Figure 3. The compounds detected were identified by library searches and comparison to reference materials analyzed on the same instrument. The major peaks are identified in Table 1. It is important to note that with the DB–5 column and conditions used here, the homologous series of aldehydes is shifted two hydrocarbons up (pentanal elutes near heptane, hexanal with octane, etc.). The qualitative reproducibility of the analytical

Table 1 The following compounds were identified in a typical chromatogram of combustion products of animal fat using a DB–5 column, Figures 3–8.

Compound	Retention Time (Mins)
Benzene	2.8
1-Heptene	3.20
n-Pentanal	3.30
1-Octene	5.35
n-Octane	5.5
n-Hexanal	5.55
1-Nonene	7.20
n-Nonane	7.35
n-Heptanal	7.4
Decadiene	8.05
1-Decene	8.72
n-Decane	8.83
n-Octanal	8.9
Undecadiene	9.7
n-Undecene	10.0
n-Undecane	10.1
n-Nonanal	10.15
4-Methyl Hexanal	10.75
Dodecadiene	11.0
1-Dodecene	11.1
n-Dodecane	11.2
n-Decanal	11.3
Cyclodecene	11.4
1-Tridecene	12.1
n-Tridecane	12.2

Figure 4 Three replicate analyses of human fat burned at micro-furnace temperature of 500°C showing qualitative reproducibility of peak profiles. Reference standards of n-aldehydes (C_5–C_{10}) shown for comparison.

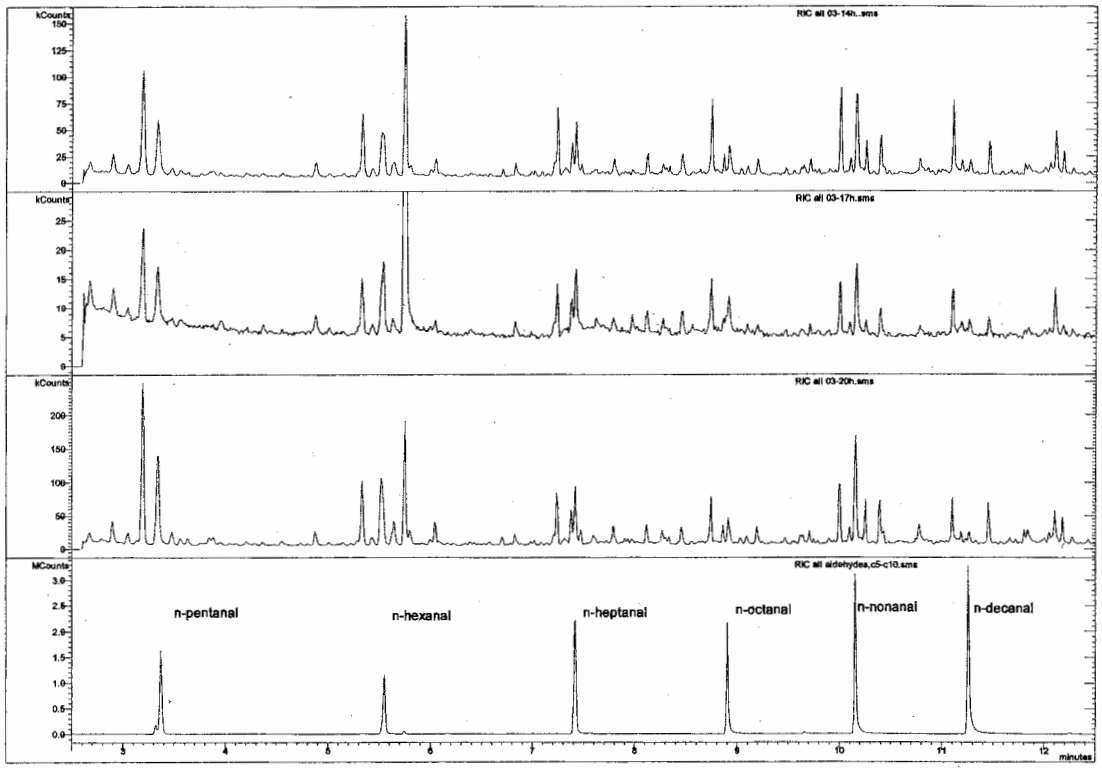


Figure 5 Three replicate analyses of human fat burned at 700°C. Note that the peak proportions are slightly different than those at 500°C, but that qualitative reproducibility between analyses of peak ratios is good.

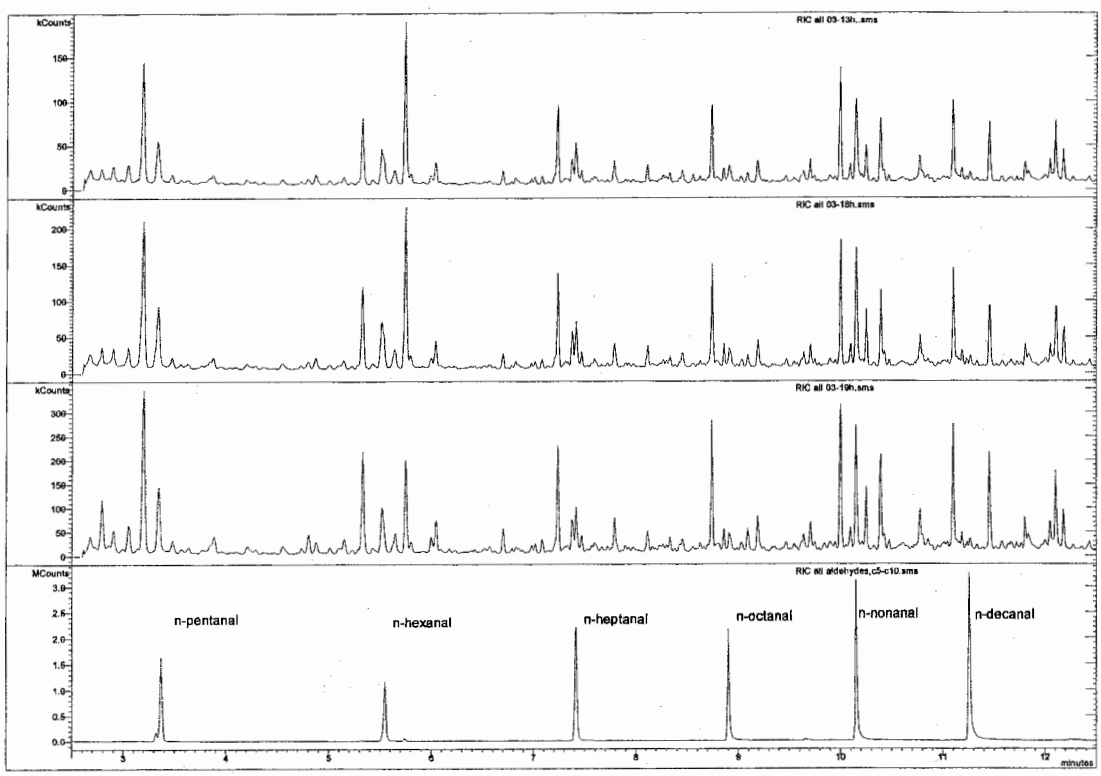


Figure 6 Three typical analyses of human fat at three different micro-furnace temperatures (300°, 500°, and 700°C) demonstrating the effects of temperature.

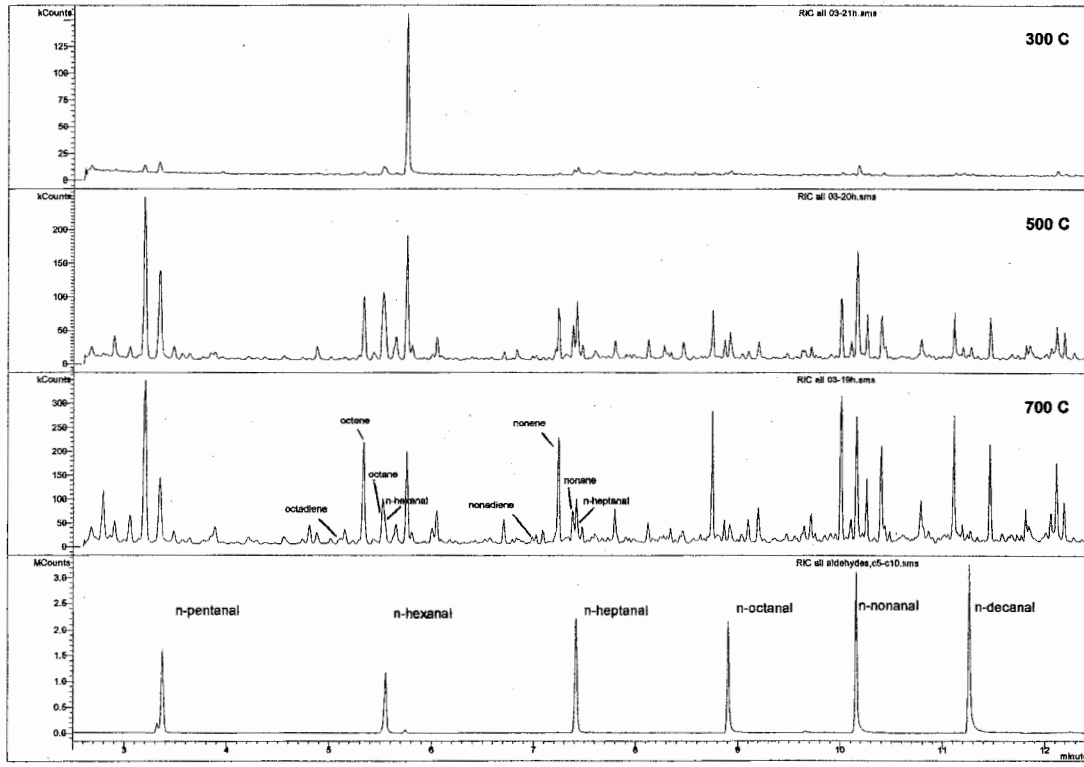


Figure 7 Comparison of volatile products from a small, free-burning fire fueled by human body fat and those from a micro-furnace test at 500°C shows a very strong correlation.

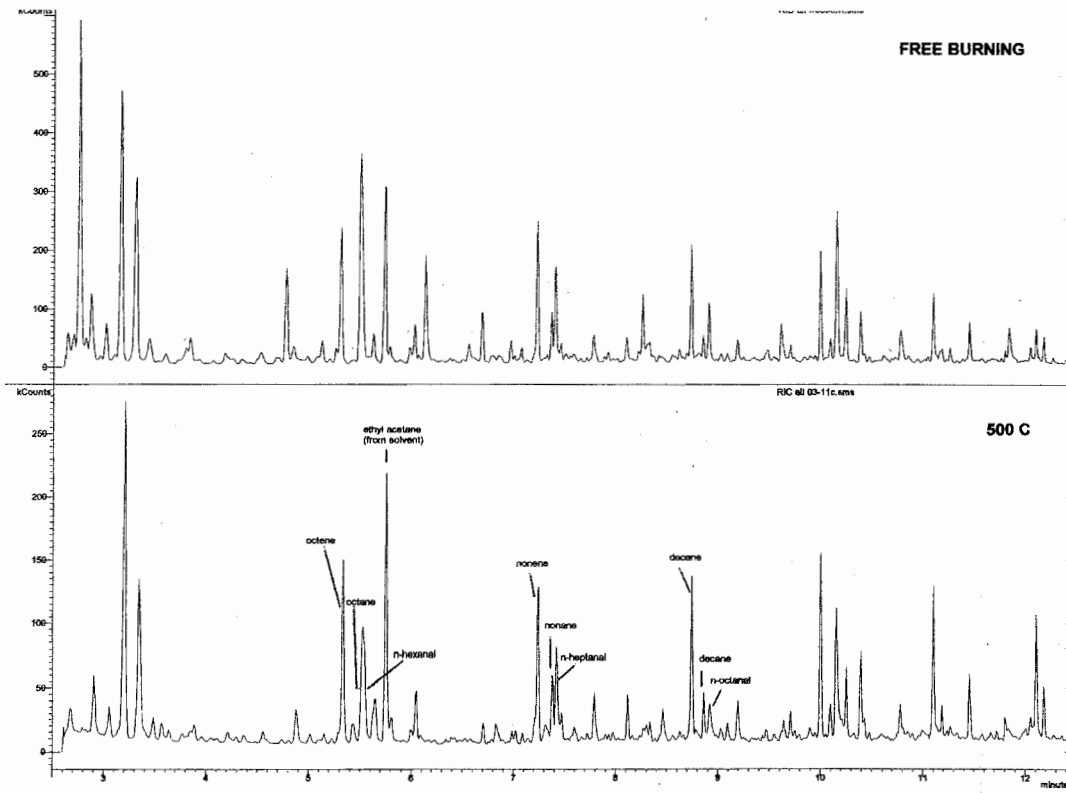


Figure 8 Comparison of a typical human fat combustion (at 500°C) and reference standards of n-alkanes and n-aldehydes. Note that hexanal (C_6 aldehyde) and n-octane nearly overlap, but that later aldehyde/alkane 'pairs' are resolved.

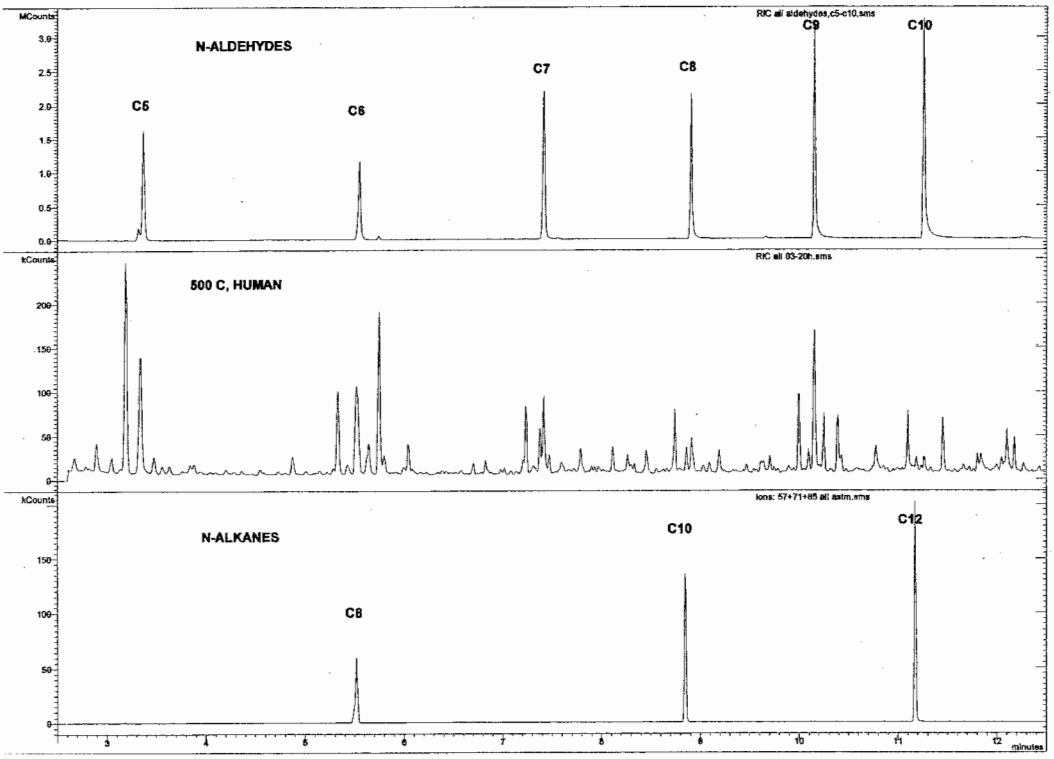


Figure 9 Total ion chromatogram (top) and selected ion chromatogram for aromatics in human fat (78, 91 and 105 ions) (bottom) show benzene, toluene and 4-methylene-5-hexanal to be present at very low concentrations. The C_2 alkylbenzenes (ethylbenzene and xylenes) are grouped around 7.0 minutes but are not labeled.

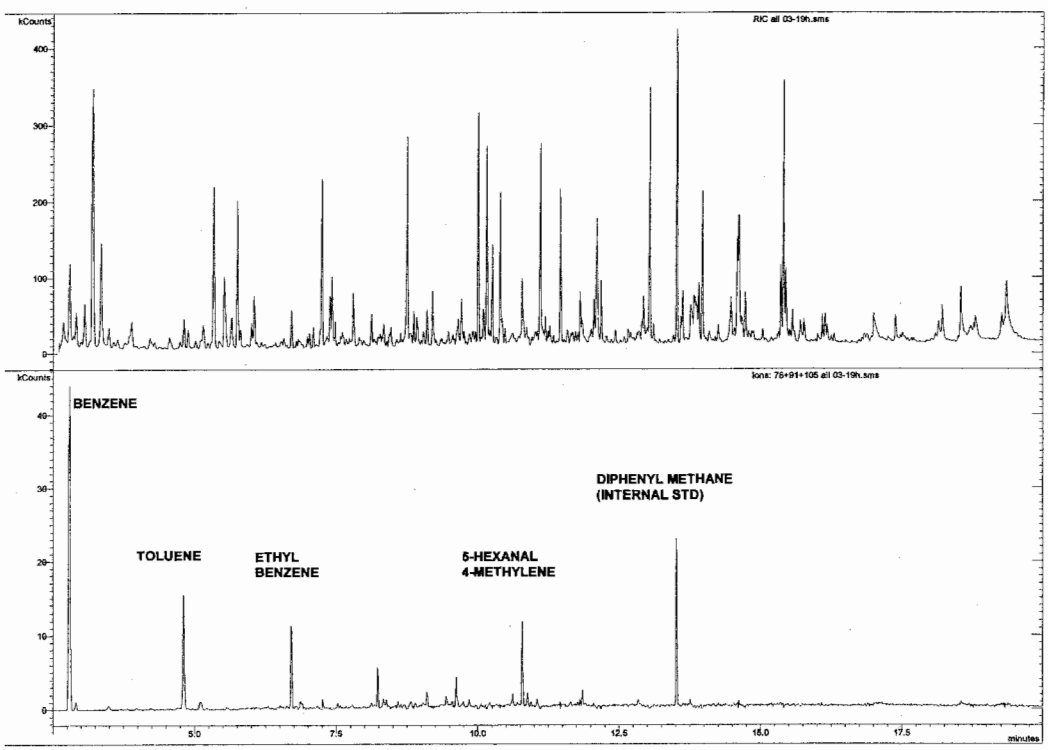
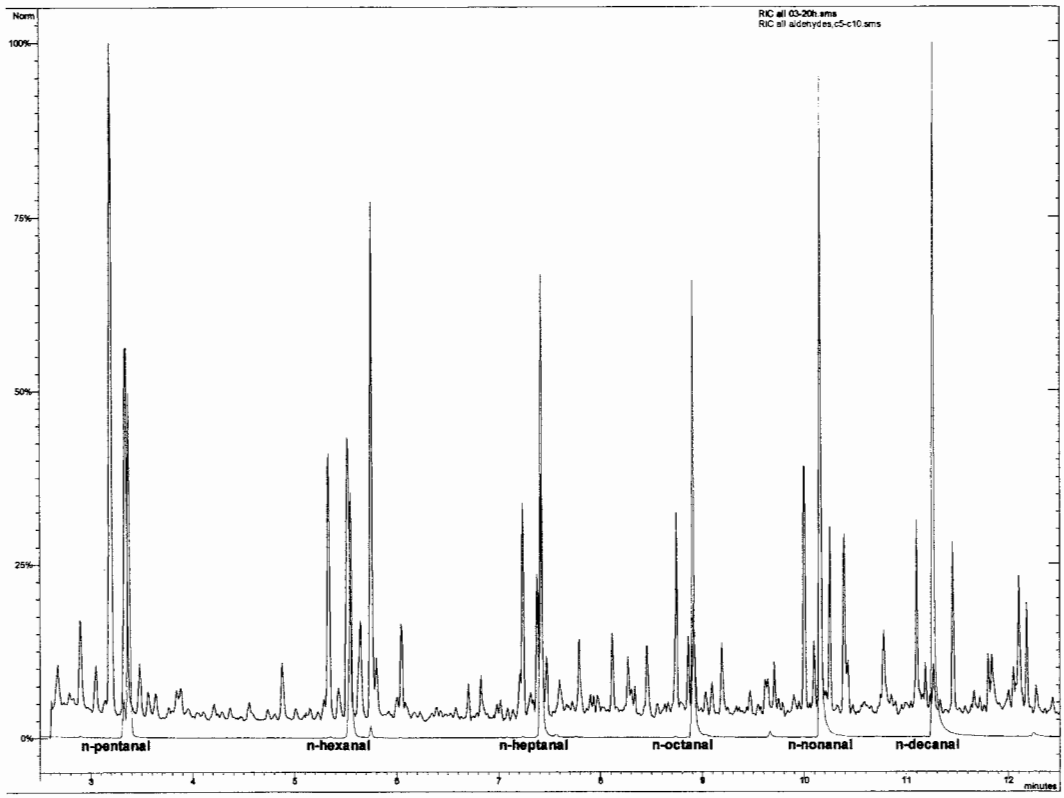


Figure 10 Expanded total ion chromatogram (2.5–12.7 minutes) of human body fat burned at 500°C overlaid with reference standard of n-aldehydes. Heptanal, octanal, nonanal, and decanal peaks are resolved under these conditions; pentanal is not (obscured by n-heptane).



approach can be seen in Figures 4 and 5, which show GC/MS chromatograms of the products from samples of human fat heated to 500°C and 700°C, respectively. As expected, due to variations in sample size (5–12 mg) and geometry (given the physical nature of the fat samples), quantitative reproducibility is not observed, but ratios of peaks are internally consistent.

To establish the influence of temperature, selected runs at 300°C, 500°C and 700°C were compared for each species of fat. Figure 6 shows representative comparison of the combustion products of human fat at three temperatures.

A comparison of human fat analyzed in the micro-furnace at 500°C v. human fat in a free-burning flame is shown in Figure 7. A sample of cotton cloth wick was tested by itself and produced only benzene (2.78 min) and toluene (4.80 min) plus light compounds obscured by the solvent peak.

The chemical species produced in human fat combustion were identified by selected ion profiling and "spectrum matching" against library standards where necessary. The results for human fat are shown in Figures 8–10 and Table 1. Note the low concentration of aromatic contributions.

There was a marked similarity noted between the volatile species produced by the combustion of polyethylene and those from animal fat. Comparisons of human fat v. polyethylene are shown in Figures 11–12. The question of species-specific profiling was addressed by comparing the profile of pork fat (shown at various temperatures in Figure 13) against other species at 500°C (Figure 14).

It should be noted that unburned clothing, if very soiled with body oils, could produce a similar volatile profile. A specimen of unburned clothing analyzed from case evidence using a similar GC/MS method is shown in Figure 15 (B Johnson – personal communication). Some variation in the appearance of the profile can be attributed to a difference in equipment used, but the similarities in peak ratios of alkanes to alkenes to aldehydes can be seen when compared to Figure 3. Dominant peaks at 2.17, 2.96, 3.68, 4.94 and 5.5 min are n-aldehydes in the GC system used to produce Figure 15. The peak at 4.34 may be n-octanal based on its retention time and size.

The cadaver samples (on carpet and wood) presented very complex total ion chromatograms with a marked homologous series of doublets as seen in Figure 16. TIC and selected ion monitoring chromatograms (SIMS) for the 6–12 minute or 9–15 minute ranges compared to those of gasoline are shown in Figures 17–19. A selected ion analysis (44 ion) for the body on wood debris is shown in Figure 20.

Discussion

The method employed here yielded qualitatively reproducible chromatograms (as in Figures 4–6) from the combustion of small (5–12 mg) quantities of animal fats to allow determination of

Figure 11 Comparison of chromatograms from human fat (free-burn) (top) and polyethylene burned at 500°C (bottom). Note extensive duplication of peaks, but note that the diene peak is always more prominent from polyethylene than from fat, and the relative proportions of alkene-alkane-aldehyde in each group are different between fat and polyethylene.

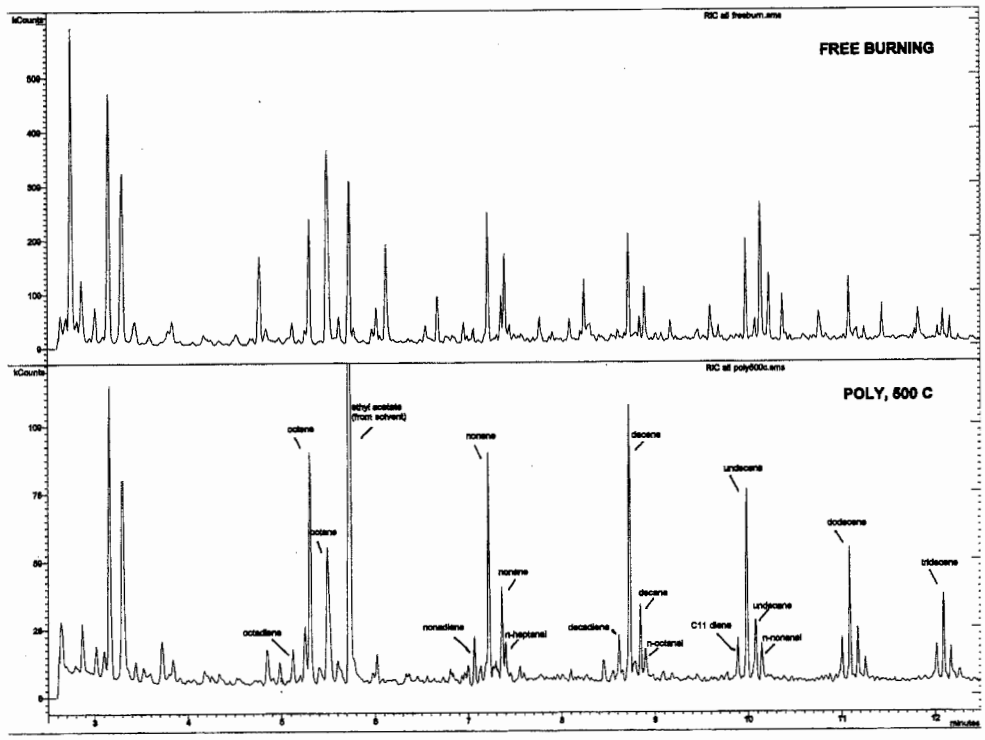


Figure 12 Comparison of polyethylene (top), human fat at 500°C (middle) and reference standards of n-alkanes (bottom). n-alkene peak dominates each group of polyethylene products accompanied by a diene. Aldehyde peaks are much higher proportionally in fat pyrolysis than polyethylene. Homologous series extends out to $>C_{23}$ for polyethylene and ends about C_{15} (aldehyde) for fat. Peak at 13.5 minutes is internal standard diphenylmethane.

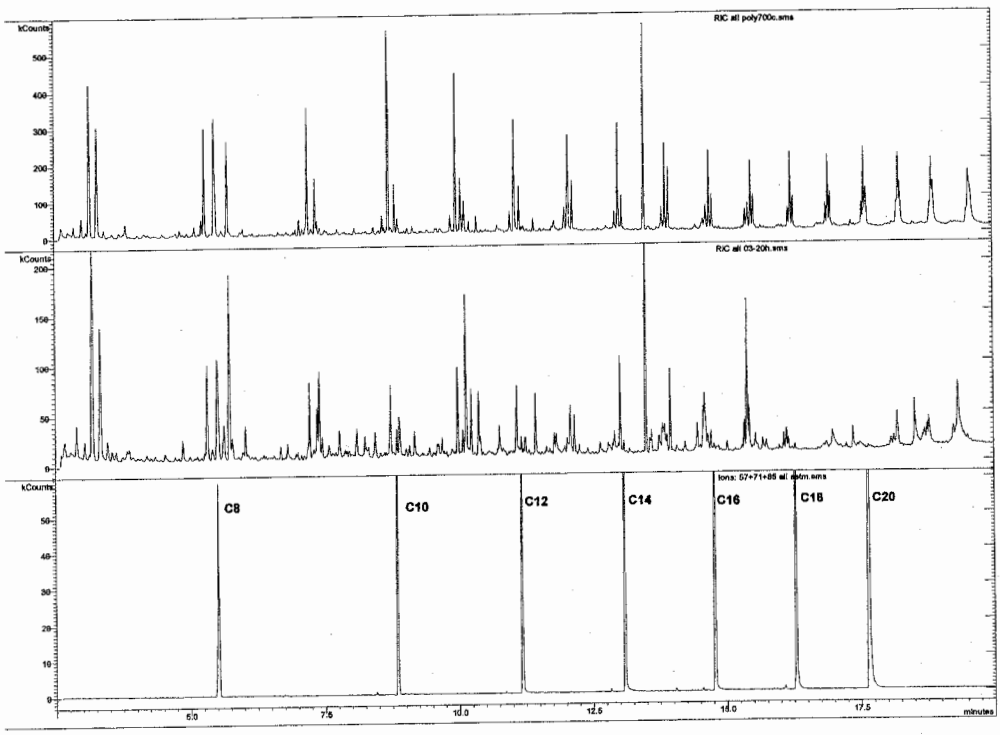


Figure 13 Comparison of volatiles from pork fat at three different micro-furnace temperatures. Same effect of increasing temperature as with human. Pork fat was the only one to produce significant volatiles at 300°C.

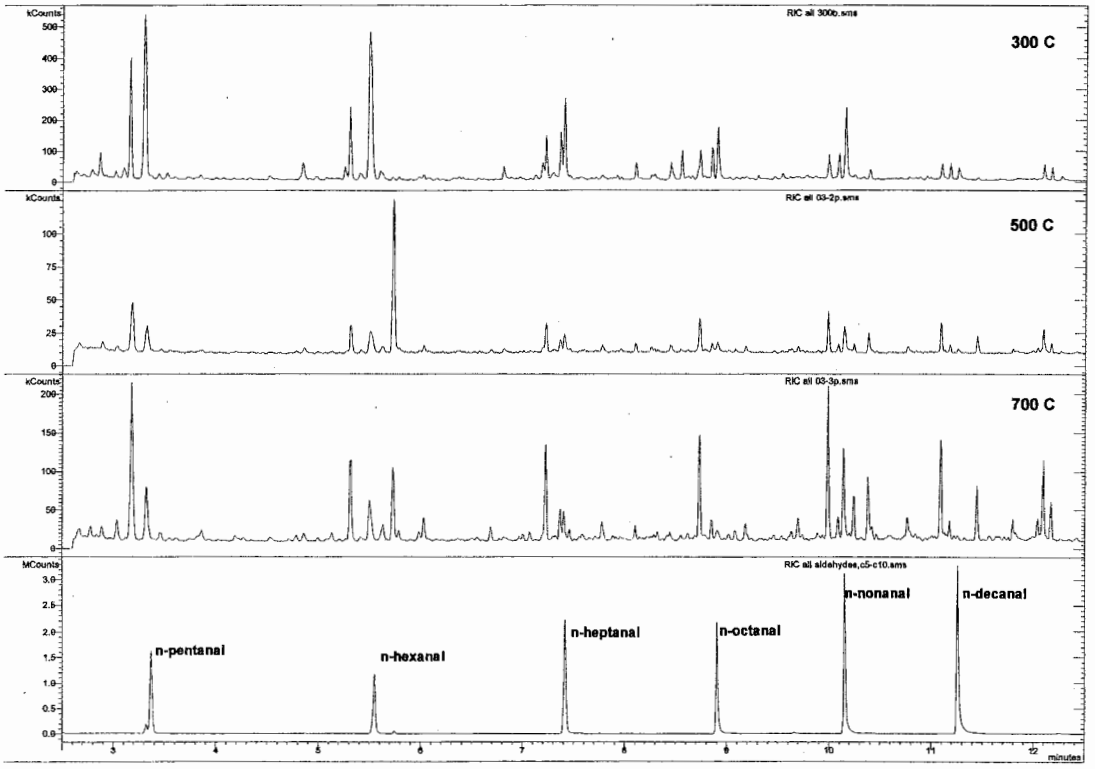


Figure 14 Comparison of volatiles from pork (top), chicken (middle), and human (bottom) at 500°C against n-aldehyde standard. Note there are no major differences detected between species except the higher nonanal peak in human fat.

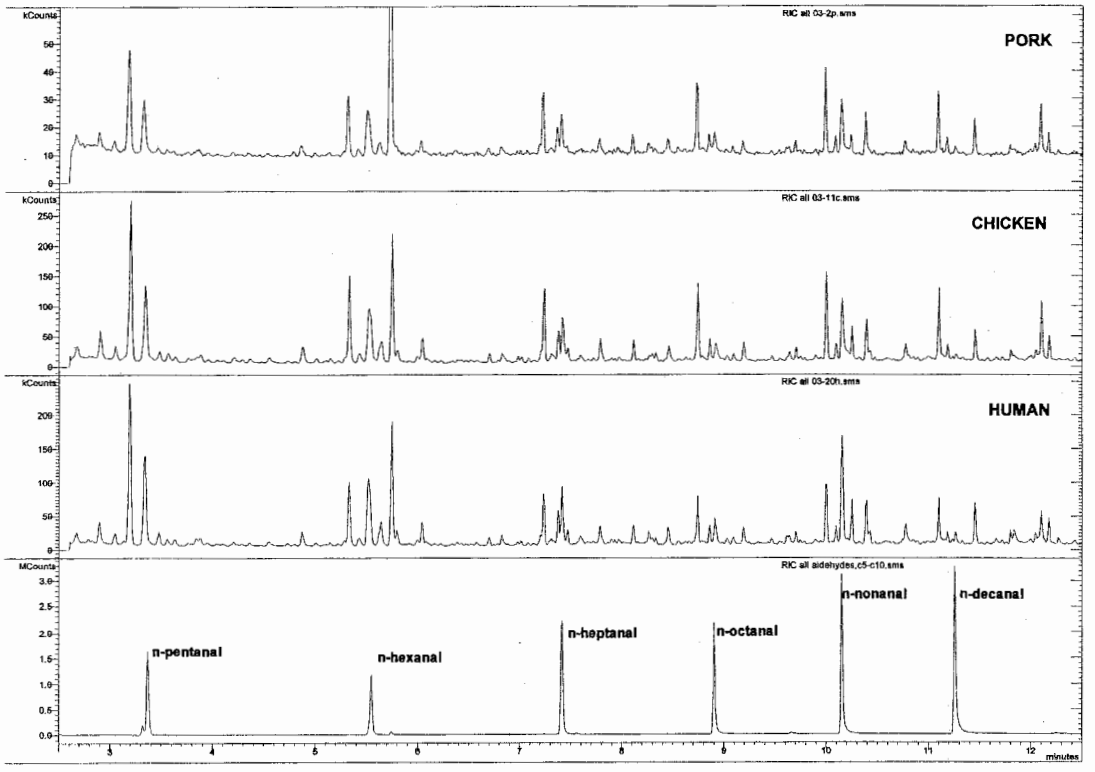
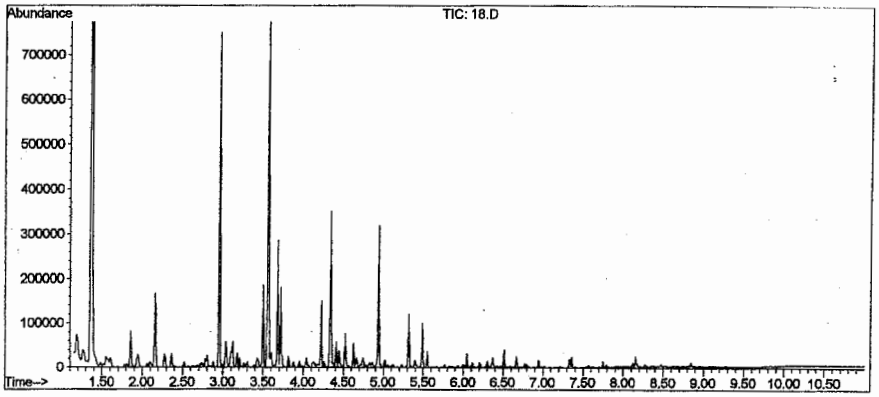


Figure 15 Volatiles from unburned, unlaundered clothing showing n-aldehydes out to n-decanal and profile very similar to burn tests. (Analysis courtesy of Brad Johnson, Sacramento County Forensic Lab.)



Retention Time	Index	Match Quality	Library Search
1.364	<600	91 Arson1	Cyclopentane
1.858	644	76 NBS	Butanal, 3-methyl-
2.169	685	91 NBS	Pentanal
2.96	789	76 NBS	Hexanal
3.045	800	91 NBS	2-Octene, (E)-
3.504	867	97 Arson1	ethylbenzene
3.561	875	97 Arson1	p-xylene
3.681	892	80 NBS	Heptanal
3.723	898	97 Arson1	p-xylene
4.225	978	72 NBS	5-Hepten-2-one, 6-methyl-
4.338	996		No match > 70
4.522	1027	80 NBS	1-Hexanol, 2-ethyl-
4.939	1100	90 NBS	Nonanal
5.32	1172		No match > 70
5.497	1206	83 NBS	Decanal

Figure 16 Volatiles from beneath cadaver burned in a house fire (duration 59 minutes) recovered from charred wood debris (top) and carpet (bottom). Homologous series of doublets dominate both.

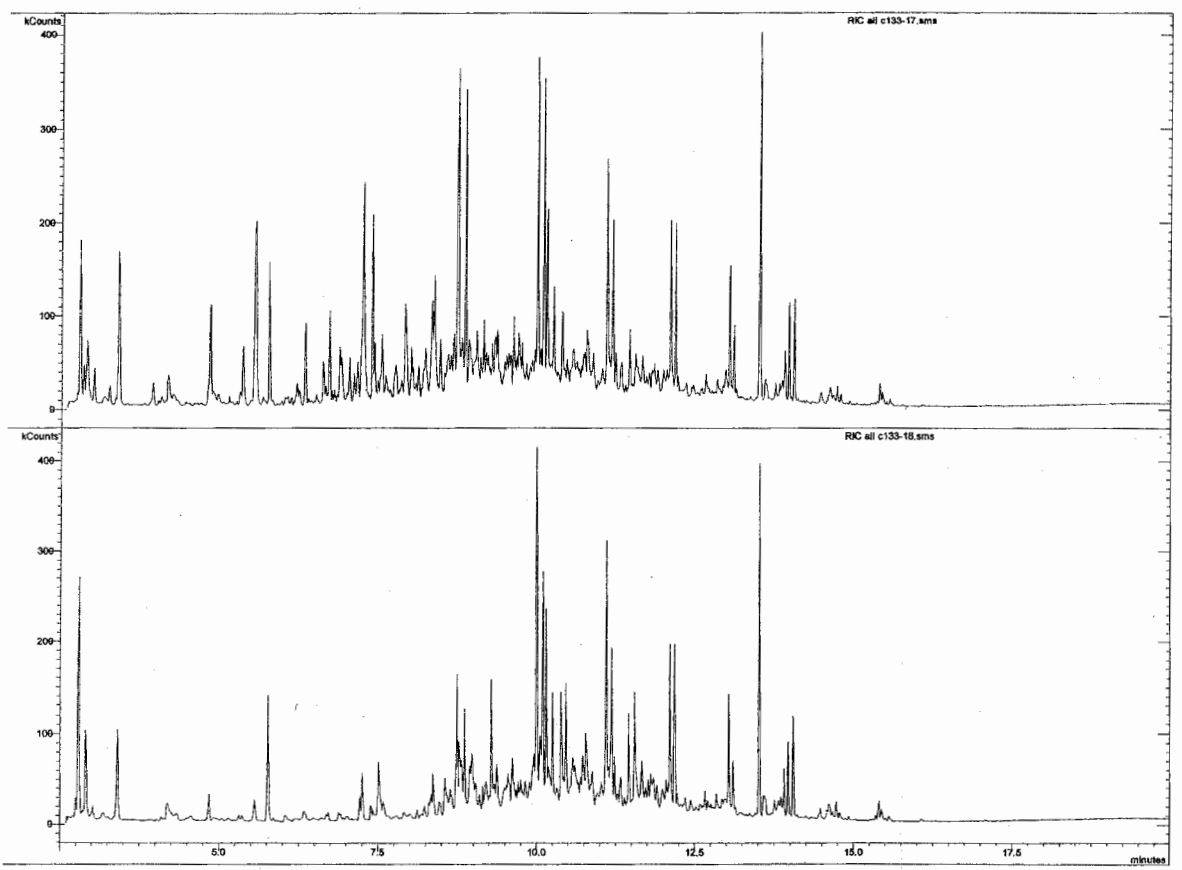


Figure 17 Comparison of expanded total ion chromatogram (6–12 minutes) from carpet under cadaver (top) and wood from under cadaver (bottom) against gasoline (center). Many of the same peaks are found in both cadaver debris samples.

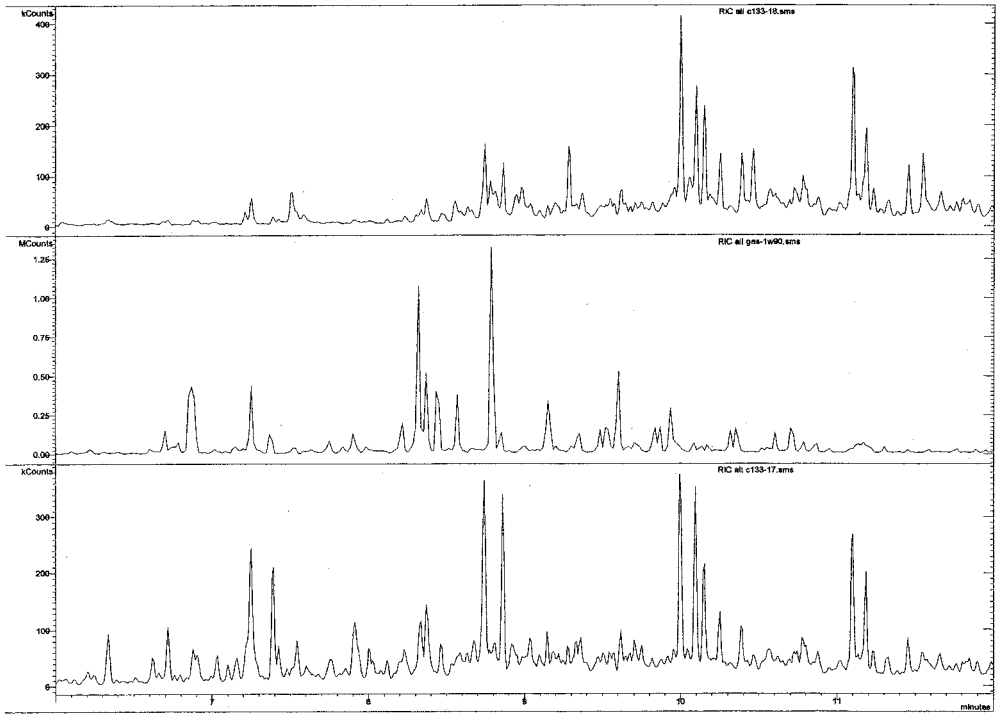


Figure 18 Comparison of selected ion chromatograms (aromatics – 91,105,119 ions) from carpet under cadaver (top) and charred wood from under cadaver (bottom) against gasoline (center). Many of the same aromatics are detected in all three, but the ratios between compounds in the C_2 and C_3 alkylbenzene groups are different.

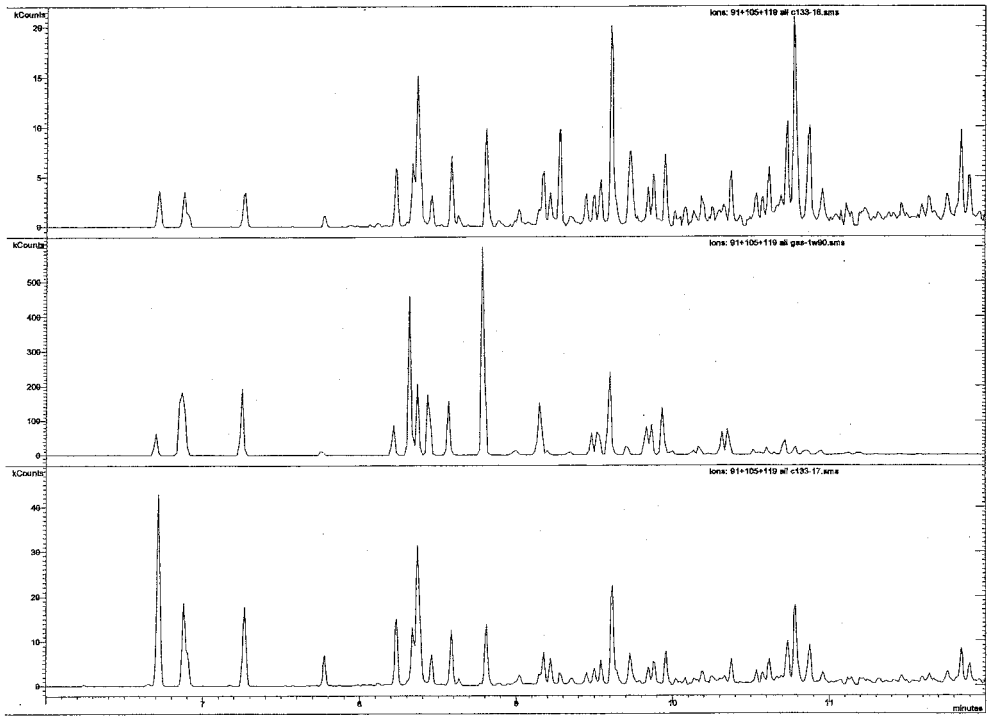


Figure 19 Comparison of selected ion chromatograms (128, 142, and 156 ions) from carpet under cadaver (top) and charred wood from under cadaver (bottom) against gasoline (center). All three chromatograms show similar profiles.

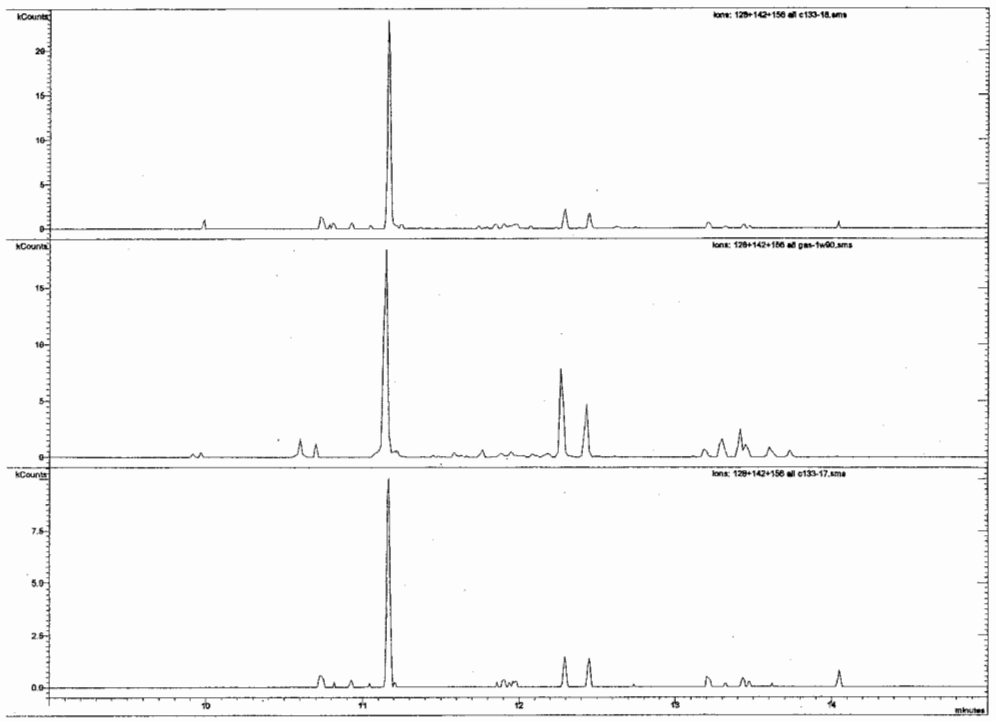
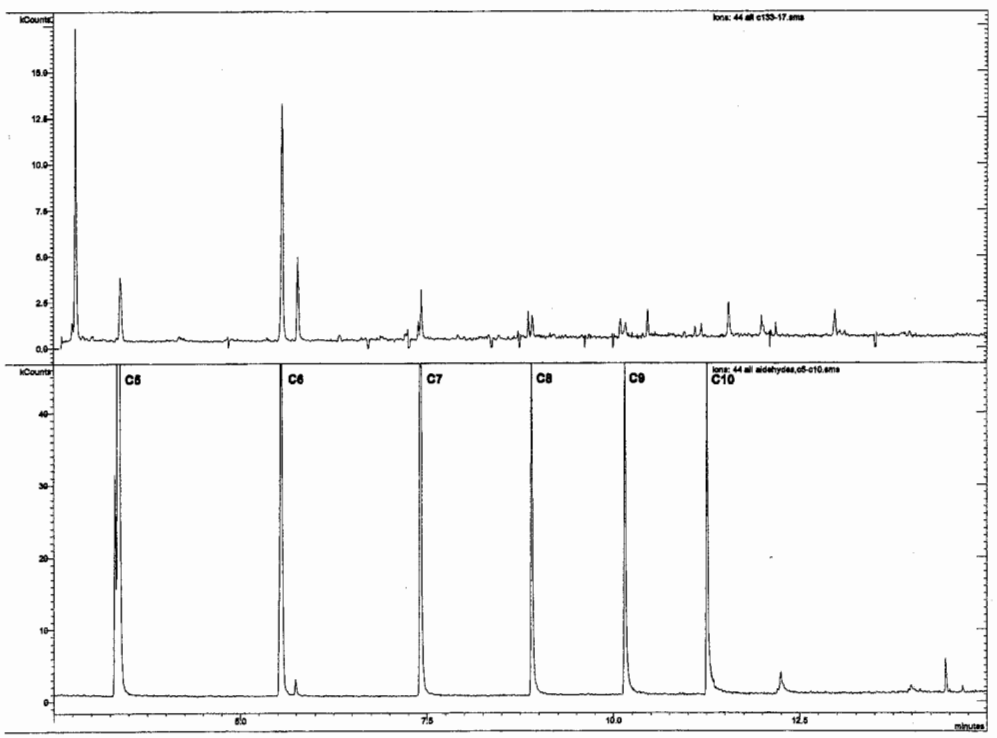


Figure 20 Selected ion chromatogram for ion 44 of wood debris from cadaver test and reference chromatogram of C_5–C_{10} aldehydes. The presence of the entire series C_5–C_{10} aldehydes is noted. C_7–C_{10} were missing from a similar chromatogram of the carpet/ cadaver debris. (Baseline noise due to very low range – 17,500 counts.)



their contributions to the volatile product profiles found in fire debris analysis. There is a clear dependency between furnace temperature and the chromatographic profile of pyrolysis and combustion products observed. It is not surprising that a micro-furnace temperature of 300°C failed to produce significant volatiles since the auto-ignition temperature of animal fat (lard) is reported to be 355°C. Temperatures above that threshold would produce pyrolysis products and true combustion products after auto-ignition. The micro-furnace method permitted the generation of chromatograms that closely resemble those from "bulk combustion" of human fat (Figures 3, 7 and 16). The optimum results were observed using a micro-furnace temperature of 500°C. The thermodynamics of solid fuel combustion predict that the surface temperature of a typical fuel is on the order of 400–500°C while the maximum flame temperature will be on the order of 800–900°C [4]. At temperatures over 700°C additional fragmentation and oxidation is observed giving fewer straight-chain aldehydes and more combustion products.

Many of the combustion products from the fat (alkanes, alkenes, dienes, aldehydes) are the same as those produced by the combustion of polyethylene. This is not surprising since the fatty acids that comprise such fats would be expected to cleave at points along the straight chain portions of the molecules. Fortunately these compounds are present in different ratios, so careful comparison can be used to distinguish them (as in Figures 11 and 12). For polyethylene, the predominant peak in each "quadruplet" is the alkene, followed in descending amplitude: alkane, diene and aldehyde. For fat, the alkene peak dominates, but the diene peak is very small or non-existent, and the aldehyde and alkane peaks are more equal in size. No alcohols or ketones were detected, although acetone and other very low molecular weight oxygenates may be obscured by the solvent peak (during which the detector is off).

Although the three animal fats tested here were from different species, significant differences between their volatile profiles were not seen (see Figure 14). This suggests that pork fat can reasonably be substituted as a comparison or "background" sample in analysis of casework involving burned human bodies. If skin, muscle or hair represent a major fuel substrate, appropriate reference or comparison samples must be tested. The chemistry of body fat is significantly different from these other tissues, but body fat represents the most combustible portion of a cadaver. For this reason, the body fat is expected to produce a significant amount of the combustion products.

The total ion chromatograms of the cadaver test specimens are readily distinguished from that for gasoline (Figure 17); however, the aromatics detected (ions 91 + 105 + 119 and 128 +142 + 156) all show considerable overlap with the aromatics found in gasoline (as in Figures 18–19). This demonstrates that relying on the aromatic profile alone to identify gasoline is not sufficient. The aliphatic:aromatic ratio for typical GC/MS analysis of an American automotive gasoline is about 2:1 while that for the cadaver tested here is about 20:1. This allows discrimination if ratio comparisons are carefully done.

The complexity of chromatograms recovered from beneath burned bodies (Figures 16–20) demonstrates the need for careful examination of the total ion chromatogram and careful use of selected ion chromatograms if errors are to be avoided. The authors have seen instances where debris from beneath a body was analyzed and concluded to contain residues of an exotic mixture of aldehydes used as an accelerant. Comparison samples of substrates (carpet, flooring and upholstery) are always useful and often critical to correct interpretation. Obtaining comparison samples of human body fat is not so straightforward, but the analyst can substitute pork fat as a comparison sample knowing it produces the same volatiles as human fat. Interestingly, all five of the homologous aldehydes (C_5–C_9) were detected by selective ion mode (44 ion) (Figure 20) in the wood debris of the cadaver test, but only pentanal, hexanal and heptanal were detected by SIMS in the carpet sample. This may be a matrix effect that deserves further study. Regrettably, comparison samples of the carpet used were not available. The doublets seen in the cadaver samples (Figure 16) may be the result of contributions from the polyethylene body bag used to transport the body.

Conclusions

Animal or human fat can produce significant quantities of volatile pyrolysis products detectable in the smoke or in the fire debris. These products represent a wide array of compounds – aromatic, aliphatic, unsaturated cyclic and straight-chain hydrocarbons, and oxygenates (aldehydes) that may be mistaken for ignitable liquid residues unless care is taken in analysis and comparison to appropriate background materials.

The method used here (open air micro-furnace) produced reproducible chromatograms for the selected materials (human, pork and chicken fat). The chromatograms of human fat ignited in the micro-furnace at 500°C were most closely comparable to those produced by a bulk sample of fat and of a human cadaver burned in a house fire. Thermodynamics of combustion predict a surface temperature of 400–500°C, and this is confirmed by the similarity between micro-furnace tests at 500°C and those of "bulk" samples.

Animal fats produced a complex, but characteristic, pattern of pyrolysis peaks dominated by a homologous series of quartets of peaks that are similar to those produced by polyethylene and similar polymers burned in air but are readily distinguished by their limited range (aldehydes $<C_{15}$) v. polyethylene (alkanes up to C_{23}) (see Figure 12) and different peak ratios (between the alkane, alkene, diene, and aldehyde in each quartet) (using MS). Animal fats characteristically produce n-aldehydes in the range of C_5–C_{10} plus ethyl acetate, toluene and benzene, alkanes, alkenes, and aromatic aldehydes. The n-aldehydes are found in higher proportions to n-alkanes and alkenes in the same quartet than are found when synthetic (hydrocarbon) polymers are burned (with dienes produced in much lower relative concentrations by fats than by polyethylene). The decanal is not always found, but hexanal, heptanal, octanal, and nonanal are consistently detected.

There appears to be no distinction between species using this

method. Differences between human and pork volatiles detected in earlier tests were apparently the result of uncontrolled variables of combustion processes (since they involved bulk, free-burning specimens). This demonstrates that pork fat can be substituted for human fat when comparison or "background" materials are needed in forensic casework where a body has been burned.

The presence of a similar chromatogram produced from clothing soiled by long use (not from eccrine sweat) suggests the breakdown products of fats can occur at lower temperatures than combustion. If accumulated over time, these may represent interferences if clothing is being examined for characteristic volatiles. Preliminary work showed that detectable quantities of volatiles were recoverable from wool or polyester fibers exposed to fat-fueled fires but that the chemistries of these substrates could affect the species adsorbed or eluted. The examination of such "secondary" targets for characteristic patterns of volatiles deserves further study.

Dedication

It was with great dismay and deep regret that we learned of the death of Bob Large just as this paper was accepted for publication. We were collaborators only on this one project but thanks to Bob's enthusiasm, curiosity and encouragement we had laid plans for several more enquiries. He will be missed as a forensic scientist and as a friend.

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