Environmental tobacco smoke (ETS) is a term now widely used to refer to the mixture of sidestream smoke and exhaled mainstream smoke that pollutes air in locations where tobacco smoking is taking place. The health effects of active cigarette smoking have been investigated intensely since the mid-1900s. Substantial evidence has been accumulated on the characteristics of tobacco smoke and on the diseases and other adverse health effects caused by active smoking (1). Although research on passive smoking—the inhalation of ETS by nonsmokers—began several decades later, there is now substantial evidence on the health effects of passive smoking as well. ETS exposure adversely affects children and adults, causing both malignant and nonmalignant diseases and other adverse health effects (2-4). Although the adverse effects of passive smoking remain a subject of investigation, expert panels and government agencies have concluded that involuntary smoking is a cause of lung cancer and heart disease in adults as well as other adverse consequences for children. ETS also contains irritant compounds and its presence reduces the acceptability of indoor air quality (2).

Nonsmokers are exposed to ETS in the home, the workplace, and other locales where smoking is permitted. With increasing restriction in the United States on cigarette smoking in public locations and workplaces, the home is becoming an increasingly dominant locale for exposure. Nonetheless, smoking is still permitted in many workplaces. Because workers spend a substantial proportion of their time at work, ETS exposure in the workplace may pose a risk to the health of workers. Surveys of concentrations of ETS markers in workplaces confirm the occurrence of ETS exposure (5,6). However, the distribution of exposures and related health risks has not yet been well characterized in large and representative samples, and consequently the precise magnitude of risk to workers from ETS exposure is uncertain, although there is agreement that ETS exposure is hazardous (2,3).

In 1994, the Occupational Safety and Health Administration (OSHA) published proposed new regulations on indoor air quality (7). Although elements of the regulations addressed indoor air quality issues in the workplace in general, specific components of the regulations addressed ETS, and a risk assessment of ETS exposure in the workplace was included. Since preparation of this risk assessment, substantial additional data on ETS exposures in the workplace have become available. Some of these data were presented at hearings on the regulations held by OSHA from 1994 to 1995; other data have been reported in the peer-reviewed literature.

To assess current understanding of ETS exposure in the workplace, the Johns Hopkins University School of Hygiene and Public Health convened a multidisciplinary workshop on 12-13 September 1997. Participants' areas of expertise included building systems, measurement of ETS, biomarkers of ETS exposure, time-activity patterns, and exposure models. Participants were asked to conduct reviews in their specific areas of expertise relevant to the following general charge: to address key issues related to ETS exposure in the workplace in order to prepare the groundwork for a risk assessment of the hazard that ETS exposure poses to workers. The elements of the charge include the following:

• Review exposure levels in various workplaces, based on compilation of information from the literature.
• Evaluate issues related to the accuracy and sensitivity of various exposure measurements.
• Review and evaluate available mathematical exposure models for ETS.
• Characterize properties of exposure models with respect to validity in predicting ETS exposure levels in various workplaces.
• Evaluate the chemical and physical properties of various smoke constituents to determine the appropriateness of using them as surrogates for measuring ETS exposure.
• Review and analyze public comments on OSHA's section on exposure of the proposed new rule on indoor air quality.

This summary of the discussions during the 2 days of the workshop, the general conclusions reached by participants, and research recommendations. Individual contributions of the workshop participants, which accompany this summary, provide more in-depth coverage of the specific areas.
Assessing the Risks of ETS Exposure

The ultimate goal of any exposure assessment is to provide an understanding of the risks associated with the exposure. For characterizing risks to a population, the full range of exposure is important; measures of central tendency provide only an indication of overall population exposure and the upper end of the exposure distribution must be described, particularly at levels that may convey unacceptable risks (8). Workshop participants reviewed the evidence on ETS exposure in the context of potential uses of this evidence in risk assessment. OSHA faces the task of determining if ETS exposure in the workplace is a significant hazard to workers and also of evaluating the consequences of control measures. Understanding ETS exposure in the workplace and its determinants is essential to accomplish both these tasks.

Workshop participants recognize that ETS exposure in the workplace has declined sharply over the last decade as control measures have been implemented, including restrictions on smoking or outright bans on smoking in the workplace. However, the absolute number of exposed workers remains large. Presentations at the workshop on the most recent large-scale workplace surveys by Jenkins (9) and Hammond (10) confirmed the impact of nonsmoking policies on ETS exposure. Nonetheless, some jobs and industries continue to involve exposure to ETS, for example, the hospitality industry, and only limited information is available for certain categories of workers who may still be exposed to ETS, including those working in small workplaces and blue-collar workers. The 16-City Study conducted in 1994 by Jenkins and colleagues (11) from Oak Ridge National Laboratory showed that some workers continue to have substantial exposures to ETS and indicated variation in levels of exposure among different worker groups.

Overall Conclusions

Participants concluded that substantial evidence was now available on ETS exposures of workers using both the direct and indirect approaches to exposure assessment, and that these data could be used to project the distribution of exposures to ETS in the nation’s workplaces. The direct approach determines exposure by actual measurement, through either personal or area monitoring. Biomarker data also provide direct assessment of ETS exposure. The indirect approach, which does not involve directly placing a monitor on a person, relies on mathematical modeling that simulates exposure distributions using a) empirical distributions of exposure in specific microenvironments, b) output from microenvironmental models, and c) human activity pattern data (12). The microenvironmental model is central to this approach (13). Microenvironments are locations with homogeneous concentrations of the contaminant of interest during the time of occupancy. In the indirect approach, information on concentrations in microenvironments is used along with time spent in the microenvironments to estimate personal exposure.

Combining data from both direct and indirect approaches, the 16-City Study conducted by Jenkins and colleagues (11) offers information on exposures of a large number of nonsmokers to various markers of ETS in indoor air, as well as data on levels of cotinine, a biomarker. Within the specific categories of workers, the data become sparse but some insight can be gained concerning the shape of the exposure distributions. The 25-Site Work Well Study of Hammond and colleagues (6) provides additional data; a number of smaller studies are also available. The workshop participants concluded that nicotine, a semivolatile organic compound, is a good tracer for particulate matter from ETS and can be used to measure exposure to ETS as a complex mixture. Cotinine, considered to be an accurate indicator of nicotine exposure (14), has been measured in participants in the National Health and Nutrition Examination Survey (NHANES) III (15); these measurements provide nationally representative information on ETS exposure. Two large time-activity surveys—the California study, which characterized activity patterns for a sample of Californians from 1988 to 1990 (16), and the national study conducted by the U.S. Environmental Protection Agency (U.S. EPA) from 1990 to 1992 (17)—provide data on the prevalence of workplace exposure to ETS, and the U.S. EPA study provides further detail on the length of exposure and the microenvironments involved.

Mass balance models can be used to predict ETS concentrations in microenvironments (18). These mathematical models use the mass-balance equation, based on the physical law of conservation of mass, to calculate the concentrations in indoor settings from a knowledge of the strength of the source of the contaminant, the volume of the indoor location into which the contaminant is emitted and diluted, the effective air exchange rate (quantity of replacement air infiltrating per unit time expressed as air changes per hour), and the rate of contaminant loss from paths other than ventilation, e.g., deposition or chemical reactions. These models predict ETS concentration by combining estimates of the rate of generation of ETS from smoking and the rate of removal by air cleaning and air exchange (18). Recent models have been defined and their performance validated in selected real-world exposure circumstances (12,18,19).

The workshop participants agreed that the exposure and time–activity databases and the mass balance models could be used to estimate the distribution of ETS exposure for workers in the United States. Although there are gaps and limitations in the available evidence, ETS exposures in the workplace can now be estimated with far greater certainty than when the initial OSHA risk assessment was prepared approximately 5 years ago. The participants appraised the available evidence and suggested an approach for describing the distribution of ETS exposures, as follows:

Data obtained by the direct approach in the 16-City Study of Jenkins and colleagues (11) are substantial additions to previous evidence. The study provides data on a suite of ETS markers for recent exposure conditions. The results were consistent with the 25-Site Work Well Study of Hammond and colleagues (6). It is uncertain whether either data set is representative of all U.S. workers, and by the nature of the approaches used to select subjects, both data sets may tend to underrepresent the higher end of the exposure distribution. Both studies, however, offer reasonably robust central estimates of exposure, both overall and for broad categories of workers.

Cotinine was judged to be a valid estimator of exposure of nonsmokers to nicotine. Dietary sources of nicotine are minor and few individuals would ingest sufficient nicotine-containing foods and beverages to compromise the validity of cotinine as an estimator of exposure to nicotine in ETS (14,20). The NHANES III data can be used to estimate nicotine exposure by applying an empirically derived relationship between nicotine intake and cotinine level (15). Data reviewed at the workshop suggested that this relationship was relatively robust under current smoking conditions. Therefore, NHANES III and possibly
other data sets can be used as additional bases for characterizing the national distribution of ETS exposures in the workplace. Available national data on cotinine levels, however, are compromised by the relatively small sample size. These data cannot be expected to provide a sharp picture of the upper end of the exposure distribution.

The time–activity surveys conducted in California and nationally draw strength from their large sizes and representative sampling designs. There is the potential to characterize exposure patterns for specific worker groups and, in the national data, exposure duration can be quantified. Both surveys are potentially limited by the need to rely on participant reports of awareness of ETS exposure. It is possible that such reports vary with education, job type, or other factors. The sampling designs of the surveys, based on random digit dialing, may tend to exclude workers at the upper end of the distribution, if such workers are less likely to have telephones or to participate in telephone surveys.

Models for predicting ETS concentrations in microenvironments were further refined during the 1990s. Ott (18), using the mass balance principle, have developed models incorporating the real-world time dependence of ETS concentrations on smoking patterns and derived parameters for these models under real-world conditions. Model performance was assessed for specific microenvironments, including a tavern, an automobile, and an airport smoking lounge. As reviewed by Ott (18), model predictions are in good agreement with the actual data. Models can be extended to additional microenvironments, using either assumptions about effective air exchange rates or actual measured values.

Workshop participants proposed an overall strategy for estimating the distribution of workplace exposures to ETS (Figure 1). The suggested approach involves using the parallel and complementary data sets on exposure obtained by the direct method and using the biomarker data as an additional but distinct approach to estimating national exposure. The principal data sets providing information obtained by the direct method include the Work Well (6) and Oak Ridge studies (11). Given the uncertain representation of the nation’s workers by these data sets, the NHANES III data (15) on cotinine levels may provide the most valid national exposure estimates. Within any particular category of workers, information will be quite limited, although for broad classes, e.g., white-collar office workers, the data may be sufficient to provide a picture of the distribution, including high-end distribution.

The time–activity survey data provide additional information on the prevalence of exposure in the early 1990s. By pairing direct exposure data with time–activity information, it may be possible to further estimate exposures for broad classes of workers. Time–activity data provide information on prevalence of exposure and the directly measured exposures from the Oak Ridge and Work Well studies can be used as estimates of the likely exposures for specific worker groups.

The mass balance-based models can be used to explore exposure under specific circumstances, such as that of the exposure of a nonsmoker who shares an office with a smoker, or levels of exposure during meetings in locations where smoking is permitted. The models also are useful tools for exploring the protection afforded by various control strategies, including ventilation and air cleaning. With additional data collection on air exchange rates in more complex office environments, the value of these models for assessing control strategies could be enhanced.

Research Recommendations

Evidence on workplace exposure to ETS continues to mount, but there is still need for research. Workshop participants agreed on the following general recommendations for research on ETS exposure in the United States:

- Conduct larger surveys with the following characteristics:
  - assessing representation of all U.S. workers
  - employing the microenvironment approach
  - characterizing high-end risk
  - paralleling direct approaches with biomarkers
- Ensure ongoing monitoring through national surveys to enhance information on occupations and exposures.
- Conduct a detailed study of ETS composition and relationship of composition to various markers, with links to doses, for a better understanding of the complex mixture of ETS.
- Investigate the gaps in the research, including high-end risk in the hospitality industry, small workplaces, and blue-collar occupations.
- Develop models. Validate the models in various workplaces, and develop a time–activity model.
- Identify and respond to research needs regarding biomarkers, including further characterization of cotinine increments from workplace exposures.

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