Personal monitoring is the most accurate approach for determining direct exposure to airborne environmental contaminants because it incorporates complex human activity patterns into the exposure assessment. Although a number of studies have sought to determine occupational exposure to environmental tobacco smoke (ETS) through personal monitoring measurements in the United States (1–5), the scope of those studies has been limited, either because of the narrow geographic distribution of the study subject base or the relatively short duration (small fraction of a normal work shift) over which the samples were acquired. This article presents the overall results of two personal exposure assessment studies conducted by the author to determine ETS in occupational settings, one across broad occupational categories for a geographically dispersed subject population (6), and another in a more restricted population of what are believed to be more highly exposed workers, restaurant and tavern servers (7).

**Experimental**

**Study 1—The 16-Cities Study**

Experimental protocols for this study are described in detail elsewhere (6). Briefly, approximately 100 nonsmoking subjects were recruited, mostly by random telephoning or marketing research databases, from each of 16 urban areas scattered through the four primary census regions of the 48 contiguous United States. Sampling equipment is described in detail in Ogden et al. (8). Briefly, it consisted of a sound insulated sampling pump (approximately 8.5 × 6.5 × 4.25, weighing approximately 3.5 lb) attached to a clip-on sampling head. The pump and supporting electronics were enclosed in a plastic housing with shoulder straps, and participants were instructed to wear the pump with the strap over the right shoulder and the pump resting on the left hip. The sampling head contained both particle and vapor phase ETS marker collection devices, and was designed to be worn in a person’s breathing zone, i.e., clipped onto a shirt collar, lapel, or pump shoulder strap, with the openings to the collection points on the sampling head within 25 cm of the subject’s mouth.

Each subject wore one sampling system while at their workplace (approximately 8–9 hr) and a second collection system while away from work. The away-from-work designation included home, commuting, shopping, dining, etc. Both particulate and vapor phase samples were acquired, as well as beginning and ending saliva samples for cotinine analysis. The latter were employed to confirm the nonsmoking status of the subjects. Vapor phase samples were collected on XAD-4 cartridges (SKC, Inc., Eighty-Four, PA) at a rate of approximately 0.7 liters/min. Constituents determined in the vapor samples included nicotine and 3-ethylpyridine (3-EP). Nicotine is an alkaloid, relatively tobacco specific, that is present almost exclusively in the vapor phase of ETS. 3-EP is a pyrolys product of nicotine and has been used as a marker of ETS vapor phase in several studies because it is less absorptive on surfaces than nicotine.

Particulate phase samples were collected on fluoropore membrane filters at a flow rate of approximately 1.7 liters/min and analyzed for respirable suspended particulate matter (RSP), ultraviolet absorbing and fluorescing particulate matter (UVPM and FPM) (9,10) and solanesol. RSP is that particulate phase material that is smaller than 3.5 μm mass median diameter. UVPM and FPM are general measures of the total combustion-derived particulate matter. In environments typically encountered, which include indoor environments into which outdoor particulate has penetrated, UVPM and FPM tend to overestimate the level of...
ETS-derived particulate matter. Solanesol is a high molecular weight terpene—tobacco specific—found only in the particle phase, and as such can be a useful specific marker for ETS-derived particulate matter. Heavner et al. (11) have discussed the use of these particulate phase markers in greater detail. Sol–particulate matter (PM), which is the solanesol level converted to a tobacco smoke RSP equivalent, is reported in this manuscript. (Note that estimated mean 8-hr limits of detection for 3-EP, nicotine, RSP, FPM, and Sol-PM were 0.016, 0.039, 23.041, and 0.28 mg/m³, respectively.)

To be included in the study, subjects had to be at least 18 years of age, non-smokers (and nonusers of other tobacco products or nicotine-containing smoking cessation aids) for at least 6 months prior to the study and work at least 35 hr/week outside the home on a regular (approximately 8 AM–5 PM) shift. Subjects who were members of selected occupational or public interest groups were excluded on the basis of perceived potential bias (lawyers, media, anti- or protoobacco groups) or on-the-job safety considerations. In some cases subjects were excluded if they worked in environments likely to have large airborne volatile organic contamination, such as dry-cleaning facilities. The fundamental study design was a 2×2 cell structure (unequally populated), with smoking and nonsmoking homes and workplaces. Demographic and lifestyle information was collected from the subjects from questionnaires administered during their first and last visits to the test coordination site. In addition, subjects completed diaries of their activities and potential sources of indoor air pollution during the time that air samples were being collected. Subjects received gratuities for their participation, and informed consent was obtained from all subjects.

The group selected for the study included 85 restaurant servers and 80 bartenders. Subjects wore a single sampling system during one work shift (minimum of 4 hr to a maximum of 9 hr). The sampling system was almost identical to that used in the 16-Cities Study, except the subjects wore the sampling pump housed in a lumbar-support fanny pack. Housing the sampling pump system in a fanny pack stabilized the pump on the subject, preventing it from moving while the subject served customers. Many subjects indicated that because the sampling system was mounted at the small of their back, it was not particularly uncomfortable. The sampling head was supported by a lanyard around the subject’s neck to maintain the location of the head in the subject’s breathing zone. Additionally, a small aluminum shroud was placed over the clear plastic filter holder to minimize postcollection photoinitiated degradation of UVPM, FPM, and solanesol. Area samples were also collected in many of the restaurants in which subjects were employed. Sampling systems identical to those used in the personal monitoring study were placed in the approximate location of the subjects’ work areas or at the boundary of the smoking and nonsmoking sections. For both area and personal measurements, particulate and vapor phase samples were acquired, as well as a beginning and ending saliva samples from each subject for cotinine analysis. As in the 16-Cities Study, particle and vapor-phase samples were collected and analyzed for RSP, UVPM and FPM, solanesol, nicotine, and 3-EP. Ventilation and air exchange measurements were not performed in the facilities studied.

Results

16-Cities Study

Subjects employed in workplaces where smoking was permitted in some form and where they actually observed smoking were exposed to substantially greater levels of ETS than those subjects working in non-smoking workplaces where the subjects observed no smoking. In Table 1 are compared approximately 8-hr time-weighted average (TWA) levels for workplaces designated smoking and nonsmoking in the study. To be included in this compilation, subjects had to report smoking observations in congruence with the self-reported status of their workplace environment. (To qualify as working in a smoking environment, subjects had to report that employees or guests routinely smoked within 100 ft of their

| Smoking status of workplace | Number of subjects | Summary statistic | Airborne concentration of ETS components, µg/m³ |
|-----------------------------|--------------------|------------------|-----------------------------------------------|
|                             |                    |                  | 3-EP  | Nicotine | RSP  | UVPM | FPM  | Solanesol |
| Nonsmoking                  | 867                | Median           | 0.027 | 0.030    | 12.8 | 0.838 | 0.452 | 0.002*   |
|                             |                    | 80th percentile  | 0.081 | 0.098    | 23.8 | 1.65  | 1.05  | 0.002*   |
|                             |                    | 95th percentile  | 0.277 | 0.274    | 48.9 | 3.64  | 3.25  | 0.018    |
|                             |                    | Interdecile range | 0.147 | 0.146    | 33.5 | 2.41  | 1.75  | 0.000    |
| Smoking                     | 331                | Median           | 0.336 | 0.558    | 30.7 | 6.39  | 4.79  | 0.021    |
|                             |                    | Mean             | 0.994 | 2.417    | 49.6 | 19.7  | 18.3  | 0.343    |
|                             |                    | 80th percentile  | 1.233 | 3.602    | 62.8 | 27.4  | 23.3  | 0.328    |
|                             |                    | 95th percentile  | 3.690 | 11.937   | 145.3| 81.1  | 76.8  | 1.64     |
|                             |                    | Interdecile range | 2.524 | 5.934    | 92.2 | 47.8  | 44.1  | 0.85     |

*To qualify as working in a smoking environment, subjects had to report that employees or guests routinely smoked within 100 ft of the subjects’ personal workplaces. This included a number of workplaces where smoking was restricted to designated areas. Actual value was nondetectable; one-half the limit of detection, in micrograms; an average flow rate and an 8-hr time were used. Interdecile range describes the difference between the 90th and the 10th percentile values, indicating spread of the data. From Jenkins et al. (6).
personal workplace. This included a number of workplaces where smoking was restricted to designated areas.) Median nicotine levels were approximately a factor of 19 greater in the smoking workplaces. RSP was approximately a factor of 2 greater, and FPM, an indicator of combustion-derived particulates, was a factor of 10 greater. The differences between the levels for the smoking and nonsmoking workplaces are statistically significant (p < 0.0001 for all ETS constituents presented in Table 1). Because the distributions of the ETS components tend to be highly skewed, all statistical tests of significance reported in this paper were performed using nonparametric tests (12). Levels encountered by the most highly exposed subjects (95th percentile) in nonsmoking workplaces (no observation of tobacco products being smoked) were approximately 50 to 100% of median levels in smoking workplaces. This suggests that not all individuals exposed to ETS in workplaces are aware of the exposure.

The ETS levels encountered by subjects working in both smoking and nonsmoking workplaces based on the smoking restrictions and conditions in the facility are summarized in Table 2. Approximately 180 subjects worked in facilities where smoking was restricted to designated areas. For approximately 70% of those participants, no smoking was observed in the workplace, and the levels of ETS encountered, in terms of 8-hr TWA concentrations, were comparable to or just slightly higher than those encountered by subjects working where smoking was completely banned. The remaining 30% of the subjects, those working in facilities with designated smoking areas who observed smoking (by sight or smell), experienced ETS levels several times greater than those working in facilities that banned smoking. However, the 80th percentile levels for nicotine and 3-EP were less than 0.5 μg/m³. One hundred thirty-four subjects worked in facilities where smoking was not restricted and reported smoking. The levels encountered by these subjects were considerably higher compared to those for subjects in other workplaces where smoking was restricted (e.g., median 8-hr TWA nicotine levels for this group were 1.03 μg/m³ compared to 0.14 μg/m³ in workplaces where smoking was restricted to designated areas but where subjects observed smoking). This difference is statistically significant, p < 0.0001.

Not surprisingly, subjects in different occupational categories were exposed to differing levels of ETS constituents in the workplace. For example, in Table 3 are compiled data from subjects in workplaces where smoking was permitted in some form and where smoking was observed. Many of the workplaces had smoking restricted to designated areas. On the basis of median ETS constituent levels, service workers encountered the highest levels. The median level of nicotine for the service category is statistically higher than the median levels of all other categories except skilled workers (p < 0.05 for all comparisons). The median level of sol-PM for the service category is statistically higher than the median levels for all other categories except skilled and unskilled workers (p < 0.05 for all comparisons).

### Table 2: Eight-hour time-weighted average ETS constituent concentrations in workplaces. Impact of smoking restrictions.

| Restriction/condition | Summary statistic | Concentration, μg/m³ | 3-EP | Nicotine | RSP | FPM | Sol-PM |
|-----------------------|-------------------|----------------------|------|---------|-----|-----|-------|
| Total ban n = 703     | Median            | 0.022                | 0.029| 12.5    | 0.42| 0.00| 0.00  |
|                       | Mean              | 0.079                | 0.086| 17.3    | 1.96| 0.31| 0.00  |
|                       | 80th percentile   | 0.070                | 0.083| 23.0    | 0.96| 0.00| 0.00  |
|                       | 95th percentile   | 0.263                | 0.205| 47.1    | 2.26| 0.31| 0.00  |
|                       | Interdecile range*| 0.123                | 0.128| 32.1    | 1.49| 0.00| 0.00  |
| Ban, but observed smoking n = 125 | Median            | 0.043                | 0.066| 15.1    | 0.49| 0.00| 0.00  |
|                       | Mean              | 0.122                | 0.208| 18.6    | 2.34| 1.46| 0.00  |
|                       | 80th percentile   | 0.122                | 0.136| 26.2    | 2.08| 0.00| 0.00  |
|                       | 95th percentile   | 0.411                | 0.857| 50.8    | 5.24| 1.78| 0.00  |
|                       | Interdecile range*| 0.233                | 0.306| 40.9    | 2.91| 0.73| 0.00  |
| Designated areas, no observed smoking n = 130 | Median            | 0.049                | 0.042| 11.2    | 0.67| 0.00| 0.00  |
|                       | Mean              | 0.111                | 0.178| 17.0    | 1.85| 0.57| 0.00  |
|                       | 80th percentile   | 0.126                | 0.120| 23.8    | 1.63| 0.00| 0.00  |
|                       | 95th percentile   | 0.342                | 0.352| 58.4    | 4.82| 1.67| 0.00  |
|                       | Interdecile range*| 0.233                | 0.241| 38.9    | 3.13| 0.50| 0.00  |
| Designated areas but observed smoking n = 52 | Median            | 0.136                | 0.135| 14.2    | 1.72| 0.00| 0.00  |
|                       | Mean              | 0.509                | 1.058| 29.5    | 9.42| 6.96| 0.00  |
|                       | 80th percentile   | 0.370                | 0.479| 31.3    | 5.17| 1.28| 0.00  |
|                       | 95th percentile   | 1.287                | 2.214| 62.3    | 21.07| 19.60| 0.00  |
|                       | Interdecile range*| 0.780                | 1.439| 41.1    | 10.50| 9.88| 0.00  |
| Smoking workplace, no restrictions but no observed smoking n = 24 | Median            | 0.069                | 0.145| 19.1    | 1.81| 0.00| 0.00  |
|                       | Mean              | 0.187                | 0.302| 32.6    | 3.19| 1.14| 0.00  |
|                       | 80th percentile   | 0.413                | 0.501| 38.9    | 3.44| 0.57| 0.00  |
|                       | 95th percentile   | 0.507                | 0.571| 94.5    | 9.67| 1.76| 0.00  |
|                       | Interdecile range*| 0.464                | 0.542| 56.8    | 4.89| 1.09| 0.00  |
| Smoking workplace, no restrictions, observed smoking n = 134 | Median            | 0.514                | 1.033| 40.4    | 7.72| 0.96| 0.00  |
|                       | Mean              | 1.462                | 3.402| 62.0    | 25.48| 16.37| 0.00  |
|                       | 80th percentile   | 1.784                | 4.637| 74.8    | 27.50| 14.43| 0.00  |
|                       | 95th percentile   | 6.057                | 14.99| 181.3   | 102.00| 87.91| 0.00  |
|                       | Interdecile range*| 3.727                | 9.317| 95.2    | 84.38| 37.56| 0.00  |

*Interdecile range describes the difference between the 90th and the 10th percentile values, indicating the spread of the data. Data from Jenkins et al. (6).
Table 3. Eight-hour time-weighted average levels of ETS constituents to which subjects working in smoking facilities were exposed.

| Occupational classification | Summary statistic | Concentration, µg/m³ |
|----------------------------|-------------------|---------------------|
|                            | 3-EP              | Nicotine            | RSP | UPPM | FFPM | Sol-PM |
| Clerical                   |                   |                     |     |      |      |        |
| n = 115                    | 0.25              | 0.31                | 25.0| 4.3  | 3.6  | 0.45   |
|                           | 1.07              | 2.25                | 48.5| 19.1 | 18.8 | 12.67  |
|                           | 1.04              | 2.38                | 46.4| 19.7 | 17.0 | 8.02   |
|                           | 4.65              | 10.96               | 121.3| 80.6 | 78.8 | 52.79  |
|                           | 2.58              | 4.96                | 86.1| 17.0 | 31.3 | 19.69  |
| Managerial                |                   |                     |     |      |      |        |
| n = 47                     | 0.33              | 0.57                | 29.5| 5.7  | 4.4  | 0.35   |
|                           | 0.95              | 2.47                | 40.1| 16.3 | 14.6 | 6.65   |
|                           | 1.21              | 3.98                | 63.6| 28.7 | 24.0 | 3.99   |
|                           | 3.72              | 11.66               | 99.5| 46.9 | 36.7 | 25.32  |
|                             | 2.20              | 5.88                | 75.8| 37.9 | 30.1 | 14.64  |
| Professional               |                   |                     |     |      |      |        |
| n = 19                     | 0.22              | 0.17                | 19.3| 3.6  | 2.6  | 0.00   |
|                           | 0.59              | 1.40                | 27.8| 8.3  | 7.5  | 3.91   |
|                           | 0.56              | 1.23                | 44.1| 7.8  | 8.0  | 2.14   |
|                           | 1.28              | 4.74                | 74.0| 28.7 | 25.6 | 16.31  |
|                           | 0.92              | 2.94                | 56.2| 17.7 | 19.4 | 10.51  |
| Sales                      |                   |                     |     |      |      |        |
| n = 47                     | 0.37              | 0.44                | 30.7| 6.4  | 3.8  | 0.51   |
|                           | 0.75              | 1.78                | 44.2| 20.2 | 18.3 | 11.05  |
|                           | 1.01              | 2.95                | 56.4| 27.8 | 23.2 | 18.83  |
|                           | 2.45              | 6.53                | 132.6| 94.2 | 77.2 | 56.81  |
|                             | 1.85              | 5.94                | 93.3| 57.0 | 57.7 | 27.02  |
| Semiprofessional           |                   |                     |     |      |      |        |
| n = 12                     | 0.08              | 0.47                | 12.0| 2.0  | 1.7  | 0.34   |
|                           | 0.34              | 0.79                | 21.6| 17.8 | 17.8 | 7.80   |
|                           | 0.44              | 1.03                | 26.9| 14.9 | 12.7 | 11.9   |
|                           | 1.19              | 2.75                | 221.1|103.4 |87.0 |41.03   |
|                             | 0.65              | 2.23                | 93.2| 64.8 | 62.7 | 20.20  |
| Services                   |                   |                     |     |      |      |        |
| n = 48                     | 0.61              | 1.28                | 45.1| 14.6 | 11.6 | 3.11   |
|                           | 1.41              | 3.97                | 64.0| 29.9 | 27.9 | 18.73  |
|                           | 2.26              | 4.79                | 79.6| 44.7 | 41.7 | 27.98  |
|                           | 4.57              | 14.45               | 209.1|96.3  |93.8 |97.83   |
|                             | 3.15              | 7.59                | 107.7|64.5  |60.5 |44.02   |
| Skilled workers            |                   |                     |     |      |      |        |
| n = 22                     | 0.33              | 0.38                | 39.7| 5.6  | 4.2  | 0.00   |
|                           | 0.68              | 2.07                | 75.2| 17.3 | 14.6 | 7.76   |
|                           | 1.12              | 2.94                | 68.4| 25.6 | 21.2 | 13.81  |
|                           | 1.77              | 9.09                | 189.1|67.9  |66.3 |32.31   |
|                             | 1.50              | 4.96                | 133.7|38.9  |33.1 |22.52   |
| Unskilled                 |                   |                     |     |      |      |        |
| n = 16                     | 0.40              | 0.79                | 30.7| 10.4 | 8.4  | 1.63   |
|                           | 1.31              | 3.05                | 45.1| 19.9 | 17.9 | 11.43  |
|                           | 1.10              | 3.62                | 60.2| 29.5 | 16.6 | 15.38  |
|                           | 4.60              | 12.14               | 102.5|66.9  |67.4 |55.21   |
|                             | 2.64              | 10.37               | 65.2| 60.0 | 59.2 | 35.61  |

*Interdecile range describes the difference between the 90th and the 10th percentile values, indicating the spread of the data. Data from Jenkins et al. (6).

Table 4. ETS constituent levels to which all restaurant wait staff and bartenders were exposed.*

| Subject category | Summary statistic | Concentration, µg/m³ |
|------------------|-------------------|---------------------|
|                  | 3-EP              | Nicotine            | RSP | UPPM | FFPM | Sol-PM |
| Servers          |                   |                     |     |      |      |        |
| n = 82           | 0.60              | 1.22                | 81  | 20   | 7.6  |
|                  | 1.75              | 5.08                | 109 | 37   | 26   |
|                  | 2.62              | 6.12                | 175 | 56   | 37   |
|                  | 6.68              | 28.9                | 386 | 127  | 124  |
|                  | 5.10              | 18.1                | 208 | 89   | 80   |
| Bartenders       |                   |                     |     |      |      |        |
| n = 80           | 1.17              | 4.45                | 112 | 41   | 27   |
|                  | 3.30              | 14.1                | 151 | 98   | 77   |
|                  | 5.96              | 27.1                | 239 | 159  | 141  |
|                  | 10.33             | 43.6                | 428 | 370  | 350  |
|                  | 7.96              | 35.1                | 338 | 314  | 222  |

*Oak Ridge National Laboratory restaurant servers/bartenders study; 4- to 9-hr personal monitoring samples. Interdecile range describes the difference between the 90th and the 10th percentile values, indicating the spread of the data. Data from Jenkins et al. (7).
affected by a few very high values. In such cases, median levels may be more descriptive of the overall distributions. In the cases of the subjects in Study 2, median nicotine levels were approximately one-third to one-fourth of their reported means.

**Area Sampling versus Personal Monitoring**

In the study of personal exposure of restaurant servers and bartenders described previously (6), area samplers were placed in many of the facilities where the subjects were employed during the period in which they worked. Summary statistical data on the comparison of area and personal monitoring data are presented in Table 6. On the basis of statistical groupings, the differences between area and personal monitoring levels encountered are not great. For example, median area levels of FPM for bartenders was 35 pg/m³ compared to 41 pg/m³ for the personal samples. Median area 3-EP levels for restaurant wait staff were 0.52 µg/m³ compared to 0.60 pg/m³ for personal levels. No statistically significant differences were found between area and subject medians (server or bartender) for any of the constituents given in Table 6. Analysis of the data reported in Table 6 suggests that area measurements are good surrogates for personal monitoring measurements in this type of environment. Although this may be true for groups of subjects, graphical examination of the data indicates that on an individual basis area samples can only estimate

### Table 5. Median workplace exposure levels. Restaurant/tavern servers versus 16-Cities Study subjects.

| Subject category | Average shift | Median exposures, µg/hr/m³ |
|------------------|---------------|----------------------------|
|                  | n | Length, hr | Nicotine | RSP | FPM | Sol-PM |
| Servers          |   |            |          |     |     |       |
| Bartender        | 80 | 5.8        | 5.8      | 22.4| 575 | 208    |
| 16-Cities Study subjects | 134 | 8.2        | 3.9      | 8.5 | 306 | 59     |

*Only subjects employed in workplaces where smoking was not restricted and who observed smoking in their workplace were included in this compilation. Data from Jenkins et al. (6,7).*

### Table 6. Comparison of ETS constituent levels. Area versus personal monitoring samples.

| Subject category | Summary statistic | 3-EP | Nicotine | RSP | FPM | Sol-PM |
|------------------|-------------------|------|----------|-----|-----|--------|
|                  |                   | Area samples | Sample | Area samples | Sample | Area samples | Sample | Area samples | Sample | Area samples | Sample |
| Server           |                   | Subject | Median  | 0.60 | 0.52 | 1.22   | 0.76   | 81     | 58   | 7     | 8      | 20     | 16     |
| Bartender        |                   | Subject | Median  | 1.17 | 1.35 | 1.41   | 1.44   | 151    | 136  | 100   | 96    | 98     | 91     |
|                  |                   | Subject | 90th percentile | 7.3 | 6.0 | 27.1   | 29.6   | 239    | 245  | 168   | 175   | 158    | 157    |
|                  |                   | Subject | 95th percentile | 10.4 | 7.6 | 43.6   | 49.6   | 428    | 399  | 377   | 374   | 370    | 361    |
|                  | Interdecile range# | 8.0 | 5.3 | 8.9 | 5.3 | 35.1   | 38.4   | 338    | 310  | 315   | 271   | 314    | 246    |

*Oak Ridge National Laboratory restaurant servers/bartenders study. #Interdecile range describes the difference between the 90th and the 10th percentile values, indicating the spread of the data. Data from Jenkins et al. (7).*
personal exposure to within a factor of 5 to 10. For example, Figures 2 and 3 graphically compare area and personal ETS levels of FPM and nicotine, respectively, for all subjects in the restaurant/tavern servers study described previously for which direct comparisons could be made. There is general correlation among the data (coefficients of determination, \( R^2 \), were 0.732 and 0.488, respectively), but the variation of personal levels, for example, at a given area concentration is considerable. This likely is due to individual activity patterns of the subjects who occupy a variety of microenvironments over the course of their work shifts. Area samples are more likely to be useful for assessing occupational exposures of individuals who are relatively stationary within their workspaces.

**Discussion**

The levels of ETS constituents to which the general workplace populations in the 16-Cities Study were exposed were lower than or comparable to those described in previous studies (2–5, 15). This may be due to one or more of several factors, including reduction of workplace smoking even in those facilities where smoking is not restricted, and differences in experimental design among the studies (greater emphasis on random subject and workplace selection in the 16-Cities Study; emphasis on subjects working regular 8-hr day shifts, which tends to produce more of a white-collar subject population). Also, lower TWA levels may reflect the degree of control that individual subjects actually have over their workplace exposures to ETS. Exposures for the 16-Cities Study subjects working in unrestricted workplaces were not particularly high; the 90th percentile levels for nicotine were less than or comparable to 15 \( \mu \)g/m\(^3\). This is considerably less than the Occupational Safety and Health Administration’s (OSHA) 1994 estimate of 50 to 100 \( \mu \)g/m\(^3\) for the most highly exposed U.S. workers (16). The OSHA estimates are comparable to those encountered by the most highly exposed bartenders working in single-room facilities (Figure 1, study 2).

Reface and Lowery (17), in a risk assessment of workplace ETS exposure, estimated that in the 1980s, exposure to nicotine from ETS of the typical non-smoker was approximately 143 \( \mu \)g/day. Exposure of the most highly exposed non-smokers was estimated to be a factor of 10 greater, or 1430 \( \mu \)g/day. Although the authors indicated they expected these levels of exposure to decrease in the 1990s, these estimates factored heavily into OSHA’s risk assessment of ETS exposure in the workplace (16). If we can assume that a typical worker engages in light activity for half the day and in sedentary activity the other half of the work day, then a TWA breathing rate of 0.8 m\(^3\)/hr (18) can be used to compute the potential inhaled quantities of ETS constituents. Applying this estimated breathing rate to the exposures in Table 5, the median potential inhaled quantity of nicotine for restaurant wait staff, bartenders, and U.S. subjects working in unrestricted smoking workplaces is 4.5, 18, and 6.8 \( \mu \)g/day, respectively. These doses are a small fraction of those estimated by Reface and Lowery (17).

![Figure 2](image2.png)  
**Figure 2.** Comparison of personal monitoring and area ETS concentration levels of FPM among restaurant servers and bartenders. Data from Jenkins et al. (6).

![Figure 3](image3.png)  
**Figure 3.** Comparison of personal monitoring and area ETS concentration levels of nicotine among restaurant servers and bartenders. Data from Jenkins et al. (6).
for the typical nonsmoker. The comparison suggests that either the 143 μg/day estimate is not relevant for modern exposures (doses) or that exposures outside the workplace (presumably a voluntary exposure) are vastly greater than workplace exposures. However, this latter conjecture is not supported by the overall data from the 16-Cities Study (6).

The use of various ETS markers has been examined as a result of these investigations (19). Although earlier studies may have relied on RSP as a marker for ETS, it is clear that in many or most environments, a relatively small fraction of RSP is derived from ETS. There clearly are too many other sources of this common descriptor for all particles of a size of 4 μm mass median diameter. In addition to nicotine, 3-EP has been suggested as a good gas-phase marker. UVPM and FPM are indicators of combustion-derived particulate matter but probably overreport particulate matter derived exclusively from tobacco combustion (9,10). If cigarette smoking is the predominant source of combustion-derived particulates in the indoor environment, then these may be useful indicators of ETS levels. However, there may be a large number of combustion sources present, including fireplaces and wood stoves, candles, incense, cooking, and outdoor sources (e.g., diesel particulates) that have penetrated the indoor environment. Solanesol has also been proposed as a marker of ETS particulates (11). Solanesol has the distinct advantage of being specific to solanaceous plants such as tobacco, tomatoes, green peppers, and eggplant. In situations in which intensive cooking of vegetables is not likely to occur, solanesol represents a potentially excellent particulate phase marker. However, its quantities in all but the most heavily ETS-polluted environments are relatively low, and its analysis not straightforward. Even in many smoking workplaces in the 16-Cities Study, its level was undetectable.

The data from the 16-Cities Study workplace samples suggest that there are reasonable correlations among potential ETS markers as long as the data are acquired in environments where smoking results in significant ETS levels. For example, comparison (log-log scale) between FPM and nicotine levels in smoking workplaces (without restrictions) is portrayed in Figure 4. The $R^2$ value is 0.701, which indicates a significant linear relationship. However, it is clear that the level of one component cannot be used to estimate another to more than an order of magnitude. This is also the case with FPM and 3-EP (Figure 5) ($R^2 = 0.555$), the latter being a gas-phase marker less inclined to interact with surfaces in the indoor environment. The range over which FPM varies at a given concentration of nicotine or 3-EP is approximately a factor of 10.

One observation is indicative of the complexity of attempting to describe ETS exposures across working environments based on a single marker. On the basis of the data presented in Table 5, the restaurant servers received proportionately greater exposures to the particulate phase ETS markers FPM and Sol-PM than to the vapor-phase markers compared to the more broadly based occupational groupings. The
extent to which other sources in a restaurant environment contribute to levels of these markers is not clear. In addition, presampling light-induced transformation of PPM and solanesol in well-lighted workplaces (relative to restaurants and bars) may be a factor. Surveys in restaurants where smoking is banned completely may need to be conducted to sort out this apparent anomaly. Overall, these comparisons indicate the necessity for direct measurement of components in the indoor environment if accurate estimates of their levels are required.

Conclusions

Workers in facilities where smoking is permitted are exposed to 10 to 20 times more ETS than those working where smoking is banned. However, in general the exposures are much lower than those estimated in earlier studies. For example, the daily intake of nicotine is 20% or less of the level estimated for exposures in the 1980s. This may be due to changes in the habits of workers who smoke; that is, they may spend less time smoking in the vicinity of nonsmokers, even if smoking is not regulated in the workplace. Restrictions clearly have the effect of diminishing exposure to ETS in the workplace. ETS levels encountered by subjects working in facilities where smoking was restricted to designated areas were 2 to 8 times less than those experienced by subjects in facilities where smoking was not restricted.

It is apparent that some occupational subgroups are exposed to greater levels of ETS than others. In general, workers in the service occupations are exposed to the highest levels. However, even the most highly exposed occupational subgroup in our studies—bartenders working in single-room facilities—are not exposed to levels as high as those estimated by OSHA. For example, the median nicotine level for bartenders in single-room facilities was 20 μg/m³, compared to OSHA estimates of 50 to 100 μg/m³. Again, this may be a function of reduced public smoking in the United States.

The data in work presented here appear to confirm the need for personal monitoring if the exposures of subjects are to be accurately determined. Many nonsmoking workers are likely to avoid those areas where ETS is present in substantial quantities. Results of studies of workers who must work in smoking environments (such as restaurants and taverns) indicate that measurement of area levels of ETS components will provide an estimate of their likely individual exposure that is accurate only to within an order of magnitude.

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