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Irritants in Cigarette Smoke Plumes

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Abstract: Concentrations of the irritants formaldehyde and acrolein in side stream cigarette smoke plumes are up to three orders of magnitude above occupational limits, readily accounting for eye and nasal irritation. "Low-tar" cigarettes appear at least as irritating as other cigarettes. More than half the irritant is associated with the particulate phase of the smoke, permitting deposition throughout the entire respiratory tract and raising the issue of whether formaldehyde in smoke is associated with bronchial cancer. (*Am J Public Health* 1982; 72:1283–1285.)

Those investigating complaints from workers at soldering operations can usually find nothing in air samples to justify such complaints, although the investigators themselves may experience eye irritation. Investigators of smoking on aircraft found carbon monoxide and other air contaminants far below any environmental limits,[1] yet passenger irritation was sufficient to cause the federal government to mandate aircraft No Smoking areas. In the cases cited, the irritation was evidently from material in a visible smoke plume rising from the soldering iron or from the cigarettes, respectively: concentrations in these small plumes might be high, although average air concentrations were so low as to be negligible.

We investigated the nature of such smoke plumes and concentrations of two specific irritants in cigarette smoke. The two principal irritants, formaldehyde and acrolein, were used as indices of irritation potential.*

Materials and Methods

A cigarette was placed in a holder and lighted. Once each minute a solenoid controlled valve opened for two seconds allowing a pump to draw a 35 cm^3 volume through the cigarette. This "main-stream" smoke was exhausted into a fume hood.

The diameter of the smoke plume (D) was measured visually on a millimeter scale. The velocity of the smoke plume (V) was measured by: a) inserting a heated thermocouple anemometer into the plume, and b) timing the rise of the "puff" between measured points. Core smoke stream flow rate then equaled

$$\frac{\pi D^2 V}{4}.$$

Smoke was collected close to the cigarette tip in an inverted cone-shaped hood. The smoke was drawn through two midget impingers in series to collect the aldehydes. When particulate-free smoke was desired, a glass fiber filter was inserted in the line.

The collecting solution was 1 per cent sodium bisulfite. Formaldehyde was analyzed by the chromotropic acid procedure, and acrolein by a modified mercuric chloride-hexylresorcinol procedure.[4]

Cigarettes were smoked in a 2.5 m^3 chamber. Relative particulate concentrations were monitored by a photometer, and samples for total suspended particulate were collected on filters. Formaldehyde was collected as before.

Results

The smoke stream diameter was measured as 2 mm. The average smoke stream velocity was 0.2 m/s, giving a flow rate of 6×10^{-7} m^3/s or 40 cm^3/min.

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*These irritants have been found in significant concentrations in experiments where side-stream smoke has been generated in a closed room,[2] and in a climatic chamber where subjects experienced strong irritation.[3] The degree to which these vapors were associated with the particulate phase also appeared important both from the standpoint of judging relative hazard and of controlling the irritant.

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TABLE 1—Typical Irritant Concentrations parts per million by volume* (ppm)

Brand	Formaldehyde		Acrolein	
	Air Sample	Core Smoke Stream	Air Sample	Core Smoke Stream
King size filter	1.7	90	0.9	50
"Conventional"	1.6	85	1.3	70
Low tar	1.5	80	1.3	70
Very low tar	2.1	110	n.a.	n.a.

*Calculated as though all the aldehyde were in the form of vapor. See also Discussion and Table 2.
n.a.: not analyzed.

Irritant concentrations for formaldehyde in four common cigarettes were 1.5 to 2.1 ppm in the sample; 80 to 110 ppm in the core smoke stream. Acrolein values were 0.9–1.3 and 50–70 ppm, respectively (Table 1). Calculations used flow rates given above.

Typical irritant concentrations for four common cigarettes are shown in Table 1. The core smoke stream concentrations are calculated using the sampling air flow rate and the core smoke stream flow rate above.

Table 2 shows that one-third to two-thirds of the irritants were in the particulate phase.

In a sealed space, particulate concentrations decreased somewhat more rapidly than formaldehyde concentrations (Table 3).

Discussion

The behavior of a jet of air has been presented by Hemeon.[5] As the jet proceeds, it gradually slows and expands as air is entrained. In laminar flows, little mixing takes place, as can be seen by watching smoke plumes rise in still air. Even when the plume is disturbed, the visible core can be observed to retain homogeneity over a distance of one to three meters. The upward velocity, which for our experiments was in the range of 0.15 to 0.2 m/s, is superimposed upon lateral air movements, so that the core with its concentrations of tens to hundreds of parts per million of the powerful irritants acrolein and formaldehyde can readily contact eyes or be breathed with only slight dilution. The

TABLE 3—Natural Removal of Formaldehyde and Particulate in a 2.5 m³ Chamber without Ventilation, Relative Concentration

	0–25 minutes	25–50 minutes	50–75 minutes
Particulate (Mass)	1	0.61	0.41
Formaldehyde	1	0.69	0.62

irritant properties of these materials may be partly inferred by their occupational limits. These are 0.1 to 0.3 ppm for acrolein and 1 to 3 ppm for formaldehyde.[6–9] Formaldehyde causes irritation to those first exposed at levels far below the limit, and can result in sensitization. It has also been reported to cause cancer of the nasal cavity in rats.[10]

The smoke plume rising from a cigarette between puffs is only a few millimeters in diameter. An air flow of 50 times the core smoke stream flow was required for capture, giving a 50-fold dilution factor. Typical concentrations found in these experiments are some three orders of magnitude above mandatory, time-weighted average occupational limits for acrolein, and almost two orders of magnitude above limits for formaldehyde. The side-stream smoke of "low tar" cigarettes was at least as high in acrolein and formaldehyde as that of traditional cigarettes.

About two-thirds of the formaldehyde and acrolein is associated with the particulate phase of side-stream cigarette smoke, possibly dissolved in its water content. Although the chamber experiment suggests that over longer periods some formaldehyde is disassociated from particulate, the visible smoke should be a rough index of the concentration of the two irritants. Particulate filtration plus washing of recirculated air could effect a significant reduction of irritant concentration in spaces where people smoke.

The association of particulate and aldehydes in smoke affects the site of reaction in the respiratory tract. Zurlo, for example, stated "Due to the solubility of formaldehyde in water, the irritant effect is limited to the initial section of the respiratory tract."[7] Fine particles, however, are deposited throughout the respiratory tract. Thus, if formaldehyde is carcinogenic in man, it could conceivably produce bronchogenic carcinomas, rather than nasal cancer, when carried deep into the respiratory tract by smoke particles.

Amounts of acrolein found in side-stream smoke are

TABLE 2—Typical Concentrations of Formaldehyde and Acrolein in Total Smoke and Vapor Phase Only

Brand	Formaldehyde			Acrolein		
	Total Smoke (mg/m³)	Vapor Phase Only (mg/m³)	Per Cent with Particulate	Total Smoke (mg/m³)	Vapor Phase Only (mg/m³)	Per Cent with Particulate
A	50	12	70	480	230	50
B	130	40	70	320	270	20
C	60	40	30	500	230	50

comparable to the 30 μg per cigarette reported in mainstream smoke,[11] but much less is inhaled. The side-stream smoke, however, is the principal source of eye irritation, and the irritants in the smoke may add to the risk of bronchial cancer.

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A Longitudinal Study of Blood Pressure in a National Survey of Children

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Abstract: Blood pressure changes over a three- to four-year period were studied in a cohort of 2,168 children examined during the US Health Examination Survey. The sample used is a representative subset of a national probability sample. Significant positive correlations between initial and follow-up blood pressures were observed. In addition, relatively obese children tended to demonstrate higher blood pressures within age-race-sex specific subgroups. (*Am J Public Health* 1982; 72:1285–1287.)

Previous studies have demonstrated the relationship between successive blood pressure measurements obtained over a pre-determined time interval.[1–4] In this report, we explored blood pressure changes over time and also investigated the relationship between adolescent blood pressure levels and childhood obesity. The data were derived from a unique data base, a national probability sample chosen to be representative of the population of children in the United States.[5–7] Accordingly, the results derived from this study are more generalizable than previous results obtained from the examination of other geographically localized, or otherwise limited populations.

Methods

Data were obtained from 2,168 children who were examined during both Cycle II and Cycle III of the US Health Examination Survey (HES), conducted by the National Center for Health Statistics (NCHS). The Cycle II examinations were conducted from 1963 to 1965, Cycle III examinations from 1966 to 1970. Overall, 7,119 children 6–11 years old were seen during Cycle II; 6,768 children 12–17 years old were seen during Cycle III. The same controlled sampling technique utilizing the same sampling units was used in the selection of participants of both cycles.[7] Only 2,177 children sampled during Cycle II either responded to

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