cause of the incident, container structure and failure, and deaths and injuries resulting from the cargo. DOT attempts to validate death and injury data. Specifically excluded from reporting requirements are releases of small quantities of certain consumer commodities, and releases from motor carrier firms doing solely intrastate business and from certain water transporters. Automobiles striking storage tanks and certain transportation-related spills at fixed facilities are also excluded.

The Acute Hazardous Events (AHE) data base was begun in 1985 and uses the NRC as its main source of data. However, data are also included from selected state governments, the Environmental Protection Agency (EPA) Region 7, some newspapers and wire services, and other sources. Information collected includes cause of event, activity taking place during the event, and type of property damaged. Attempts are made to eliminate deaths and injuries not caused by hazardous materials. Because emphasis was placed upon events involving chemicals covered by Superfund legislation and air releases from fixed sites, many events which appear in the NRC data base are excluded. AHE is maintained and augmented by EPA and its contractors, primarily Industrial Economics, Incorporated, and has been updated through 1986.[4] If events appear in more than one source, they are checked for consistency; otherwise, data are not validated.

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Formaldehyde Exposures from Tobacco Smoke: A Review

THAD GODISH, PHD

Abstract: Reports of formaldehyde levels in mainstream, sidestream, and environmental tobacco smoke from nine studies are reviewed. Considerable disparity exists between formaldehyde production rates determined from mainstream-sidestream studies and those reporting levels in environmental tobacco smoke. Tobacco smoke does not appear to increase vapor-phase formaldehyde levels significantly in indoor environments, but formaldehyde exposure in mainstream smoke may pose a risk of upper respiratory system cancer and increase the risk of cancer in smokers. (*Am J Public Health* 1989; 79: 1044–1045.)

Introduction

Formaldehyde is a major oxidation by-product of combustion processes including tobacco smoking. It is produced in both the mainstream (MS), and sidestream smoke (SS), and has been reported in substantial levels in environmental tobacco smoke (ETS).

Formaldehyde levels in mainstream, sidestream, and environmental tobacco smoke reported by a number of investigators are summarized in Table 1. Reported studies vary in testing methodologies and expression of concentrations. Concentration units are those originally reported and those calculated and standardized by the author from original data, assuming a smoking rate of 35 ml/puff and 10 puffs/cigarette.

As seen in Table 1, formaldehyde concentrations in mainstream smoke[1–4] ranged from about 10 μg/cigarette to over 100 μg/cigarette. Differences in concentrations reflect differences in tobacco type and brand. Higher average concentrations reported by the Surgeon General in 1986[3] reflect those of regular non-filter cigarettes.

Sidestream vapor-phase formaldehyde concentrations also varied somewhat. Ayer and Yeager[5] reported 15–48 ppm. Hoffman's observations ranged from nondetectable to 34.2 μg/cigarette, with an average of 12.1 μg/cigarette for 16 different brands.[4]

Room or large chamber formaldehyde levels associated with environmental tobacco smoke[6–9] indicate that formaldehyde concentrations in such rooms are high. For example, in the studies of Howlett, *et al,*[8] one cigarette smoked in an environmental chamber caused the formaldehyde level to increase to 0.21 ppm within a half hour. Formaldehyde production rates calculated from ETS concentrations (Table 1) are substantially higher (one to two orders of magnitude) than those reported for MS, SS, and MS-SS combined.

The considerable disparity in formaldehyde production rates determined from MS-SS and ETS studies suggests differences due to methodologies employed in sampling and analysis. In the mainstream-sidestream smoke studies reported by the Surgeon General[2,3] and by Hoffman,[4] gas and particulate phase materials were separated by high-efficiency filtration. In studies by Weber, *et al,*[6] no attempt was made to remove particulate phase materials. Sundin[7] employed particulate phase filtration of unknown efficiency. Attempts to remove particulate phase materials in ETS samples were not reported by Howlett, *et al,*[8] and Klus, *et al.*[9]

In mainstream-sidestream smoke studies,[2–4] smoke samples were analyzed by the 2,4 dinitrophenylhydrazene-HPLC method which is specific for free formaldehyde. The chromatropic acid method[10] on the other hand was used in the studies of Weber, *et al,*[6] and Sundin[7]; it is likely to have been employed in the two other environmental tobacco smoke studies as well because it is the dominant method used to determine formaldehyde concentrations in air. In the chromatropic acid method, formaldehyde forms a stable addition product on sample collection in sodium bisulfite solution. On analysis, the addition product is destroyed yielding free formaldehyde. Any solution which contains free formaldehyde, a formaldehyde addition product, or organic compounds which produce formaldehyde on sulfuric acid destruction will test positive for formaldehyde.

On analysis with the chromatropic acid method, the particulate phase of tobacco smoke has been shown to contain appreciable quantities of formaldehyde.[5] This formaldehyde may be present as free formaldehyde dissolved in liquid water or it may be produced by the destruction of formaldehyde addition products and possibly other organic

Address reprint requests to Thad Godish, PhD, Indoor Air Quality Research Laboratory, Ball State University, Muncie, IN 47306. This paper, submitted to the Journal September 6, 1988, was revised and accepted for publication December 29, 1988.

TABLE 1—Formaldehyde Concentrations in Mainstream, Sidestream, and Environmental Tobacco Smoke

Mainstream			Sidestream		Environmental Tobacco Smoke	Cited Reference
μg/puff	ppm/puff	μg/cig.	μg/cig.	ppm/cig.	μg/cig.*	
1.7	40	17				1
1–9	23–210	10–90				2
7–10	166–234	70–100				3
0.9–11.9	22–279	9.2–118.9	N.D.–34.9			4
(7.4)	(177)	(74.2)	(12.1)			
				15–48		5
					1629	6
					731	7
					740	8
					441	9

*Calculated from data derived from large chamber studies.

compounds in the solid or liquid phase. Because it is incorporated into their molecular structure, addition products are unlikely to yield significant quantities of free formaldehyde under normal circumstances. Formaldehyde dissolved in water can vaporize from the particulate phase, can remain in solution and react with other particulate phase compounds, or can remain in solution as free formaldehyde and then react with body tissues on inhalation. The potential for particulate phase tobacco smoke to produce and release free formaldehyde is unknown, and the health consequences of particulate phase materials are also unknown.

Effect of Tobacco Smoking on Indoor Formaldehyde Levels—Because of uncertainties associated with formaldehyde in the particulate phase of tobacco smoke samples and the lack of specificity of the chromatropic acid method for free formaldehyde, reported ETS studies are of limited usefulness in assessing the effect of tobacco smoking on vapor-phase formaldehyde levels in indoor air. Formaldehyde concentrations in indoor air can, however, be calculated from production rates reported by the Surgeon General[2,3] and by Hoffman.[4] The following "worst case" conditions are assumed: 1) 20 cigarettes/30 minutes smoking rate; 2) production rates of 120 and 34 μg/cigarette for MS and SS; 3) MS formaldehyde not retained by smoker; 4) zero air exchange rate in a 30 m^3 environmental chamber; and 5) no sinks or other sources present. Under these assumptions, 3080 μg formaldehyde would be produced resulting in a concentration of 0.085 ppm. In a 194 m^3 space (typical of a single-wide mobile home) the concentration would be considerably lower (0.012 ppm). Even under these extreme circumstances, the effect of cigarette smoking on formaldehyde levels in indoor spaces would be negligible. This is consistent with the residential measurements of Dally, *et al,*[11] and Ritchie and Lehnen.[12]

Exposures to Smokers—Formaldehyde levels in mainstream smoke appear to be high. When dilution inspiration is taken into consideration, formaldehyde exposures on a per puff basis appear to be in the range of 1.5–19.5 ppm/puff. The cumulative daily exposure duration for a single pack/day consumption would be approximately 6 minutes and 40 seconds; the cumulative daily dose, 188–2382 μg (depending on brand smoked). Exposures at the upper end of the range for a one pack/day consumption would be approximately equivalent to an exposure of 0.25 ppm 22 hours/day in a mobile home environment.

Health Risks—Recent epidemiological studies indicate that formaldehyde exposures associated with residential environments are great enough to cause a variety of acute symptoms.[13–15] Formaldehyde may also cause asthma.[16,17] In addition, the US Environmental Protection Agency (USEPA) has concluded that sufficient evidence exists to implicate formaldehyde as a human carcinogen.[18] USEPA risk assessments predict that individuals with average exposures of 0.16–0.19 ppm 16 hours/day for 10+ years in a mobile home have upperbound risks of $1.5–3.40 \times 10^{-4}$. Mainstream tobacco smoke exposures would be expected to confer their own formaldehyde cancer risk and to increase the risk of upper respiratory system cancer associated with exposures to formaldehyde-contaminated indoor air.

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