# Secondhand Smoke in Pennsylvania Casinos: A Study of Nonsmokers' Exposure, Dose, and Risk

James L. Repace, MSc

*Objectives.* I assessed air pollution, ventilation, and nonsmokers' risk from secondhand smoke (SHS) in Pennsylvania casinos exempted from a statewide smoke-free workplace law.

*Methods.* I measured respirable suspended particles (RSPs), particulate polycyclic aromatic hydrocarbons (PPAHs), and carbon dioxide inside and outside casinos; measured changes in patrons' urine cotinine after casino visits; and assessed SHS impact on workers and patrons, using exposure and response models, air quality standards, and odor and irritation thresholds.

*Results.* PPAH and RSP concentrations in casinos were, on average, 4 and 6 times, respectively, that of outdoor levels despite generous ventilation and low smoking prevalence. SHS infiltrated into nonsmoking gaming areas. Patrons' urine cotinine increased 1.9 ng/mL on average after about 4-hour visits.

*Conclusions.* SHS-induced heart disease and lung cancer will cause an estimated 6 Pennsylvania casino workers' deaths annually per 10 000 at risk, 5-fold the death rate from Pennsylvania mining disasters. Casinos should not be exempt from smoke-free workplace laws. (*Am J Public Health.* 2009;99:1478–1485. doi:10.2105/AJPH.2008.146241)

Casino gambling is a popular pastime. Nationally, 467 commercial casinos generated gross gaming revenues totaling $34.13 billion in 2007, paid $5.79 billion in state and local taxes, and employed 360 818 workers who earned $13.8 billion collectively.[1] Twenty-five percent of the adult US population—54 million people 21 years or older—visited casinos in 2007, with the average gambler making 7 visits a year.[1] Secondhand smoke (SHS) is endemic in casinos; only 8 of 23 states, plus Puerto Rico, have 100% smoke-free commercial casinos or racinos (combination casinos and racetracks).[2] The gaming and tobacco industries have adamantly opposed smoke-free casinos, promoting ventilation alternatives instead.[3,4]

SHS causes an estimated 40 000 to 60 000 heart disease and lung cancer deaths annually in the United States,[5] with no safe level of exposure.[6] Even brief SHS exposure increases the risk of heart attack or cancer.[7] Casino workers have complained to the National Institute for Occupational Safety and Health (NIOSH) about exposure to SHS[8] and have filed lawsuits alleging injuries from SHS.[9–12]

Research on levels of SHS in casinos has been limited. In a study of 27 New Jersey casino workers, NIOSH reported median personal breathing zone nicotine levels of 10 $\mu g/m^3$ (equivalent to 100 $\mu g/m^3$ of respirable suspended particles [RSPs] from SHS[13]) and median serum cotinine concentrations 2 to 3 times higher (1.34–1.43 ng/mL) than those observed in a representative sample of US workers (0.65 ng/mL).[8] A study of airborne RSPs and particulate polycyclic aromatic hydrocarbons (PPAH) in a Delaware casino before and after a statewide smoke-free workplace law was enacted showed that, before the legislation, 95% to 98% of these air pollutants (205 $\mu g/m^3$ and 163 ng/$m^3$, respectively), were caused by SHS.[14] A dosimetry study of 18 nonsmoking patrons of an Upper Midwest casino showed that exposure to SHS for an average of 4.25 hours resulted in increased free urine cotinine (adjusted for creatinine) of 3.9 ng/mL as well as absorption of a tobacco-specific lung carcinogen, 4-(methylnitrosamino)-1-(3-pyridil)-1-butanone (NNK).[15]

SHS is highly irritating; nearly three fourths of nonsmokers are disturbed by smoky air.[16] In a study by Junker et al.,[17] the median threshold for sensory irritation (eye, nasal, and throat) of RSPs from SHS was 4.4 $\mu g/m^3$, and even at this low level, 67% of the nonsmoking participants judged the air quality unacceptable.[17] The median odor-detection threshold of RSPs from SHS is about 1 $\mu g/m^3$.[17]

Although Pennsylvania's Clean Indoor Air Act makes smoking illegal in restaurants, office buildings, schools, sports arenas, theaters, bus and train stations, and most bars, an exemption permits smoking in up to 50% of gaming floors.[18] Field studies of SHS are effective in promoting smoke-free workplace legislation.[19]

The work reported in this article was part of a Stanford University study that investigated air quality in casinos. I report on SHS atmospheric and biomarkers and ventilation in August 2007 in 5 Pennsylvania casinos: the Mohegan Sun (Wilkes-Barre), Philadelphia Park (Bensalem), Harrah's (Chester), The Meadows (Meadowlands), and Presque Isle Downs (Erie), all built between 2006 and 2007. I addressed the following research questions: (1) What were the levels of air pollution from RSPs and PPAHs inside Pennsylvania casinos relative to the outside? (2) What was the change in urine cotinine experienced by a casino patron and the equivalent personal breathing zone exposure to RSPs and PPAHs from SHS? (3) Could the average level of RSP air pollution in the casinos be predicted and generalized by a model? (4) Based on measured SHS exposure and dose data, what were the risks of lung cancer and heart disease mortality from SHS for casino workers, the air pollution hazard to patrons and workers, and the odor and irritation levels from SHS in these modern casinos? Exposure was defined as the atmospheric SHS concentration that contacts a person's boundary. Dose was defined as the inhaled, absorbed, and metabolized body fluid concentration of cotinine, the metabolite of SHS nicotine. Exposure and dose were related by a pharmokinetic model.

## METHODS

In Pennsylvania, I conducted area-monitored SHS exposure for 3 casinos (Mohegan

Sun, Philadelphia Park, and Harrah's) and dose of SHS in 8 patrons for 3 casinos (The Meadows, Philadelphia Park, and Presque Isle Downs), with 1 casino in both the area-monitored and dose portion of the study. Each area-monitored casino was sampled once, and measurements for burning cigarette density, carbon dioxide as an index of ventilation, and pollutant concentration were obtained. Casinos were not informed of the monitoring, to prevent bias or interference.[8,14,15] SHS dose (urine cotinine)[20] was measured in 8 volunteer patrons who visited 3 casinos (3 volunteers at The Meadows, 3 at Philadelphia Park, and 2 at Presque Isle Downs; 1 volunteer sample from the last-named casino was lost to follow-up). Models were used to generalize air quality measurements and to transform dose into personal exposure. Health and welfare effects for casino patrons and workers were assessed through the use of odor and irritation thresholds, air quality standards, and exposure–response models.

### Atmospheric and Biomarker Measurements

A SidePak AM510 aerosol monitor (calibration factor=0.39; TSI Inc, St Paul, MN) measured real-time area RSP concentrations in 10-second intervals (i.e., $PM_{2.5}$, particulate matter less than 2.5 μg in diameter that can easily be inhaled into the lungs and is copiously emitted by cigarettes, pipes, and cigars).[21,22] A synchronized EcoChem PAS 2000CE (EcoChem Analytics Inc, League City, TX) measured carcinogenic and atherogenic particulate-phase PPAHs in 10-second intervals; a TelAire carbon dioxide ($CO_2$) monitor (General Electric, Fairfield, CT) assessed ventilation.[22] Room dimensions, person counts, average number of burning cigarettes, and times of entry and departure were recorded.[14,20,22]

Free urine cotinine, a sensitive SHS biomarker, was measured by liquid chromatography–tandem mass spectrometry (quantitation limit=0.1 ng/mL) from samples provided by local nonsmoking volunteer patrons before and after each 4- to 5-hour casino visit during which they played slot machines. Local clinics processed and shipped samples. Cotinine analyses were provided by E. Giesbrecht of the Center for Addiction and Mental Health, University of Toronto, Ontario. Volunteers were requested to avoid SHS for 1 week prior to casino visits. Postvisit urine samples were collected on the following day.

### Ventilation and Air Exchange Rates

The American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) prescribes ventilation rates based on building use (e.g., offices, restaurants, bars, and casinos) and maximum area occupancy. Ventilation rates for casinos in which smoking is permitted (hereafter called "smoking casinos") were last prescribed by obsolete ASHRAE standard 62-2001, which I used to evaluate measured ventilation rates.[23] This standard recommended an outdoor air supply rate for casinos of 30 $ft^3$/min per occupant (or 15 L/sec per occupant) for a maximum (default) occupancy of 120 persons per 1000 $ft^2$ of floor area. Since 2005, before any of these casinos were built, ASHRAE has recommended ventilation rates only for nonsmoking premises, citing numerous government reports linking SHS exposure to disease.[24]

Ventilation rates per occupant relate to air exchange rates (the number of times in 1 hour that the air in a room is completely replaced with outside air) as follows: assuming a 14-foot ceiling, the ASHRAE 62–2001 default air exchange rate $C_v$ for a casino at maximum design occupancy is calculated as:

$$(1)\quad C_v = (30\,ft^3/\text{min per occupant}) \times (120\ \text{occupants}/14\,000\,ft^3]) \times (60\ \text{min/h}) = 15\ \text{outdoor air changes per hour}\ (h^{-1}),$$

where $C_v$ is the dilution rate of indoor pollution by ventilation.[25]

### Predicted Prevalence of Active Smoking

The percentage of gamblers who smoke is less than or equal to the percentage of smokers in the adult population.[26] The estimated prevalence of smoking in Pennsylvania (among those aged 18 years or older) ranges from 23% to 29% for the various regions of Pennsylvania and averages 25%.[27] Thus, for a large group of adults encountered at random in a Pennsylvania casino, about 25% might be expected to be smokers. However, only one third of the smokers would be expected to be observed smoking cigarettes at any given time.[14,26] The average number of active smokers (i.e., those with burning cigarettes) is thus expected to be one third of 25%, or 8.3% (range=7.7%–9.7%).

### Predicted Active Smoker Density

SHS levels are directly proportional to smoker density.[14,26] If the prevalence of smoking among a casino's patrons equals the smoking prevalence for Pennsylvania, then at the ASHRAE maximum occupancy, and assuming a 14-foot ceiling and a unit floor area of 1000 $ft^2$ (for volume of 14 000 $ft^3$, or 396 $m^3$), the burning cigarette density (i.e., active smoker density) is:

$$(2)\quad D_s = (8.3\ \text{active smokers}/100\ \text{occupants}) \times (120\ \text{occupants}/396\,m^3) = 2.52\ \text{active smokers per}\ 100\,m^3.$$

### The Active Smoker Model

The effect of ventilation on SHS levels may be understood by a simple analogy. Imagine a bathtub in which water is running in and draining out at such a rate that the water level remains constant. At the same time, India ink is poured in uniformly, turning the water black. To clarify the water while keeping its level in the tub constant, water ingress and egress must be increased by the same amount; the water will then become a shade of gray. The lightest gray obtainable (i.e., the clearest the water can ever get) will be a balance between the rate the ink enters and the maximum rate of water flow. The tub water can never regain its pristine state while ink is still pouring in. The ink pouring rate is analogous to the smoking rate, the water flow rate is analogous to the air exchange rate, and the amount of water in the tub is analogous to the space volume. The shade of gray (i.e., the degree of pollution) is analogous to the SHS concentration. This is the essence of the Active Smoker Model, which calculates the amount of RSP pollution from SHS in the air.[14,25]

In algebraic terms, the Active Smoker Model, which shows that the ratio of burning cigarette density, $D_s$, to the air exchange rate, $C_v$, predicts time-averaged concentrations of RSP from SHS.[14] The units of SHS RSP are micrograms per cubic meter of air; the numerical constant incorporates the surface adsorption rate (adding 30% to the ventilation rate), the smoking rate, and the emission rate of RSP from SHS and has units of microgram-hours per burning cigarette.[25] Thus, the predicted concentration of RSP from

SHS for a Pennsylvania smoking casino, assuming ASHRAE 2001 default occupancy and ventilation and Pennsylvania's smoking prevalence, is calculated as:

$$(3)\ \text{SHS RSP}_{\text{casino}} = 650\text{D}_s/\text{C}_v = 650(2.52\,\text{BC}/100\,\text{m}^3)/(15\text{h}^{-1}) = 109\mu\text{g}/\text{m}^3.$$

Because both $D_s$ and $C_v$ contain volume in the denominator, SHS $\text{RSP}_{\text{casino}}$ depends on the ratio of the generation rate to the removal rate and is volume independent. Assuming a background RSP concentration of 12 $\mu g/m^3$ from outdoor non-SHS sources infiltrating indoors,[28] a field study of fine-particle pollution that results from smoking in a Pennsylvania casino with ASHRAE default levels of occupancy and ventilation (full occupancy, average smoking prevalence, and standard ventilation rate) would be expected to show an estimated total RSP concentration of about 109+12=121 $\mu g/m^3$. This result serves as a prediction of expected casino total RSP concentrations under ASHRAE standard conditions, and it generalizes the results of the field study to casinos having different occupancies, volumes, smoker densities, or air exchange rates. The corresponding expected SHS nicotine concentration[13,29] is:

$$(4)\ \text{N}_{\text{casino}} = \text{SHS RSP}_{\text{casino}}/10 = 109\mu\text{g}/\text{m}^3/10 = 10.9\mu\text{g}/\text{m}^3,$$

which is within 10% of NIOSH measurements.[8]

### Carbon Dioxide and Per-Occupant Ventilation Rates

Design ventilation rates can be compared with actual ventilation rates by measuring the difference between the $CO_2$ concentrations in the casinos and outdoors. ASHRAE standard 62-2001[23] specifies an equation for $C_s$, the equilibrium $CO_2$ concentration in parts per million (ppm) in a building. If equilibrium is not present (i.e., if the $CO_2$ concentration has not reached steady state), ventilation rates will be overestimated. The ASHRAE equation is:

$$(5)\qquad C_s = (G/V_o) + C_o,$$

where $V_o$ is the outdoor airflow rate per occupant recommended by ASHRAE 62-2001 for gambling casinos that permit smoking (30 $ft^3$/min per occupant, or 15 L/sec per occupant), $C_o$ is the default outdoor air $CO_2$ concentration (400 ppm), and $G$ is the conversion factor (5000 ppm/L/sec per occupant). Thus, for an ASHRAE standard 62-2001 casino, the expected $CO_2$ concentration for the default occupancy and prescribed ventilation rate is $C_s$=(5000/15)+400=733 ppm.

### Relationship Between Markers

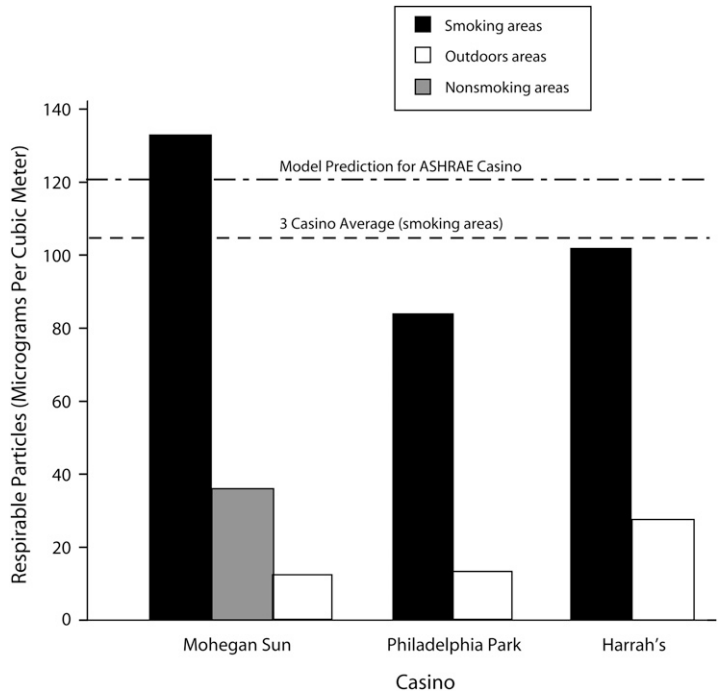
Dosimetry captures personal breathing zone exposure to SHS much better than area monitors, because dosimetry incorporates exposure concentration, duration, proximity, and respiration rate. I used dosimetry to assess SHS risk.[25,29,30] Personal breathing zone exposure to RSPs from SHS can be estimated by measuring urine cotinine with the "Rosetta stone" equations.[29] Equation 6 relates RSPs from SHS to urine cotinine, U, for an assumed respiration rate of 0.7 $m^3$/hour for a person sitting and gambling.[20,29] For example, for a 4-hour exposure duration, the average time spent gambling by 5 of 7 of the volunteer patrons, the cotinine-estimated SHS-RSP concentration is:

$$(6)\ \text{SHS RSP}_{\text{casino}} = 364\,\text{U/H} = 91\text{U}(\mu\text{g}/\text{m}^3).$$

Because cotinine levels decay exponentially after 11 hours, I normalized all measured doses to 11 hours using the mean life for cotinine.[29]

## RESULTS

For 3 of the casinos in which air quality was measured by area monitors (Mohegan Sun, Philadelphia Park, and Harrah's), the average RSP concentration measured in the smoking areas was 106 $\mu g/m^3$ (range=84–133 $\mu g/m^3$), 6 times higher than the outdoor average of 18 $\mu g/m^3$ (range=10–28 $\mu g/m^3$). The average total RSP for the ASHRAE-standard casino predicted by the Active Smoker Model was 121 $\mu g/m^3$, a 14% difference. Figure 1 shows the measured indoor and outdoor RSP concentrations at the Mohegan Sun (late Wednesday




*Note.* Measurements were taken on August 15 at the Mohegan Sun (late Wednesday morning) and Philadelphia Park (mid-afternoon Wednesday), and on August 31 at Harrah's (Friday evening).

**FIGURE 1—Measured indoor and outdoor levels of respirable suspended particles (RSPs) at the Mohegan Sun, Philadelphia Park, and Harrah's casinos: Pennsylvania, 2007.**

morning), Philadelphia Park (mid-afternoon Wednesday), and Harrah's (Friday evening). Table 1 details the parameters measured and the smoker density calculated for each casino.

All casino smoking areas were heavily polluted, with time-averaged RSPs higher than those outdoors by a factor of approximately 11 for Mohegan Sun, 6 for Philadelphia Park, and 3.5 for Harrah's. During the same time period (11:55 AM to 12:12 PM), the RSP concentration in the Mohegan Sun's smoking area was over 5 times higher (201 $\mu g/m^3$) than in its separate, equally large nonsmoking area (37 $\mu g/m^3$; $P<.001$), but SHS in the nonsmoking area was still 3 times higher than were outdoor levels (13 $\mu g/m^3$; $P<.001$).

Figure 2 compares indoor and outdoor PPAH concentrations at the 3 casinos. The average concentration of PPAH in the smoking areas of the 3 casinos was 20 $ng/m^3$ (range=14–29 $ng/m^3$), 4 times the outdoor average of 5 $ng/m^3$ (range=3–6 $ng/m^3$). The concentration in the Mohegan Sun's nonsmoking area was 37% higher than were outdoor concentrations. When the ratios of either the arithmetic or geometric mean concentrations of RSPs from SHS to PPAHs from SHS for each of the 3 casinos were compared, the ratio for Harrah's was lower than were those of the other casinos (Table 1); the reason for this anomaly is unknown. However, a regression analysis of RSPs from SHS versus PPAHs from SHS (indoors minus outdoors) for the 3 casinos yielded the ratio 2172:1 ($r^2=0.29$) in units of $\mu g/m^3$, which was in good agreement with previous measurements.[14,22]

## Smoker Prevalence, Occupancy, and Ventilation

The 3-casino average observed prevalence of active smoking (Table 1) was 6.7% (range=4.6%–9.7%), compared with the predicted 8.3% (range=7.7%–9.7%). Because, as explained in the Methods section, total smoking prevalence is expected to be 3 times the prevalence of observed active smoking, estimated average smoking prevalence for the 3 casinos is 3×6.7%=20.1% (range=13.8%–29.1%), which is lower than the state smoking prevalence of 25% (range=23%–29%), as expected.[26]

**TABLE 1—Physical Parameters of Study Casinos and Real-Time Air Quality Measurements: Pennsylvania, 2007**

| Casino | Area, $ft^2$ | Ceiling Height, ft | Volume, $m^3$ | No. People Present, Mean (SD)[a] | Average No. People Per 1000 $ft^2$ | No. Burning Cigarettes, Mean (SD)[a] | PPAH Level, $ng/m^3$ (SD) | Outdoor PPAH Level, Mean $\mu g/m^3$ (SD) | Indoor RSP Level, Mean $\mu g/m^3$ (SD) | Outdoor RSP Level, Mean $\mu g/m^3$ (SD) | Estimated Smoker Prevalence, % | Burning Cigarettes per 100 $m^3$ Q105 AU | Estimated Air Exchange Rate ($C_v$), $h^{-1}$ | Ratio of Total RSP to Background RSP | Ratio of Total PPAH to Background PPAH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mohegan Sun | | | | | | | | | | | | | | | |
| Smoking section[b] | 14 145 | 12 | 4806 | 171 (43) | 12 | 16.7 (9.1) | 16.1 (14.5) | 2.78 (2.38) | 133 (67) | 12.6 (4.4) | 29.3 | 0.35 | 1.89 | 11 | 5.8 |
| Nonsmoking section[b] | 14 145 | 12 | 4806 | . . . | . . . | 0 | 3.81 (2.55) | 2.78 (2.38) | 36[a] (43) | 10.5[a] (10) | 0 | 0 | | 3.4 | 1.4 |
| Philadelphia Park[c] | 31 671 | 12 | 10 761 | 477 (30) | 15 | 22 (1.4) | 14.1 (15.0) | 5.56 (3.94) | 84 (44) | 13.3 (3.3) | 13.8 | 0.20 | 1.67 | 6 | 2.5 |
| Harrah's[d] | 160 000 | 28.83 | 13 119 | 2875 | 18 | 169 (35) | 29 (29) | 5 (10) | 102 (34) | 28 (12) | 17.6 | 0.13 | 1.14 | 3.6 | 5.8 |
| All smoking areas, mean | | | | | | | 19.7 (8.1) | 5.4 (2.6) | 106 (25) | 18 (8.7) | | | | 5.9 | 3.6 |
| All smoking areas, median | | | | | | | 16.1 | 5.6 | 102 | 13 | | | | 7.8 | 2.9 |
| ASHRAE standard casino design | 1 000 | 14 | 14 000 | 120 | 120 | . . . | . . . | . . . | 121 | 12 | 25 | 2.52 | 15 | 10 | . . . |

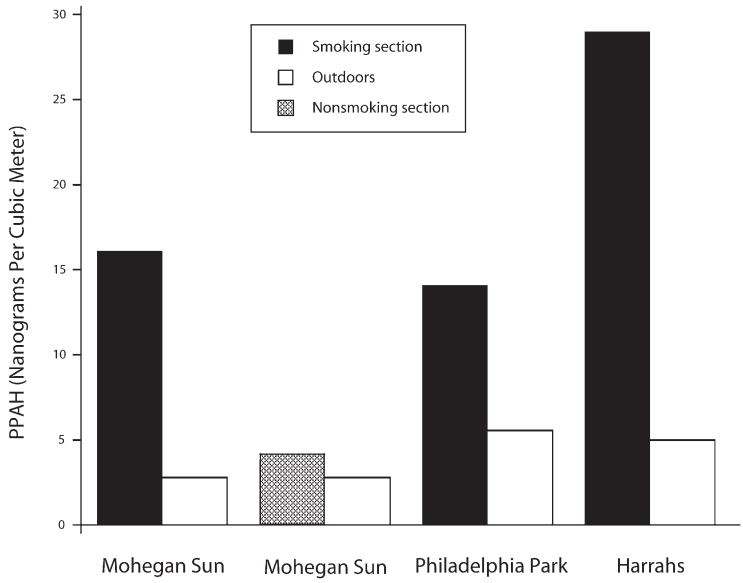
*Note.* PPAH = particulate polycyclic aromatic hydrocarbons; RSP = respirable suspended particles; ASHRAE = American Society of Heating, Refrigerating, and Air Conditioning Engineers. Ellipses indicate that ASHRAE does not specify values for these parameters.

[a]Smoking areas of all casinos measured with S1 SidePak (TSI Inc, St Paul, MN); nonsmoking area of Mohegan Sun measured with Stanford SidePak.

[b]The Monhegan Sun is located in Wilkes-Barre. Observations were made on August 15 from 11:20 AM to 12:15 PM in the nonsmoking section and 11:41 AM to 12:15 PM in the smoking section. The maximum occupancy was 910 people.

[c]Philadelphia Park is located in Bensalem. Observations were made on August 15 from 3 PM to 4 PM. The maximum occupancy was 1950 people.

[d]Harrah's is located in Chester. Observations were made on August 31 from 8 to 9:30 PM. The maximum occupancy was 2750 people.




*Note.* ASHRAE=American Society of Heating, Refrigerating, and Air Conditioning Engineers. Concentrations in the smoking sections are shown for all 3 casinos and for the nonsmoking section at the Mohegan Sun only.

**FIGURE 2—Measured indoor and outdoor levels of particulate polycyclic aromatic hydrocarbons (PPAHs) at 3 Pennsylvania casinos in 2007.**

For the 3 casinos for which area occupancy was recorded, Mohegan Sun had an occupancy level of only 19% of the maximum, Philadelphia Park averaged only 25% of the maximum, and Harrah's was at maximum occupancy. Occupancies were not measured in the cotinine study.

These casinos were well ventilated: the mean observed $CO_2$ concentration was 730 ppm (SD=46 ppm; 23 L/sec per occupant), compared with a predicted $CO_2$ concentration for the ASHRAE 2001 model casino of 733 ppm (15 L/sec per occupant; Table 2).

## Cotinine-Estimated Respirable Suspended Particle Levels

Table 3 shows total RSP and PPAH personal breathing zone exposure, that is, cotinine-derived RSPs from SHS (based on the urine cotinine of volunteers) plus estimated background RSPs, which was estimated from Pennsylvania's $PM_{2.5}$ outdoor–air quality monitoring network.[27,31] Smoker density was not recorded.

The estimated personal breathing zone concentration of RSPs from SHS was calculated using equation 6; the median increase in urine cotinine for all volunteers was 1.9 ng/mL (Table 3). For postexposure urine cotinine collected after 11 hours, the measured dose was adjusted[29] for the decay of cotinine. For cotinine-estimated RSP exposures from SHS, the mean personal breathing zone level (weighted by the time volunteers spent in the casinos) averaged over all 7 volunteers was 160 μg/m$^3$ (SD=81 μg/m$^3$). Outdoor RSP levels were not recorded in the biomarker study. Outdoor background RSP levels, estimated from the Pennsylvania $PM_{2.5}$ air quality–data monitoring network,[31] averaged about 14 μg/m$^3$ for the appropriate dates, yielding a total estimated combined personal breathing zone RSP exposure of 174 μg/m$^3$.

## Odor and Irritation From Secondhand Smoke

Log-probability analysis (not shown) indicated that all of the RSPs measured in the smoking areas of the 3 casinos exceeded the Junker et el. odor acceptability threshold[17] by factors ranging from 10 to 1000, with geometric mean factors ranging from 64 to 104, whereas the Mohegan Sun's nonsmoking area exceeded it by a factor of 24. With respect to irritation, the 3 casino smoking areas exceed the Junker et al. threshold by factors of about 2.5 to more than 100. Thus, both odor and irritation levels for nonsmokers were massively exceeded by the SHS in casino smoking areas. In the nonsmoking area of the Mohegan Sun, the odor threshold was exceeded by factors ranging from 3 to more than 200, whereas the irritation threshold was exceeded for 99.9% of the data by factors ranging up to 200. This may result in loss of nonsmokers' patronage.[32]

## Risk Calculation

The estimated risk of SHS exposure for casino workers was calculated by transforming the RSPs from SHS derived from the casino patrons' cotinine into its equivalent SHS nicotine, and then estimating risk with an exposure response model.[29,30] Based on dosimetric levels

**TABLE 2—Ventilation Rates Derived From Carbon Dioxide in 3 Casinos in Which Smoking Is Permitted: Pennsylvania, 2007**

| Casino | Avg Outdoor $CO_2$, ppm (SD) | Indoor $CO_2$, ppm (SD) | Casino Area, 1000 ft$^2$ | Casino Occupancy (SD) | People per 1000 ft$^2$ | Estimated Ventilation Rate, L/s per Occupant |
|---|---|---|---|---|---|---|
| Mohegan Sun | 473[a] | 730[b] (191) | 14.1 | 171[c] (43) | 12 | 19.4 |
| Philadelphia Park | 468[b] | 776[b] (74) | 31.7 | 477[b] (30) | 15 | 16.2 |
| Harrah's | 537[b] | 684[b] (116) | 160 | 2875[b] (105) | 18 | 34 |
| Mean for 3 casinos | 493 (38) | 730 (46) | . . . | . . . | 15 (3) | 23 (9) |
| ASHRAE Standard 62-2001 Design Value[d] | 400 | 733 | 1 | 120 | 120 | 15 |

*Note.* ASHRAE = American Society of Heating, Refrigerating, and Air Conditioning Engineers.
[a]One measurement.
[b]Two measurements.
[c]Three measurements.
[d]ASHRAE no longer recommends ventilation rates for smoking premises.[21] All casinos exceeded the ventilation rate per occupant recommended by ASHRAE Standard 62-2001.

**TABLE 3—Urine Cotinine and Respirable Suspended Particle (RSP) Concentrations Attributable to Secondhand Smoke (SHS) Among Visitors to 3 Casinos in Which Smoking Is Permitted: Pennsylvania, 2007**

| | Time of Previsit Urine Sample, (Hours Spent in Casino) | Arrival Time | Hours Elapsed Between Leaving Casino and Urine Sample | Previsit Urine Cotinine, ng/mL | Postvisit Urine Cotinine, ng/mL | Change in Urine Cotinine, ng/mL | Adjusted[a] Estimated SHS RSP, μg/m$^3$ | Estimated Outdoor Background RSP,[b] μg/m$^3$ | Estimated Total RSP[c] | Ratio, Total RSP to Background |
|---|---|---|---|---|---|---|---|---|---|---|
| The Meadows, Meadowlands (Washington County) | | | | | | | | | | |
| Participant 1 | 3:39 PM (4) | 5:30 PM | 11.33 | 0.1 | 2.3 | 2.2 | 204 | 14 | 218 | 16 |
| Participant 2 | 3:45 PM (4) | 5:30 PM | 11.25 | <0.1 | 1.0 | 0.9 | 83 | 14 | 97 | 7 |
| Participant 3 | 4:55 PM (4) | 5:30 PM | 12.97 | <0.1 | 3.1 | 3.0 | 295 | 14 | 309 | 22 |
| Philadelphia Park, Bensalem (Bucks County) | | | | | | | | | | |
| Participant 4 | 3:30 PM (4) | 5:00 PM | 15 | <0.1 | 2.0 | 1.9 | 201 | 14 | 215 | 15 |
| Participant 5 | 3:00 PM (5) | 5:00 PM | 10 | <0.1 | 2.1 | 2.0 | 146 | 14 | 160 | 11 |
| Participant 6 | 3:00 PM (5) | 5:00 PM | 11 | <0.1 | 2.0 | 1.9 | 139 | 14 | 153 | 11 |
| Presque Isle Downs (Erie County) | | | | | | | | | | |
| Participant 7 | 9:30 PM (4) | 12:00 PM | 16 | <0.1 | 0.6 | 0.5 | 55 | 11 | 66 | 5 |
| Participant 8 | 11:30 PM | 2:00 PM | 17 | <0.1 | . . . | . . . | . . . | 11 | . . . | . . . |
| Mean for 3 casinos | | | | | | 1.9[d] (0.5–3.0)[e] | 160 (81) | 13.6 | 174 (82) | |

[a]Adjusted for postvisit elapsed time greater than 11 hours.
[b]US Environmental Protection Agency.[26]
[c]Total RSPs are RSPs from SHS plus outdoor RSPs.
[d]Median.
[e]Range.

of SHS calculated for casino patrons in this study, casino workers are exposed to SHS at a concentration of 160 μg/m$^3$ (or to 16 μg/m$^3$ of SHS nicotine[13,30]) during the typical 250 8-hour workdays a year. An exposure–response relationship relating a 40-year working lifetime average exposure to SHS nicotine to cumulative excess risk of coronary heart disease and lung cancer mortality is given by the expression:

$$(7)\quad ER = (11 \text{ deaths per } 1000 \text{ workers}) / (40 \text{ years} - 7.5\mu g/m^3 \text{ SHS nicotine 40-year working} - \text{lifetime average}).^{13,30}$$

The combined excess risk of mortality from SHS exposure for nonsmoking workers exposed to an average exposure concentration, N, is then estimated by the equation:

$$(8)\quad \text{Risk} = ER \times N.$$

For Pennsylvania casino workers this is calculated as:

$$(9)\quad \text{Risk} = ER \times N = (11 \text{deaths} / 1000 \text{ workers} - 7.5\mu g/m^3) \times 16\mu g/m^3 = 23.5 \text{ deaths per } 1000 \text{ workers in } 40 \text{ years}.$$

Pennsylvania's gaming industry will ultimately provide 12 364 direct employment positions.[33] Assuming that 75% are nonsmokers, there will be an estimated 5.9 deaths per 10 000 nonsmoking workers per year attributable to SHS. An estimated 91% of these deaths will be from coronary heart disease, and 9% from lung cancer.[30]

## DISCUSSION

Mining is described as the most dangerous industry.[34] Sixteen Pennsylvania miners died in 15 disasters from 1995 to 2002, a rate of 1.2 deaths per 10 000 mine workers per year.[34] The estimated rate of worker deaths per year from SHS is about 5 times the average annual death rate for Pennsylvania miners in coal mine disasters. By the workplace standards of the US Occupational Safety and Health Administration (OSHA), which employs a 45-year average time period, casino workers' risk from SHS-induced lung cancer and heart disease combined is 26 times the level indicating significant risk of material impairment health.[30]

Pennsylvania's new clean indoor air law permits smoking in 25% to 50% of casino floors. Confining smokers to a smaller area will increase the local smoker density in the smoking area and not protect nonsmoking areas from drifting or recirculated tobacco smoke.

Another comparison is afforded by evaluating the cotinine-derived RSP plus background RSP concentrations (174 μg/m$^3$) through use of the federal Air Quality Index. A worker or patron in a casino for 8 hours a day and exposed to a background RSP concentration of 14 μg/m$^3$ for the remaining 16 hours of the day would be exposed to an average daily concentration of RSP of 67 μg/m$^3$. Some casino

patrons spend entire 24-hour periods within the confines of a casino and may experience longer periods of exposure than do workers, increasing their daily exposure to 174 μg/m$^3$. By Air Quality Index standards,[20,22,35] 24-hour $PM_{2.5}$ levels of 65.5 to 150.4 μg/m$^3$ constitute "unhealthy" air, and levels of 150.5 to 250.4 μg/m$^3$ constitute "very unhealthy" air. By comparison, the average outdoor air quality level of 14 μg/m$^3$ for the dates of the study was in the "good" range (<15 μg/m$^3$).[28] Assuming a concentration of RSPs from SHS 2000 times that of PPAHs,[14] a casino worker's 8-hour work-shift exposure to cotinine-derived PPAH is 80 ng/m$^3$, which is 15 times higher than that in outdoor levels.

## Risk Uncertainty

The uncertainty in dose-based risk assessment is driven by uncertainty in exposure, dose, and dose–response. Exposure uncertainty is driven by daily differences in SHS concentrations in a single casino and among casinos. For the 3 casinos in this study, the standard deviation between casinos was about 25%. Although the monitors provided readings every 10 seconds over several hours and 7 volunteers visited 3 casinos, only single days were measured, so that the results are less robust than if repeated sampling days in the same location had been performed. NIOSH found a 50% variation in the personal exposures of casino workers, although the median nicotine concentration differed by less than 10% from the Active Smoker Model prediction, which predicted the average 3-casino total RSP to within 14%. The lung cancer risk model used here for casino workers has an estimated uncertainty of less than 5%; mortality predictions of all credible published models differ by about 50%.[36,37] The heart disease risk model used here may underestimate risk by as much 50%.[30] The largest uncertainty in measured cotinine is because of individual biological differences, which have been estimated to contribute 40% to the variance.[30] Thus, average risk uncertainty is estimated to be within ± 200% based on currently available data. Additional casino measurements will provide better estimates.

## Conclusions

Despite ventilation rates per occupant 50% higher on average than those formerly recommended by ventilation engineers for smoking-permissible casinos, the average RSP concentration measured inside 3 Pennsylvania casinos in which smoking was permitted averaged 6 times that of outdoor levels; PPAH concentrations averaged 4 times outdoor levels, exposing both workers and patrons to harmful levels of air pollution. In the only casino with a separate nonsmoking floor, considerable amounts of RSPs and PPAHs infiltrated the nonsmoking salon. Based on measured RSP levels, SHS odor and irritation thresholds were massively exceeded in smoking areas and considerably exceeded in 1 nonsmoking salon. Using default values, the Active Smoker Model predicted combined RSP observations to within 14%.

Based on cotinine-derived RSP levels, SHS in Pennsylvania casinos produces an estimated excess mortality of approximately 6 deaths per year per 10 000 workers at risk, 5 times the rate at which Pennsylvania coal miners have died in mining disasters and 26 times OSHA's significant risk level. Nonsmoking workers or patrons exposed to casino SHS at the observed level of occupancy for 8 hours would experience "unhealthy air" according to the US Air Quality Index and, at maximum occupancy or exposure duration, "very unhealthy" air. Cotinine-derived PPAHs from SHS increases workers' 24-hour exposure to PPAHs by more than 5 times measured outdoor background levels.

Further research is needed to generalize exposures observed in this study to the casino industry as a whole. It is clear, however, that Pennsylvania casino workers and patrons are put at significant excess risk of heart disease and lung cancer from SHS through a failure to include casinos in the state's smoke-free workplace law. ■


## About the Author

*James L. Repace is with Repace Associates Inc, Bowie, MD, and the Department of Public Health and Family Medicine, Tufts University School of Medicine, Boston, MA.*

*Correspondence should be sent to James L. Repace, MSc, Repace Associates Inc, 101 Felicia Ln, Bowie, MD, 20720 (e-mail: repace@comcast.net). Reprints can be ordered from http://www.ajph.org by clicking on the "Reprints/Eprints" link.*


*This article was accepted October 22, 2008.*


## Acknowledgments

Financial support was provided by the Pennsylvania Alliance to Control Tobacco and from the Department of Civil and Environmental Engineering, Stanford University (project contract 20327320; Human Exposure Analysis to Pollutants From Secondhand Smoke). Funding originated from the Flight Attendant Medical Research Institute, Miami, FL.

J. B. Meyer and J. Kulaga provided invaluable assistance with air quality and cotinine data collection and volunteer recruitment. Cotinine analyses were provided by E. Giesbrecht of the Center for Addiction and Mental Health, University of Toronto, Toronto, Ontario.


## Human Participant Protection

The cotinine study was approved by the Pennsylvania Alliance to Control Tobacco's institutional review panel.

## References


1. American Gaming Association. State of the states—the 2008 AGA survey of casino entertainment. Available at: http://www.americangaming.org/survey/index.cfm. Accessed August 20, 2008.
2. Americans for Nonsmokers Rights. 100% smoke-free casinos and other gambling venues #18. 2007. Available at: http://www.no-smoke.org/goingsmokefree.php?id=519#maps. Accessed September 20, 2007.
3. Beringer SG, Martin M, Susman TM. *Indoor Air Quality and the Gaming Industry.* Washington, DC: American Gaming Association; 2006.
4. Mandel LL, Glantz SA. Hedging their bets: tobacco and gambling industries work against smoke-free policies. *Tob Control.* 2004;13:268–276.
5. Air Resources Board, California Environmental Protection Agency. Proposed identification of environmental tobacco smoke as a toxic air contaminant. 2006. Available at: http://www.arb.ca.gov/regact/ets2006/ets2006.htm. Accessed December 8, 2008.
6. *The Health Consequences of Involuntary Exposure to Tobacco Smoke: A Report of the Surgeon General.* Washington, DC: US Dept of Health and Human Services; 2006.
7. US Centers for Disease Control and Prevention. Smoking and tobacco use fact sheets. Available at: http://www.cdc.gov/tobacco/data_statistics/Factsheets. Accessed December 8, 2008.
8. Trout D, Decker J, Mueller C, Bernert JT, Pirkle J. Exposure of casino employees to environmental tobacco smoke. *J Occup Environ Med.* 1998;40:270–276.
9. *Mullen v Treasure Chest Casino LLC*, 186 F3d 620 (5th Cir 1999), settled out of court.
10. *Januszewski v Horseshoe Hammond*, No. 2:00CV352JM (ND Ind.), settled out of court.
11. *Avallone et al. v American Tobacco Company, et al.*, Superior Court of New Jersey, Middlesex County, April 23, 1998, dismissed.
12. *Badillo et al. v American Tobacco Co.* (class action US Dist Ct Nevada 1997 decertified).
13. Repace JL, Lowrey AH. An enforceable indoor air quality standard for environmental tobacco smoke in the workplace. *Risk Anal.* 1993;13:463–475.
14. Repace JL. Respirable particles and carcinogens in the air of Delaware hospitality venues before and after a smoking ban. *J Occup Environ Med.* 2004;46:887–905.
15. Anderson KE, Kliris J, Murphy L, et al. Metabolites of a tobacco-specific lung carcinogen in nonsmoking

casino patrons. *Cancer Epidemiol Biomarkers Prev.* 2003;12:1544–1546.

16. Weber A, Grandjean E. Acute effects of environmental tobacco smoke. In: O'Neill IK, Brunnemann KD, Dodet B, Hoffmann D, eds. *Environmental Carcinogens: Selected Methods of Analysis.* Vol 9. Lyon, France: International Agency for Research on Cancer, World Health Organization; 1987:59–68. IARC Scientific Publications No. 81.

17. Junker MH, Danuser B, Monn C, Koller T. Acute sensory responses of nonsmokers at very low environmental tobacco smoke concentrations in controlled laboratory settings. *Environ Health Perspect.* 2001;109: 1045–1052.

18. General Assembly of Pennsylvania. Senate Bill No. 246, Session of 2007: The Smoke Free Pennsylvania Act. Available at: http://www.legis.state.pa.us/CFDOCS/Legis/PN/Public/btCheck.cfm?txtType=HTM&sessYr=2007&sessInd=0&billBody=S&billTyp=B&billNbr=0246&pn=2099. Accessed December 8, 2008.

19. Johnson L. Study: air worse in smoky bars than on truck-choked roads. *Associated Press.* September 19, 2004.

20. Repace J, Hughes E, Benowitz N. Exposure to secondhand smoke air pollution assessed from bar patrons' urine cotinine. *Nicotine Tob Res.* 2006;8:701–711.

21. Repace JL. Air quality in Virginia's hospitality industry a report prepared for Virginians for a Healthy Future. January 2006. Available at: http://www.repace.com/reports.html. Accessed December 8, 2008.

22. Repace JL, Hyde JN, Brugge D. Air pollution in Boston bars before and after a smoking ban. *BMC Public Health.* 2006;6:266–280. Available at: http://www.biomedcentral.com/1471-2458/6/266. Accessed December 8, 2008.

23. American Society of Heating Refrigerating and Air Conditioning Engineers. Standard addendum ASHRAE. 62 O to ANSI/ASHRAE Standard 62. 2001. Available at: http://www.ashrae.org/docLib/20042215511_347.pdf. Accessed December 8, 2008.

24. American Society of Heating Refrigerating and Air Conditioning Engineers. Position document on environmental tobacco smoke. 2005. Available at: http://www.ashrae.org/content/ASHRAE/ASHRAE/ArticleAltFormat/20058211239_347.pdf. Accessed December 8, 2008.

25. Repace JL. Exposure to secondhand smoke. In: Ott W, A Steinemann A, Wallace L, eds. *Exposure Analysis.* New York, NY: CRC Press; 2006:201–235.

26. Pritsos CA, Pritsos KL, Spears KE. Smoking rates among gamblers at Nevada casinos mirror US smoking rate. *Tob Control.* 2008;17:82–85.

27. Pennsylvania Department of Health. Pennsylvania tobacco facts 2007. Available at: http://www.dsf.health.state.pa.us/health/search/Search.asp?qu=smoking+prevalence&Go.x=18&Go.y=15&Go=Submit. Accessed December 8, 2008.

28. US Environmental Protection Agency. PM2.5 air quality for Pennsylvania and EPA air quality index (AQI) for August 13 at 6:00 PM, August 15 at 11 AM and 3 PM, and on August 31 at 7 PM. 2007. Available at: http://cfpub.epa.gov/airnow/index.cfm?action=airnow.displaymaps&Pollutant=PM2.5&StateID=60&domain=super. Accessed December 8, 2008.

29. Repace JL, Al-Delaimy WK, Bernert JT. Correlating atmospheric and biological markers in studies of secondhand tobacco smoke exposure and dose in children and adults. *J Occup Environ Med.* 2006;48:181–194.

30. Repace JL, Jinot J, Bayard S, Emmons K, Hammond SK. Air nicotine and saliva cotinine as indicators of passive smoking exposure and risk. *Risk Anal.* 1998; 18:71–83.

31. Bureau of Air Quality, Pennsylvania Department of Environmental Protection. Background annual average outdoor RSP levels (PM2.5) by county for Pennsylvania, 2004. Available at: http://www.dep.state.pa.us/dep/deputate/airwaste/aq/aqm/aqreport.htm. Accessed December 8, 2008.

32. Biener L, Fitzgerald G. Smoky bars and restaurants: who avoids them and why? *J Public Health Manag Pract.* 1999;5:74–78.

33. *Spectrum Report: Preparing for the Pennsylvania Gaming Industry. A Report for Deputy Secretary S.Vito, Pennsylvania Department of Labor & Industry.* Northfield, NJ: Spectrum Gaming Group LLC; October 2006.

34. CNN.com. Pennsylvania mining fatalities July 26, 2002. Available at: http://archives.cnn.com/2002/US/07/25/mine.pa.fatalities/index.html. Accessed Oct. 27, 2007.

35. US Environmental Protection Agency. Guideline for reporting of daily air quality—air quality index (AQI). 1999. Available at: http://www.paworkforce.state.pa.us/professionals/lib/professionals/pdf/conferences/oct-17-06/sgg_report_111506.pdf. Accessed December 8, 2008.

36. Repace JL, Lowrey AH. Risk assessment methodologies in passive smoking-induced lung cancer. *Risk Anal.* 1990;10:27–37.

37. Repace JL, Lowrey AH. A quantitative estimate of nonsmokers' lung cancer risk from passive smoking. *Environ Int.* 1985;11:3–22.

38. Achutan C, West C, Mueller C, Boudreau Y, Mead K. *Environmental and Biological Assessment of Environmental Tobacco Smoke Exposure Among Casino Dealers: Bally's, Paris, and Caesar's Palace Casinos, Las Vegas, Nevada, May 2009.* National Institute for Occupational Safety and Health: Atlanta, GA. Available at: http://www.cdc.gov/niosh/hhe. Accessed June 22, 2009.