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# Designing for Smoking Rooms

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June 2003

This research was supported by funds provided by the Cigarette and Tobacco Surtax Fund of the State of California through the Tobacco-Related Disease Research Program, Office of the President, University of California, Grant Numbers 1RT-505, 8RT-0157, and 8RT-0157S and the Assistant Secretary for Energy Efficiency and Renewable Energy, Building Technologies Program, U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

LBNL-53201

**Designing for Smoking Rooms**

Following the U.S. Environmental Protection Agency's classification of Environmental Tobacco Smoke (ETS) as a Group A carcinogen in 1992, California passed legislation in 1994 (Assembly Bill 13[1]) prohibiting most employers from exposing nonsmoking workers to ETS. As a result of this legislation, work place smoking restrictions were added to the California Labor Code.[2] This statute prohibits any employer from knowingly or intentionally permitting the smoking of tobacco products in enclosed places of employment.

Prohibition of smoking at the workplace does not apply to breakrooms designated by employers for smoking, under specified conditions. There are additional exemptions to specific workplaces that are not related to the subject matter in this article.

**Smoking Breakrooms**

Smoking is allowed in specially designed and operated breakrooms that meet the following criteria:

a. Air from the room is exhausted directly to the outside by an exhaust fan;

b. No smoking room air is recirculated to other parts of the building; and

c. Smoking rooms are in a non-work area where employees are not required to be present as part of their work responsibilities other than custodial or maintenance work when the room is unoccupied.

Criteria a and b are the major focus of this article, and in particular, we consider the level of negative pressurization and other separation techniques that are effective in achieving the "no air … is recirculated…" criterion of b. This article does not consider any of the ventilation goals in the smoking breakrooms themselves. Rather, our focus is on minimizing leakage of air from these breakrooms to nonsmoking areas.

**California Study of Smoking Rooms**

**Phase I.** From 1991 to 1994, prior to the passage of AB13, we studied the effectiveness of various smoking-area designs in containing ETS within smoking areas in 23 public buildings.[11,12] The designs studied ranged from open, adjacent, and/or contiguous smoking/nonsmoking areas to smoking rooms that were completely isolated from adjoining areas with walls and doors. We measured nicotine in the smoking and nonsmoking areas, pressure differentials between smoking and nonsmoking areas, smoking room airflow rates, and building ventilation rates. In addition, we tagged the air in the smoking room with a tracer gas (sulfur hexafluoride [$SF_6$]) and measured its concentration in the smoking and nonsmoking areas.

Among the designs studied, we found that enclosed areas with no air recirculation to nonsmoking areas and with exhaust to the outside were clearly the most effective in reducing exposure of non-smokers to ETS. Although only a small number (4 out of 23) of the smoking areas met the restrictions currently in AB13, the study indicated that the most important variables relevant to smoking room performance were room de-pressurization, door opening patterns, and in the case of open ceiling plenums between smoking and nonsmoking areas, leakage into the return air ceiling plenum above the smoking room.

**Sidebar: California Local Government Smoking Ordinances**

In 2001 our group conducted a telephone survey of all 62 local tobacco control jurisdictions in California regarding their ordinances for the operation of smoking rooms. The results indicated that 29% (N=18) have ordinances prohibiting smoking anywhere at the workplace, including smoking rooms, while the remainder do not have any specific ordinances more strict than the California Labor Code and, therefore, do not prohibit the operation of smoking rooms.

The California Department of Health Services conducts ongoing statewide surveys aimed at collecting information about Californians' smoking behaviors, including operation of smoking rooms. Based on these surveys, we estimated that about 122,000 California workers, or 0.8% of the workforce were working in buildings where smoking rooms were operating in 1999. For 2000, these estimates were slightly lower (100,000 workers or 0.6% of the workforce), indicating a decline in smoking at the workplace.

**Sidebar: Existing Design Guidelines for Containment Rooms**
Many organizations have issued guidelines for negatively pressurized rooms. These guidelines are based on field experience using smoke test methods.

1. A "rule of thumb" for designing negatively pressurized rooms has been that a 10% differential between a room's supply and exhaust (or return) airflow is adequate to prevent room air leakage to adjoining spaces.[3] Guttman[4] reported that this 10% rule of thumb "is a hangover from an old ASHRAE guide."

2. The Francis J. Curry National Tuberculosis Center[5] recommends that the negative pressure differential across Tuberculosis isolation rooms be approximately –7.5 Pa (0.03 in. $H_2O$). The same Center recommends that exhaust should exceed supply by at least 47 L/s (100 cfm).

3. CDC[6] recommends 0.25 Pa (0.001 in. w.c.) negative pressure for TB isolation rooms and that the exhaust should be 10% or 24 L/s (50 cfm) greater than the supply.

4. The California Office of Statewide Health Planning and Development (OSHPD7) and the California Mechanical Code recommend for TB isolation rooms the same pressure differential as CDC, but also specify that the exhaust should be 35 L/s (75 cfm) greater than the supply, that the room should be under negative pressure, and that the velocity at the "transfer opening" be 0.51 m/s (100 fpm).

5. For laboratories, the American National Standard for Laboratory Ventilation[8] specifies that where air must be contained, the exhaust and supply airflow rates must be maintained through any opening between the controlled space and adjoining areas, including open doorways, so that the following velocities be achieved at the opening: a) minimum velocity: 0.25 m/s (50 fpm); and b.) preferred velocity: 0.51 m/s (100 fpm).

6. For areas undergoing asbestos containment, OSHA[9] recommends that these areas be negatively pressurized at 5 Pa (0.02 in. w.c.).

7. Wiseman[10] recommends a minimum negative pressure of 2.5 Pa (0.01 in. w.c.) and advices a pressure 12 Pa (0.05 in. w.c.) or higher for "critical areas."

**Phase II.** The purpose of this study was to quantify the effect of the variables identified during Phase I of the study relevant to smoking room performance under controlled laboratory conditions. This study was conducted from 1999 to 2002.

Twenty-seven experiments were conducted in a simulated smoking room with a smoking machine and an automatic door opener. The characteristics of the test chamber are described in *Table 1.* Smoking room performance was quantified primarily by tagging smoking room air with $SF_6$ and monitoring its concentration in both the smoking and nonsmoking areas. Because the dynamics and transport of the various ETS components can differ substantially from that of $SF_6$ and from each other, we measured three particle and two gas phase ETS tracers in a subset of these experiments. The particle-phase ETS tracers measured were: total particulate matter (PM), PM-phase scopoletin, and optical absorption of PM at 370nm (UVPM). The two gas-phase tracers measured were: nicotine and 3-ethenylpyridine (3-EP).

Three potential air leakage mechanisms were investigated in the chamber tests:
a. Through the gap under the door and wall cracks when the smoking room was pressurized relative to the nonsmoking area;
b. Around the ceiling tiles in an open plenum that connected with the nonsmoking area when the smoking room was pressurized relative to the plenum; and
c. Via the pumping action of the door as occupants enter and exit the smoking room.

Data collected from the 27 laboratory experiments allowed us to quantify the various types of leakage flows, the effect of these leaks on smoking room performance and nonsmoker exposure, and the relative importance of each leakage mechanism.

**Table 1. Experimental Parameters**

| | Smoking Room | Non-Smoking room |
|---|---|---|
| Room Dimensions | 2.2m x 4.6m x 2.4m (7.2 ft x 15 ft x 7.9 ft) | 2.2 x 4.6 x 2.4<br>(7.2 ft x 15 ft x 7.9 ft) |
| Room Floor Area | 10.2 $m^2$ (110 $ft^2$) | 10.2 $m^2$ (110 $ft^2$) |
| Room Volume | 25 $m^3$ (870 $ft^3$) | 25 $m^3$ (870 $ft^3$) |
| Door size<br>Gap under door | 2.1m x 0.89m (6.9 ft x 2.9 ft)<br>0.64 cm (0.25 in) | |
| Supply flow rate | 3 – 54 L/s (6.3 – 114 cfm) | 26 – 100 L/s (outside plus recirculated)<br>(55 – 212 cfm) |
| Supply flow per floor area | 0.05 – 1.1 cfm / $ft^2$ | 0.5 – 1.9 cfm / $ft^2$ |
| Exhaust flow | 13 – 99 L/s (27.5 – 210 cfm) | 11 – 61 L/s (23 – 130 cfm) |
| Exhaust flow per floor area | 0.25 – 1.9 cfm / $ft^2$ | 0.21 – 1.2 cfm / $ft^2$ |
| % outside air | 100% | 30 – 70% |
| ACH | 0.4 to 7.9 $hr^{-1}$ | 1.9 – 15 $hr^{-1}$ |
| Calculated velocity at door opening with door open (@99 L/S or 210 cfm exhaust) | 0.053 m/s (10 ft/min) | |
| Ceiling plenum height | 23 cm (9 in) | |
| Linear feet of ceiling tiles | 61 m (200 ft) | |

The most important findings of interest to designers of smoking rooms are summarized next. A detailed discussion of all the experimental findings has been published elsewhere.[13]

**Smoking Room Effectiveness**

The impact of each leakage mechanism on smoking room effectiveness was evaluated using the following performance measure:

• The *smoking room exhaust efficiency* is the percentage of smoking room air that is successfully exhausted to the outdoors by the ventilation system serving the smoking room.[12,13] Smoking room air containing ETS that is not exhausted to the outdoors can be sorbed on smoking room surfaces and/or leak into adjoining, nonsmoking areas. The steady-state exhaust efficiency, $n_{exh,}$ is given by

$$\eta_{exh} = Q_{exh,SR}\left[\mathrm{ETS}\right]_{SR}/S \times 100\% \quad (1)$$

where $Q_{exh,\ SR}$ is the smoking room exhaust flow in units of volume per time, $[\mathrm{ETS}]_{SR}$ is the ETS or $SF_6$ concentration in the smoking room exhaust duct at steady-state in units of mass per volume, and $S$ is the generation rate of ETS or $SF_6$ in units of mass per time. Higher exhaust efficiencies indicate that most of the smoking room air is removed by the smoking room's exhaust.

**Flow Under Closed Door**

We fitted the data for the flow under the door and the data for the pressure differential between the smoking room and the adjoining nonsmoking room to the power law equation as described in the *2001 ASHRAE Handbook—Fundamentals*, Chapter 26:

$$Q = c(\Delta P)^n \quad (2)$$

where $Q$ is the flow under the door in L/s, $c$ is the flow coefficient in L/s/(Pa)$^n$, and $n$ is a dimensionless pressure exponent.

Fitting our data to the above equation resulted in $c$ = 6.10 L/s/(Pa)$^{0.573}$ and $n$ = 0.573.

Assuming that the flow coefficient is linearly proportional to the gap under the door (6 mm or 0.25 in. for our experiment), we produced the following equation:

$$Q_{under\ door} = 1{,}100 A_{gap}(\Delta P_{SR})^{0.573} \quad (3)$$

where $Q_{under\ door}$ is flow under the door in L/s, $\Delta P_{SR}$ is the pressure differential between the smoking room and the adjoining nonsmoking area(s) in Pa, and $A_{gap}$ is the area of the door gap in m$^2$.

**Flow Around the Perimeter of Ceiling Tiles**

Similarly, using Equation 2 and fitting the data for the experiments where the ceiling plenum was open between the smoking and nonsmoking areas, we obtained $c$ = 28.5 L/s/(Pa)$^{0.484}$ and $n$ = 0.484 for flow from the smoking room to the plenum.

Assuming that the flow coefficient is linearly proportional to the total perimeter of ceiling tiles installed in a smoking room (200 linear feet for our experiment), we produced the following equation:

$$Q_{SR\text{-}cp} = 0.142\, L_{cp}(\Delta P_{cp})^{0.484} \quad (4)$$

where $Q_{SR\text{-}cp}$ is the flow through the perimeter of the ceiling plenum tiles in units of L/s, $L_{cp}$ is the perimeter of the ceiling tiles in m, and $\Delta P_{cp}$ is the pressure differential between the smoking room and ceiling plenum in Pa. The proportion of ETS contaminants in this leakage flow that enters the nonsmoking area of a building will depend on whether the plenum air is recirculated or leaks into the nonsmoking areas, the percentage that is recirculated, and on the extent to which the contaminants deposit on surfaces in the return or leakage air path or are removed by filters.

**Pumping of Smoking Room Air by Opening and Closing of the Entry Door**

Each opening and closing of the smoking room swing-type door transferred approximately 24 ft$^3$ (670 L) of smoking room-laden air from the smoking room to the adjacent nonsmoking area. The effective leakage rate in units of L/s can be determined by multiplying this volume by the number of door openings per unit time, $D$

$$Q_{door\text{-}pumping} = 670\ \mathrm{L} \times D[openings/hr] \times\ 2.8 \times 10^{-4}\ hr/s \quad (5)$$

This volume was measured when door pumping was the only leakage mechanism of the smoking room, i.e., the room was not ventilated and not depressurized.

We anticipate that this leakage rate would scale approximately linearly with door size.

Equations 3 and 4 allow a designer to specify exhaust airflows for a smoking room based on target values for $\Delta P_{SR}$ and $\Delta P_{cp}$ (target values are discussed later in this article). These equations apply for the experimental setup that we studied and may not fully describe other rooms with considerably different leakage mechanisms.

**Leakage Mechanisms and Pressure Gradient**

Plotting the various leakage flows as a function of the appropriate pressure drop (*Figure 1*) indicates that:

a. Depressurization eliminates undesirable leakages under door gaps and around ceiling tiles (instead, the leakage goes from nonsmoking to smoking area);

b. Pumping of smoking room air via door opening is the only leakage mechanism in depressurized smoking rooms; and

c. In our experiments, leakage to the ceiling plenum was a stronger function of $\Delta P$ than leakage through the door.

Since the quasi-steady state concentration of a pollutant originating in an enclosed space is roughly inversely proportional to the space's pollutant-free ventilation rate, a higher ventilation rate in a smoking room reduces concentrations of ETS contaminants in the smoking room air, which, in turn, diminishes the adverse effects of leakage from the smoking room to the nonsmoking room. To first order, for the high ventilation rates in smoking rooms, the concentrations of ETS constituents in the smoking room air will increase in direct proportion to ETS constituent production rate and decrease in proportion to the reciprocal of the smoking room's ventilation rate. A more complete discussion of ETS concentrations during and after smoking can be found elsewhere.[14,15]

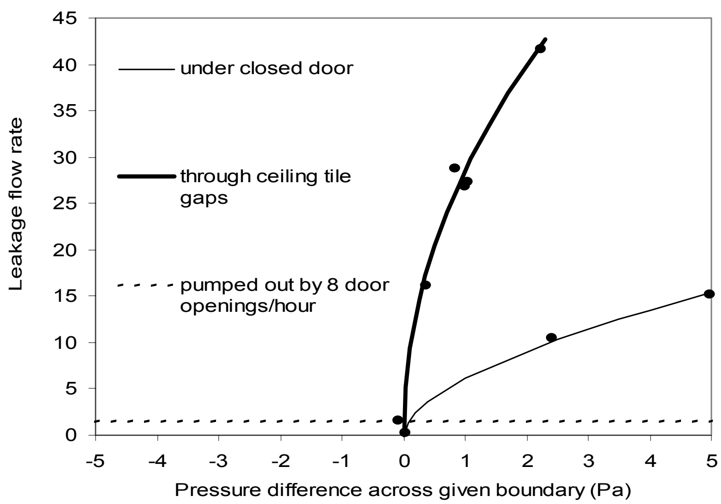


Figure 1. Leakage flow from smoking room to non-smoking room as a function of pressure differentials across smoking room's door and ceiling plenum

**Effect of Entry Door Type on Room Leakage**

We conducted the majority of our experiments with a swing-type entry door to the smoking room. In addition, we conducted a limited number of experiments with a sliding-type entry door as well as with an open doorway (no door) in order to compare the leakages of smoking room air to the nonsmoking area of these configurations.

The "pumped out by eight door openings/hr" curve in *Figure 1* was determined using a swing-type door. When we replaced this type of smoking room door with a sliding door, the volume of air pumped out per opening was reduced by 77%. Therefore, the volume shown in Equation 5 is reduced to only 5.4 $ft^3$ (150 L) in the case of a sliding door.

Intuitively, using a smoking room with a fixed, open doorway would be a way to completely eliminate smoking room air leakage via door pumping. However, thermally-induced circulation flows through the doorway can cause air from the smoking room to leak into the nonsmoking room, even when the net flow across the doorway is towards the smoking room. In our "open doorway" test, $SF_6$ concentrations in the nonsmoking room were comparable to those found in our tests with a door in place, but it required ventilation rates that were two to four times higher to achieve the same results. Thus, using a door and maintaining the smoking room depressurized was a much more effective way to control leakage from the smoking room. Open doorways with higher face velocities than ours may be more protective, though they presumably would require even higher exhaust flows.

In our experiments, we were able to achieve 99 L/s (210 cfm) of exhaust flow or velocities of 0.053 m/s (10 fpm) through the open doorway. As was mentioned previously, for a laboratory with open doorways, the American National Standard for Laboratory Ventilation[8] recommends a minimum velocity of 0.25 m/s (50 fpm) with 0.51 m/s (100 fpm) being the desired velocity. For a standard size door, these velocity requirements translate into exhaust airflows of 470 L/s and 940 L/s respectively (1,000 and 2,000 cfm). These exhaust flows are unrealistically high, especially for smaller size rooms. For large smoking rooms with large numbers of users, such as in some airports, the open-door smoking room may possibly be more practical and superior to a smoking room with a swinging door. It should be pointed out that the open doorway may be perceived as a hazard by some nonsmokers.

**Recommended Pressure Differential**

*Figure 2* shows the $\eta_{exh}$ as a function of the pressure differential between the smoking and nonsmoking room. The graph shows that for pressure differentials of –5 to –7 Pa (–0.02 to –0.03 in. W.C.), exhaust efficiencies of at least 90% were achieved. This pressure difference will vary with the total amount of leakage in the smoking room's envelope. Temperature differentials of 2°C (3.6°F) did not result in measurable additional leakages.

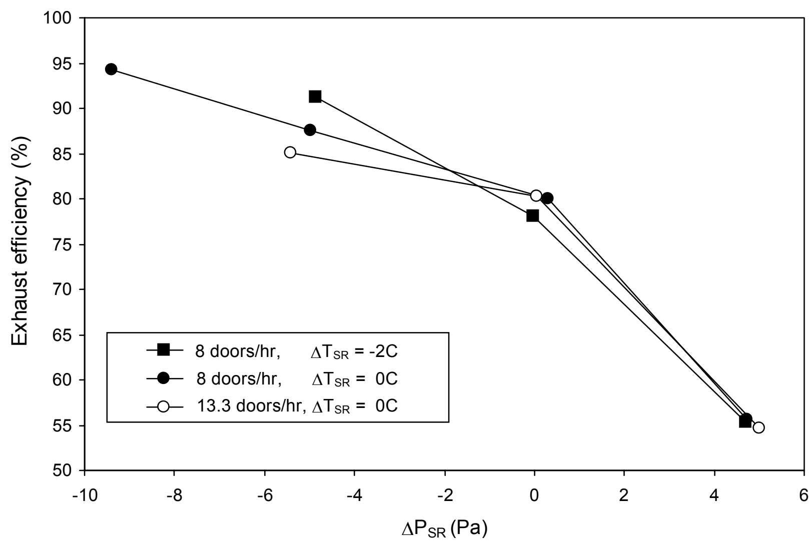


Figure 2. Exhaust efficiency as a function of the pressure differential between smoking and non-smoking rooms.

**Correlation Between $SF_6$ and Other ETS Markers**

We used the *exposure ratio* to correlate $SF_6$ to the other ETS tracers. The exposure ratio is the ratio of ETS or $SF_6$ concentration in the nonsmoking area divided by the corresponding concentration in the smoking area. Lower exposure ratios indicate better protection for occupants of nonsmoking areas

As shown in *Figure 3,* all ETS tracer exposure ratios showed good correlation with $SF_6$ (i.e., all fluctuated together in response to the various smoking room configurations). However, all ETS tracers exhibited lower-*magnitude* exposure ratios than $SF_6$, implying less leakage to nonsmoking-room air. 3-EP showed the highest levels in nonsmoking room air, whereas nicotine showed the lowest.

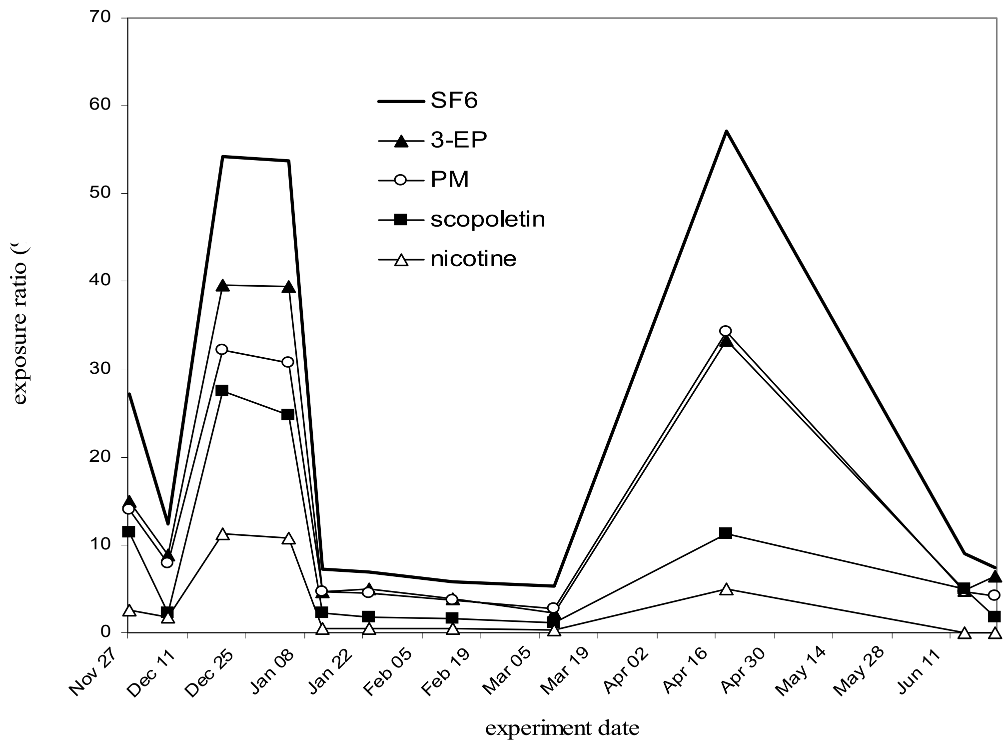


**Figure 3. Exposure ratios (ratio of concentrations in non-smoking and smoking rooms) for $SF_6$, 3-EP, PM, scopoletin, and nicotine.**

**Other Considerations**

There were many issues related to the health and comfort of non-smokers occupying areas adjoining smoking rooms that our research did not intent to address. Some of these issues include:

a. Health effects associated with low-level ETS exposures in the nonsmoking areas;

b. Leakage of residual and sorbed ETS from a smoking room when the room is unoccupied and its ventilation is turned off;

c. Ventilation rates for odor control in the smoking rooms; and

d. Transfer of ETS from smoking areas to nonsmoking areas by occupant clothing.

**Conclusions**

Our test results indicate that designers of smoking rooms should consider the following:

1. Maintain smoking rooms depressurized relative to the adjoining nonsmoking areas. Our results showed that for pressure differentials between –5 to –7 Pa (–0.02 to –0.03 in. w.c.), exhaust efficiencies of at least 90% were achieved.

2. Air from the smoking rooms should be exhausted to the outside without recirculation to other occupied spaces.

3. *Figure 2* may be used to estimate the pressure differential to maintain a desired level of smoking room efficiency. Equations 3 and 4 can then be used to estimate exhaust airflow requirements to maintain the pressure differential.

4. Increasing the smoking room ventilation rate will diminish the concentration of ETS contaminants in any air that happens to leak from the smoking room to the nonsmoking area.

5. If a smoking room shares a common plenum with adjacent nonsmoking spaces, either block off plenum or ensure that the smoking room is under slightly negative pressure relative to the ceiling plenum.

6. Even when smoking rooms are maintained under negative pressure, operating swing-type entry doors to enter and exit smoking rooms results in pumping up to 10% of smoking room air into adjoining nonsmoking areas.
7. Sliding-type entry doors minimize leakage due to the "pumping" effect.
8. Automatic closure mechanisms are recommended for swing-type and sliding-type doors to avoid leakage through an open doorway.
9. An open doorway requires high exhaust flows to ensure that air flows from the nonsmoking area to the smoking area and is unlikely to be a practical configuration for the most common, smaller size smoking rooms.

**Acknowledgments**

This research was supported under the auspices of the *Public Health Institute* and *Lawrence Berkeley National Laboratory*, by funds provided by the Cigarette and Tobacco Surtax Fund of the State of California through the Tobacco-Related Disease Research Program, Office of the President, University of California, Grant Numbers 1RT-505, 8RT-0157, and 8RT-0157S. Substantial "in kind" support was provided by the California Department of Health Services. We would like to thank: the *Tobacco Control Section of DHS* for sharing with us the CTS and CATS data; the *Cancer Center* of the *University of California at San Diego* for their assistance with data analysis; and Stella Aguinaga Bialous, Thomas Houston, M.D., Hal Levin, and Larry Schoen, P.E. for their review of this article.

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