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Platform W1B Indoor Exposures & ETS Abstract W1B-07

Indoor and Outdoor Carcinogen Pollution on a Cruise Ship

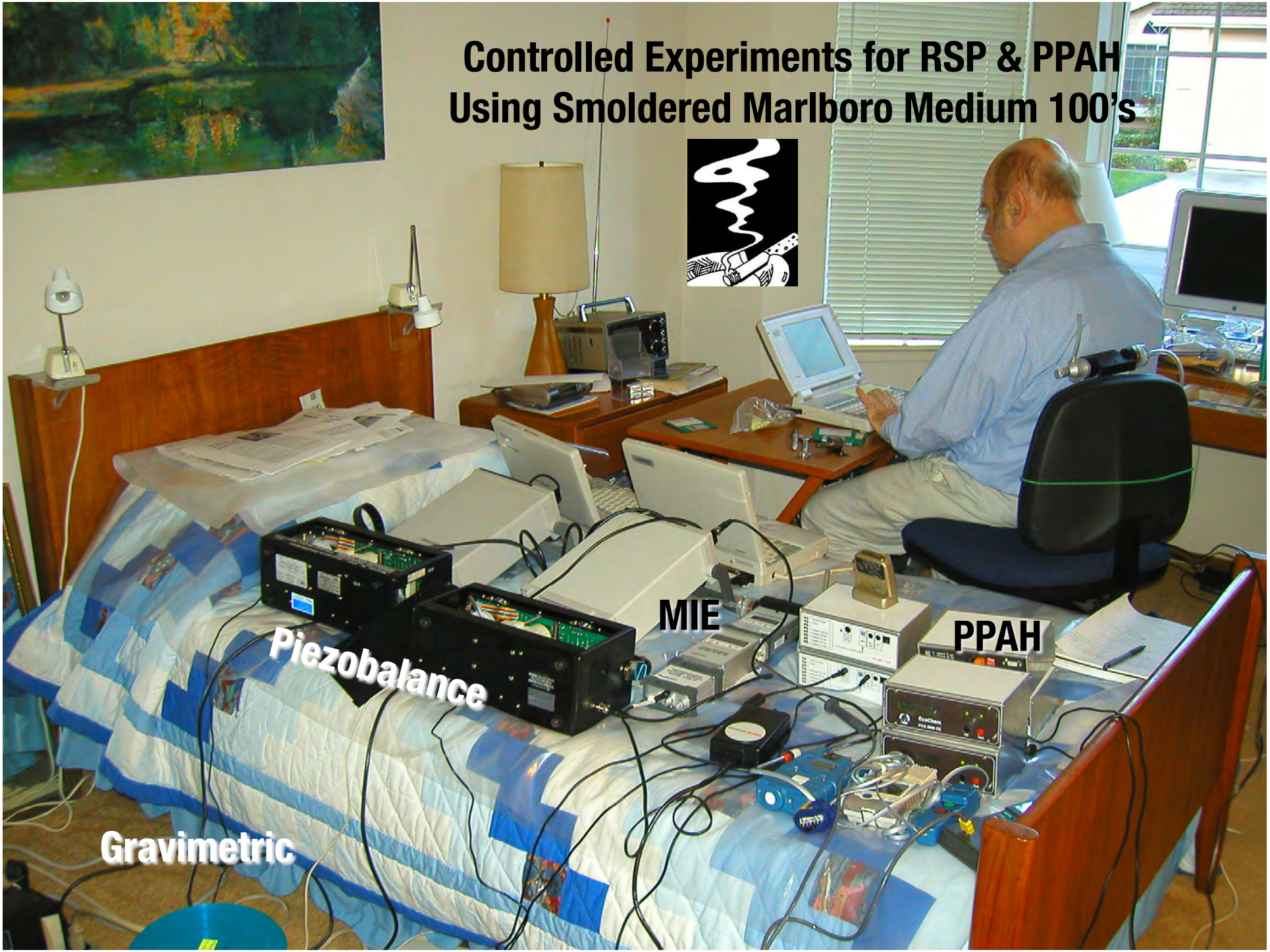
James L. Repace, Tufts University School of Medicine and Repace Associates, Inc.

Supported by the Flight Attendant Medical Research Institute Wm. F. Cahan Distinguished Professor Award


Regal Rec

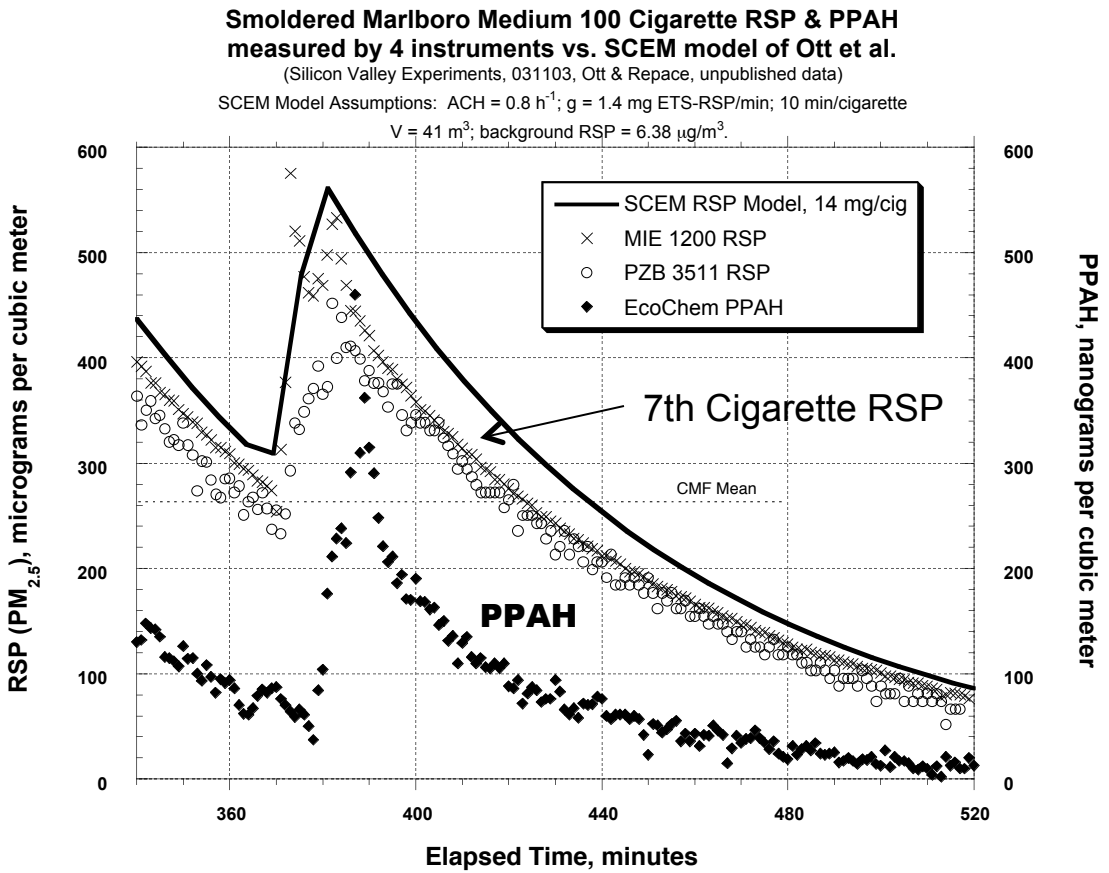
ETS Indoor & Outdoor Air Pollution

- Can ETS be detected outdoors?
- What pollutants should be measured?
- How to eliminate confounders?
- What instruments should be used?
- How to calibrate the instruments?
- Relative ETS levels in outdoor vs. indoor venues?
- Is ETS outdoors a health risk to outdoor workers?
- What are the implications for outdoor bans?


Controlled Experiments for RSP & PPAH
Using Smoldered Marlboro Medium 100's
MIE
PPAH
Piezobalance
Gravimetric

PPAH Emissions from 7 Smoldered Marlboros: Controlled Expt.†

†*JL Repace, JOEM 46:887-905(2004)*



Concentration Ratio = $\frac{RSP}{PPAH} = \frac{2054^{*}}{1} = \frac{\frac{ER_{RSP}}{CR_{RSP}}}{\frac{ER_{PPAH}}{CR_{PPAH}}} = \frac{\frac{14{,}000\mu g/cig}{1m^3/\min^{-1}}}{\frac{E_{PPAH}\mu g/cig}{1.9m^3/\min^{-1}}}$

PPAH Emissions/cigarette = ER_{PPAH} = 13.0 μg/cig

**(from Delaware field survey regression)*

WILMINGTON, DELAWARE RSP/PPAH AQ STUDY

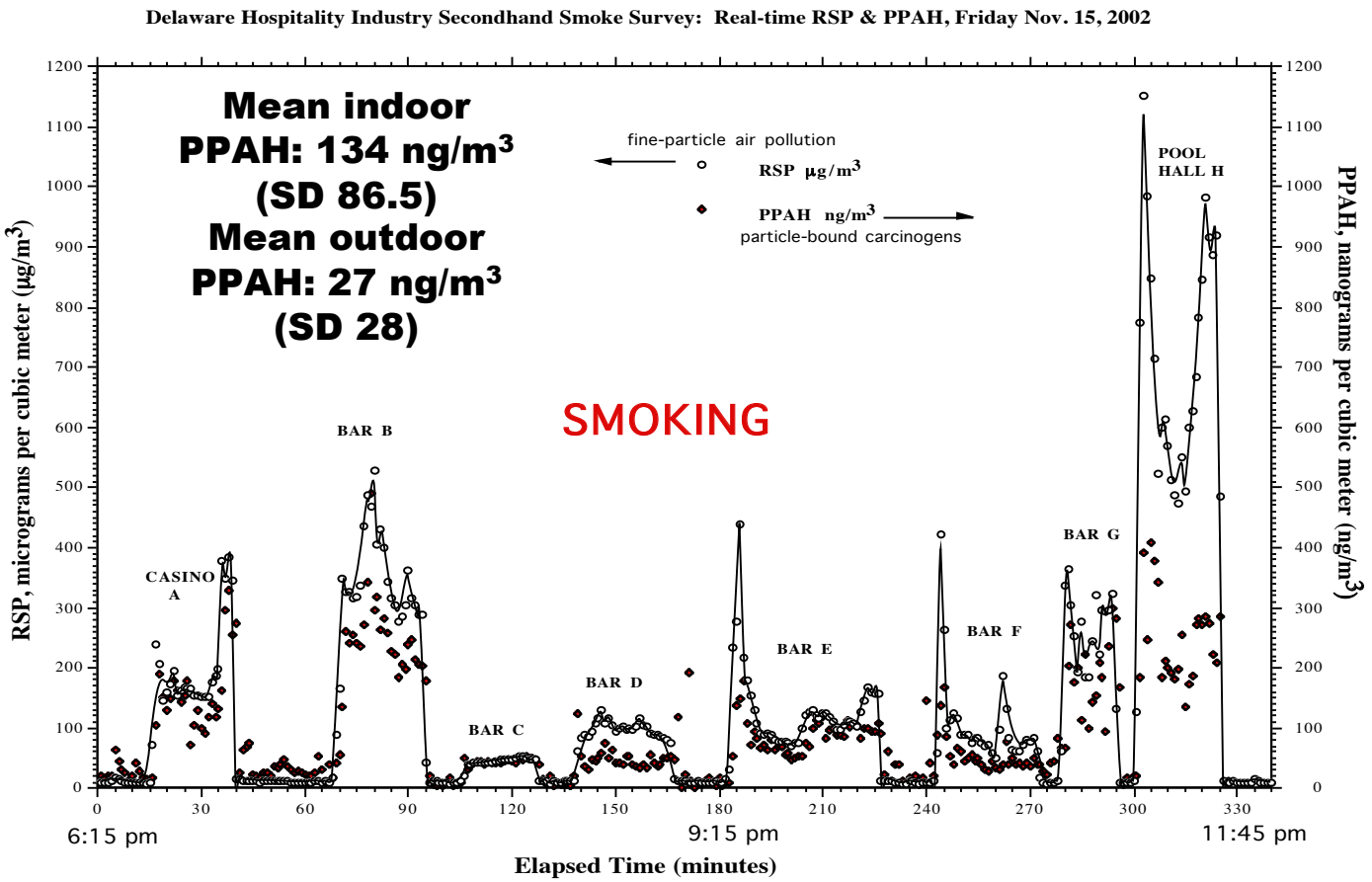


Figure 3. Real-time respirable-particle (RSP) air pollution and airborne carcinogens (PPAH) in a casino, 6 bars, and pool hall before a smoking ban. Data recorded on Friday Evening, November 15, 2002. Outdoor & in-transit location measurements precede & follow each Venue sampled. All venues were crowded, with persons observed to be smoking throughout the sampling periods.

JL Repace, JOEM 46:887-905(2004)

WILMINGTON, DELAWARE RSP/PPAH AQ STUDY

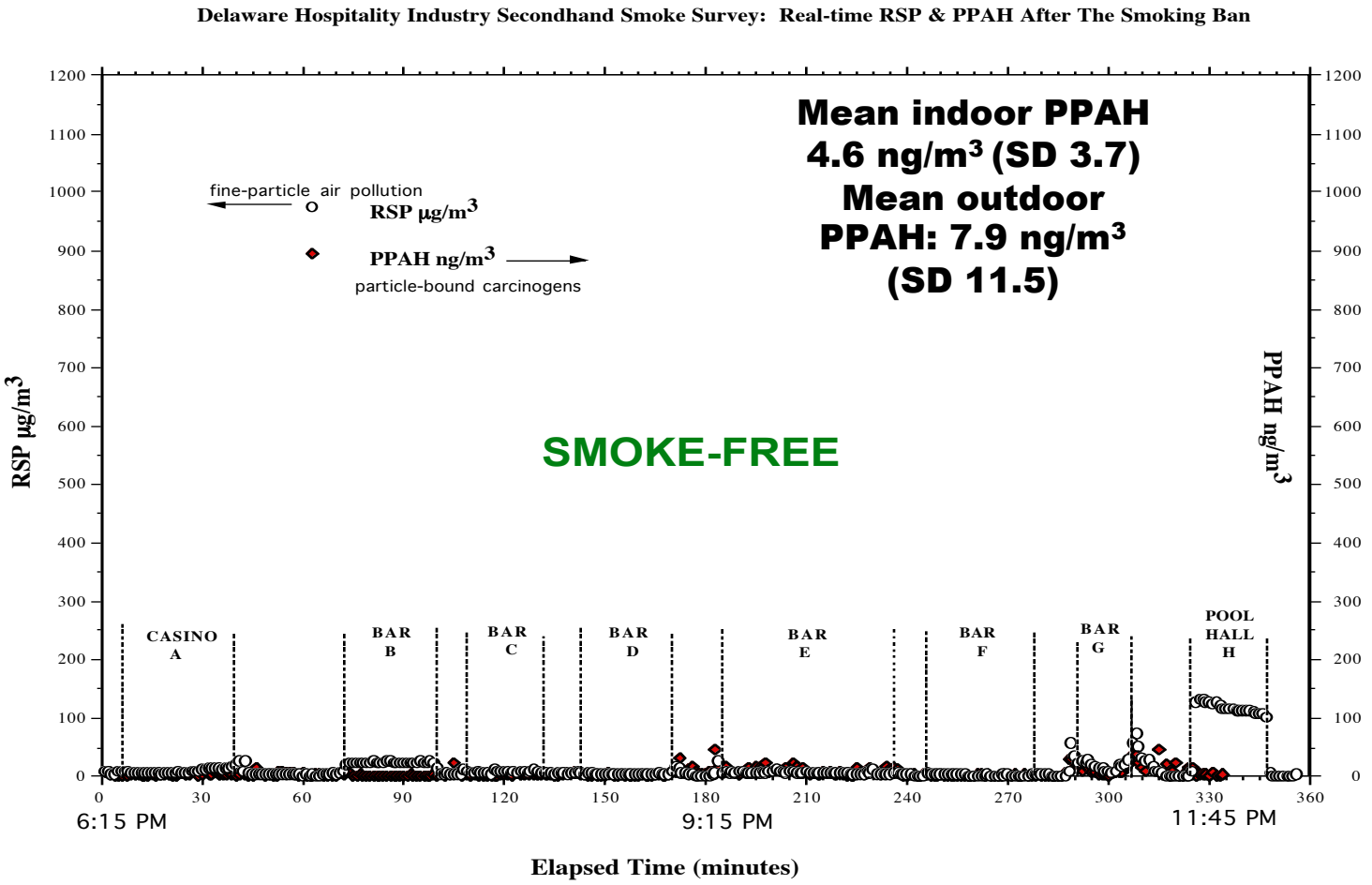


Figure 6. Real-time respirable-particle (RSP) air pollution and airborne carcinogens (PPAH) in the casino, 6 bars, and the pool hall after the smoking ban. Compare with Figure 3. Data recorded on Friday Evening, January 24, 2003. Outdoor & in-transit location measurements precede & follow each Venue sampled. All venues were crowded, and all appeared to be in compliance with the Delaware smoking ban.

JL Repace, JOEM 46:887-905(2004)

REGRESSION RSP vs PPAH, DELAWARE AQ STUDY

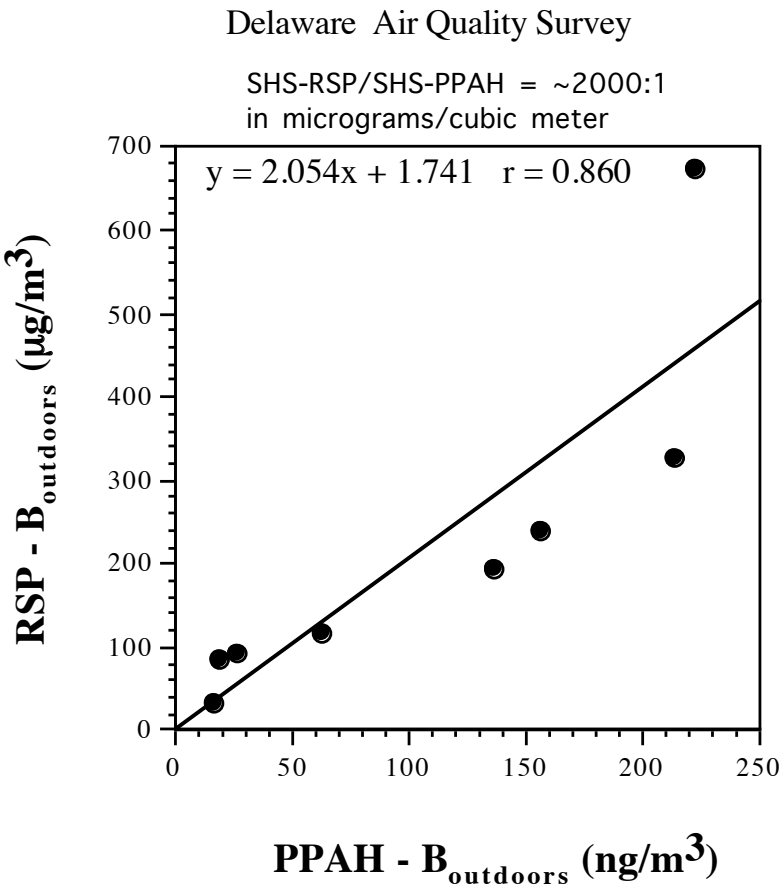


Figure 5. A plot of total indoor RSP minus the average outdoor/hotel RSP background (estimated SHS-RSP) versus total indoor PPAH minus the average outdoor/hotel PPAH background (estimated SHS-PPAH) pre-smoking ban for the 8 hospitality venues on November 15, 2002. A strong linear correlation between SHS-RSP and SHS-PPAH is seen ($r^2 = 0.74$), with a RSP/PPAH ratio of ~2000:1 .

JL Repace, JOEM 46:887-905(2004)

10 PPAH In Cig. Smoke

vs. IARC CARC. Status

Table 4. Carcinogenic PPAH, IARC Status, Amount in Cigarette Smoke*

Particulate Phase PAH (PPAH) †[4 or more rings][G]	IARC Carcinogen In Lab Animals (a) Humans (h)	Amount Measured In Mainstream Smoke (MS) (ng/cig)	Amount Measured in Sidestream Smoke (SS) or SHS (ng/cig)*	Reference*
Benz(a)anthracene†	Sufficient[a]	20-70	412	*A,B,F*
Benzo(b)fluoranthene†	Sufficient[a]	4-22	132	*A,B,F*
Benzo(j)fluoranthene†	Sufficient[a]	6-21	32	*A,B,F*
Benzo(k)fluoranthene†	Sufficient[a]	6-12		*A,F*
Benzo(a)pyrene†	Sufficient[a,h]	20-40 8.5-11.6	74	*A,B,* *F*
Dibenzo(a,e)pyrene†	Sufficient[a]	present		*F*
Dibenzo(a,i)pyrene†	Sufficient[a]	1.7-3.2		*A*
Dibenz(a,h)anthracene†	Sufficient[a]	4		*A*
Indeno(1,2,3-cd)pyrene†	Sufficient[a]	4-20	51	*A,D*
5-methylchrysene†	Sufficient[a]	ND-0.6		*A*
All PPAH in SS machine-smoked 1R4F research cigarette	-	-	1,067	*B*
All PPAH in SHS human-smoked Camel, Merit, Winston, Benson & Hedges cigarettes	-	-	13,500	*C*
All PPAH in SHS smoldered Marlboro Medium 100s			**13,000**	*E*
All PPAH in SHS human-smoked Marlboro Lite 100s	-	-	**13,300**	***this experiment***

*References: *A*. Hoffmann & Hoffmann (1998); *B*. Gundel et al. (1995); *C*. Rogge et al. (1994); *ng/cig = nanograms per cigarette. Blank cells indicate no data available; IARC = International Agency for Research on Cancer. *D*. Hecht (2004). E. Measured by EcoChemPAS2000CE; Repace (JOEM, 2004). *F*. IARC Monographs, Volume 83 (2004). *G*. Hoffmann and Wynder (1967).

Rogge, et al.

Si Valley Expts.

Cruiseship

All Cruise Lines
- Celebrity Cruises
  - Summit

summit ship facts

Occupancy: 1,950
Tonnage: 91,000
Length: 965 feet
Beam: 105 feet
Draught: 26 feet
Cruising Speed: 24 knots
Electric Current: 110/220 AC
Ship's Registry: Bahamas
Delivery: September 2001

Gas-Turbine Powered:
Low PPAH emissions;
10-day Eastern Caribbean Cruise
February 2004

9-Night Southern Caribbean Sailing - Round-trip from Fort Lauderdale

	Destination	Arrives	Departs
Day 1	Fort Lauderdale		4:30 PM
Day 2	At Sea		
Day 3	At Sea		
Day 4	Castries	8:00 AM	5:00 PM
Day 5	Bridgetown	7:00 AM	5:00 PM
Day 6	Philipsburg	10:30 AM	6:30 PM
Day 7	Charlotte Amalie	7:00 AM	6:00 PM
Day 8	At Sea		
Day 9	At Sea		
Day 10	Fort Lauderdale	7:00 AM	

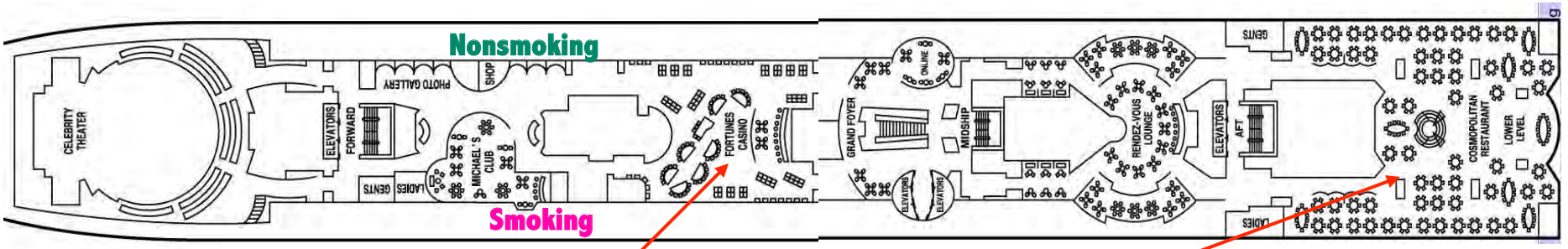
St. Lucia
Barbados
St. Maarten
St. Thomas

} **1st Monitoring Study: Feb. 15-16, 2004**

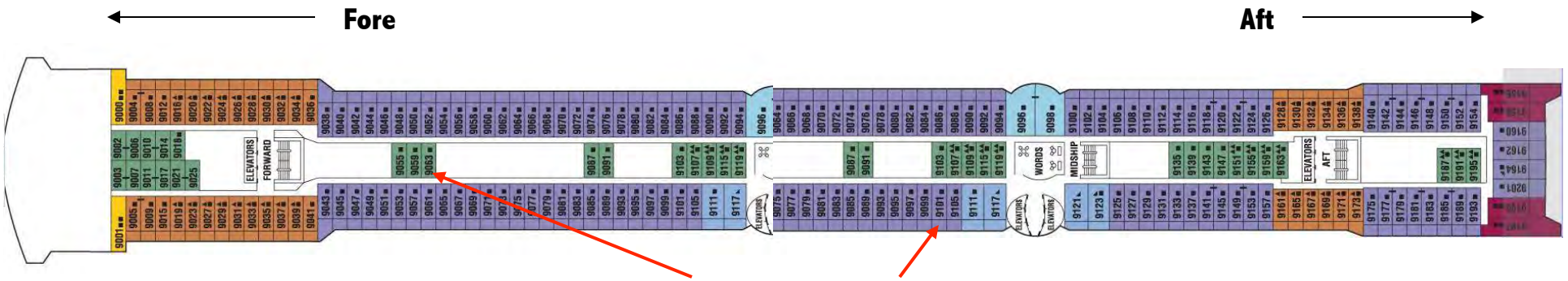
} **2nd Monitoring Study: Feb. 21-22, 2004**


Caribbean Basin
Florida (U.S.A.)
80°
70°
60°
Grand Bahama
Great Abaco
Freeport
Miami
Gulf of Mexico
Bimini Islands
Straits of Florida
Nassau
Eleuthera
The Bahamas
New Providence
Cat Island
Cay Sal Bank (The Bahamas)
San Salvador
Tropic of Cancer
Andros Island
Great Exuma
Rum Cay
Havana
Matanzas
Long Island
Crooked Island
Pinar del Rio
Santa Clara
Cienfuegos
Mayaguana
Atlantic Ocean
Turks & Caicos Islands (U.K.)
Acklins Island
Yucatan Channel
Isla de la Juventud
Cuba
Camagüey
Great Inagua
Grand Turk
Holguin
Santiago de Cuba
Guantánamo
20°
George Town
Cayman Islands (U.K.)
Guantánamo Bay U.S. Naval Station
Windward Passage
Cap-Haitien
Santiago
Haiti
Dominican Republic
Mona Passage
British Virgin Islands
Anguilla (U.K.)
St. Martin (Fr.)
Navassa Island (U.S.)
Port-au-Prince
Santo Domingo
San Juan
Sint Maarten (N.A.)
St. Barthélemy (Fr.)
Montego Bay
Les Cayes
Isla Mona (P.R.)
Puerto Rico (U.S.)
U.S. Virgin Islands
Antigua and Barbuda
Saba (N.A.)
St. John's
Swan Islands (Hon.)
Jamaica
Kingston
Basseterre
St. Kitts & Nevis
Montserrat (U.K.)
Basse-Terre
Honduras
Puerto Lempira
Guadeloupe (Fr.)
Isla Aves (Ven.)
Dominica
Roseau
Caribbean Sea
Martinique (F.R.)
Fort-de-France
Castries
St. Lucia
St. Vincent and The Grenadines
Kingstown
Barbados
Bridgetown
Netherland Antilles
Aruba
Curacao
Bonaire
Willemstad
Islas Los Roques (Ven.)
La Blanquilla (Ven.)
St. George's
Grenada
Isla de Margarita (Ven.)
Trinidad and Tobago
Tobago
Isla La Tortuga (Ven.)
Barranquilla
Santa Marta
Maracaibo
Venezuela
Port of Spain
Trinidad
Cartagena
Caracas
Barcelona
10°
0
400
800 km
0
nautical miles
500
Columbia
Celebrity Cruises
a true departure
TO AND FROM FT. LAUDERDALE
ST. THOMAS
ST. MAARTEN
ST. KITTS
ST. LUCIA
BARBADOS
Caribbean Sea
10-night southern caribbean sailing on summit


At Sea: 1st Monitoring Study



Deck 4: Casino & Indoor Restaurant Deck

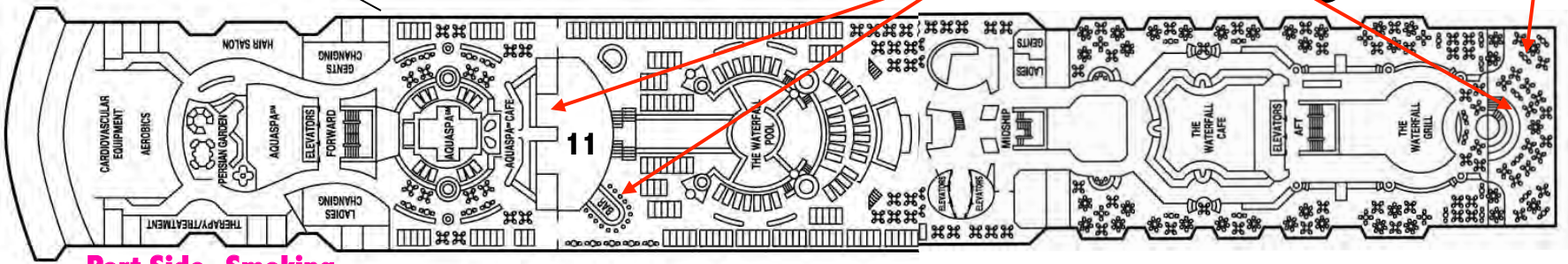


Decks 5-9, Inside & Outside Staterooms

Starboard Side- Nonsmoking

Cigar Bar

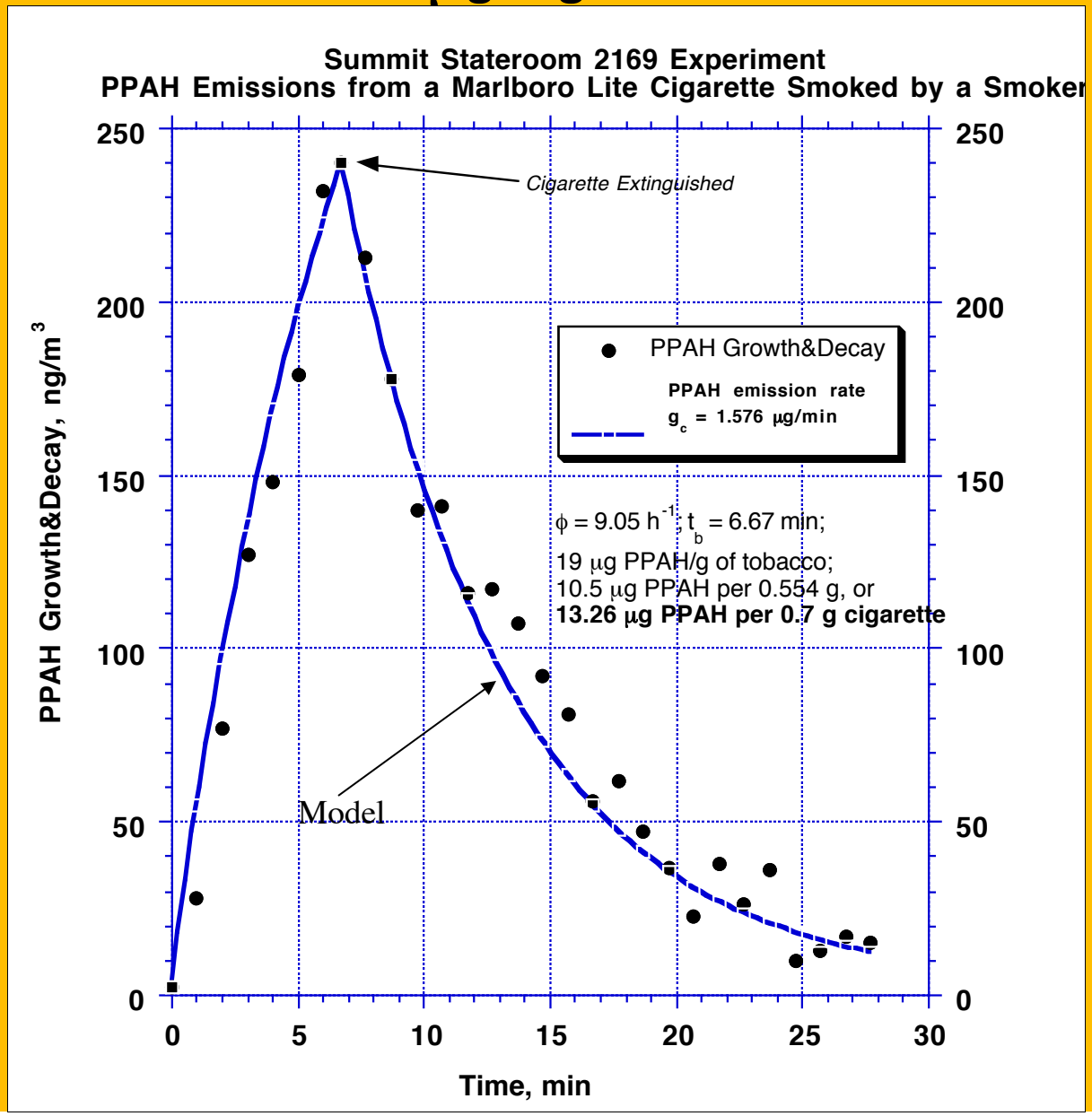
Decks 10-11, Pool Deck, Outdoor Smoking Bars



Port Side- Smoking

CONTROLLED EXPERIMENT - INSIDE STATEROOM

EcoChem PAS2000CE Human Smoker Calibration Experiment:
ETS PPAH Emissions: 13.3 μg/cigarette from Mass-Balance Model



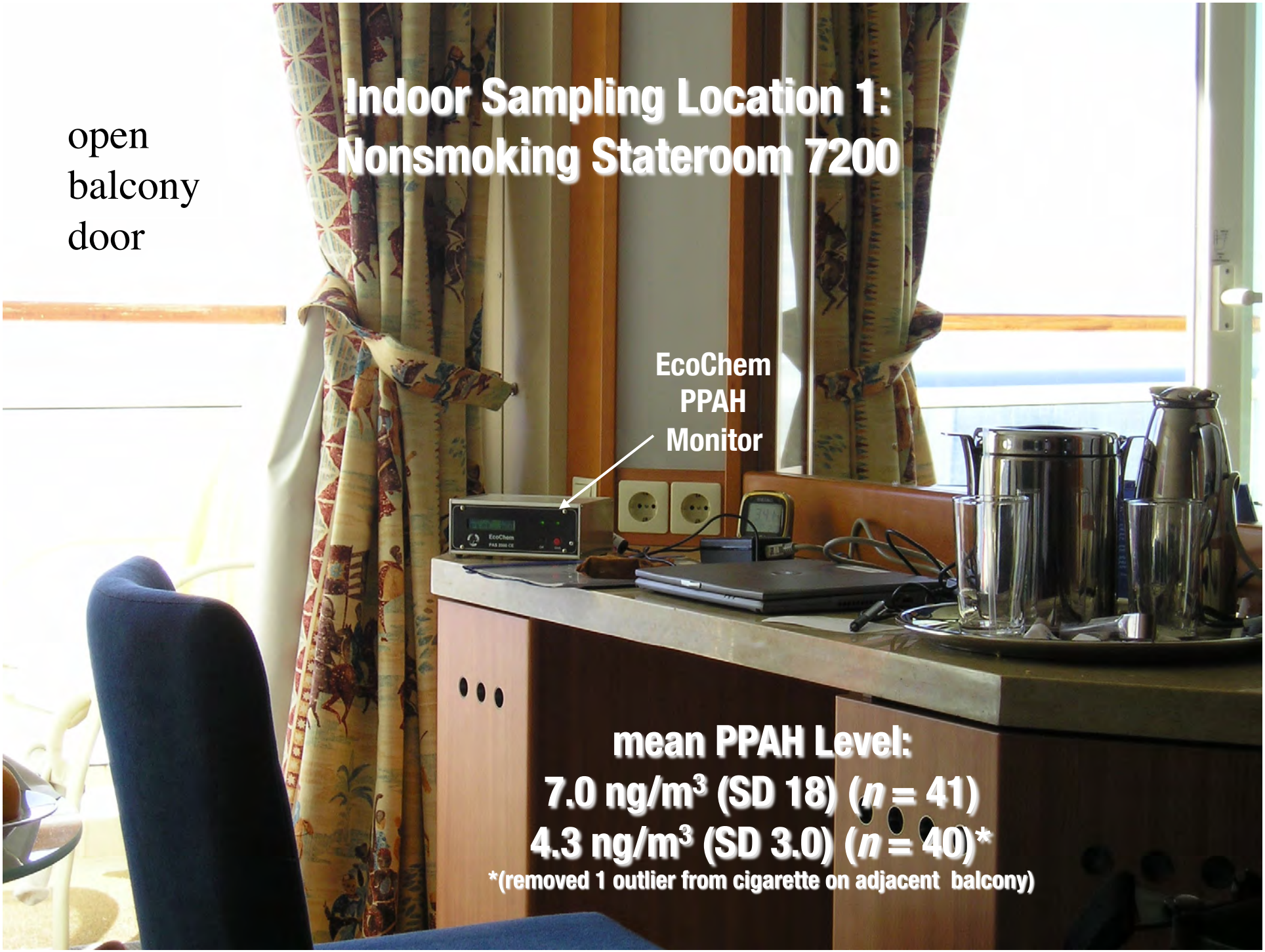
vs. 13.5 μg/cig (human smokers) reported by Rogge, et al. ES&T 1994; 26:1375-1388,

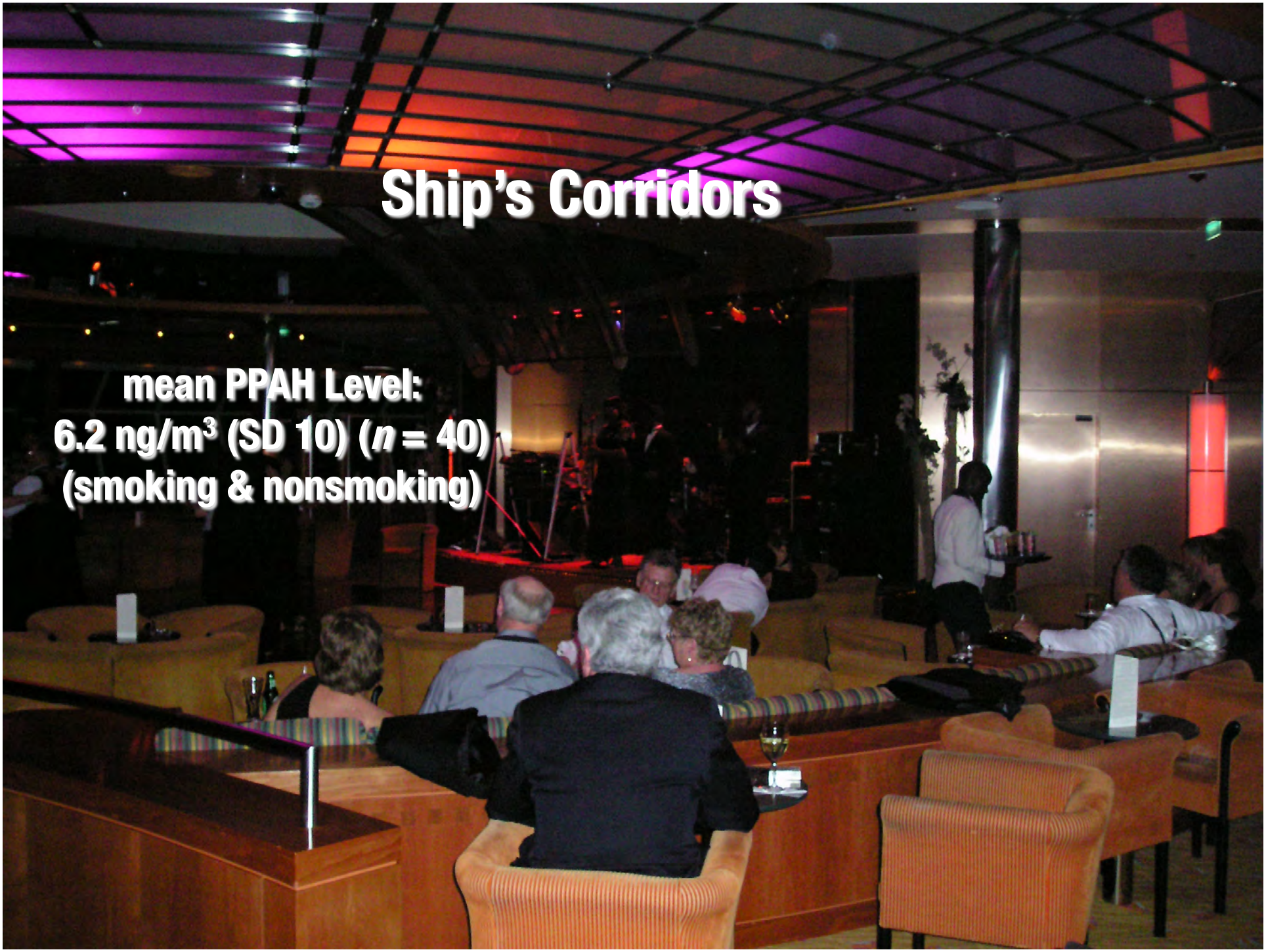
vs. 13.0 μg/cig (smoldered) estimated from Repace, JOEM 2004;46:887-905.


Deck 11
Pool Deck 10
port (smoking) side

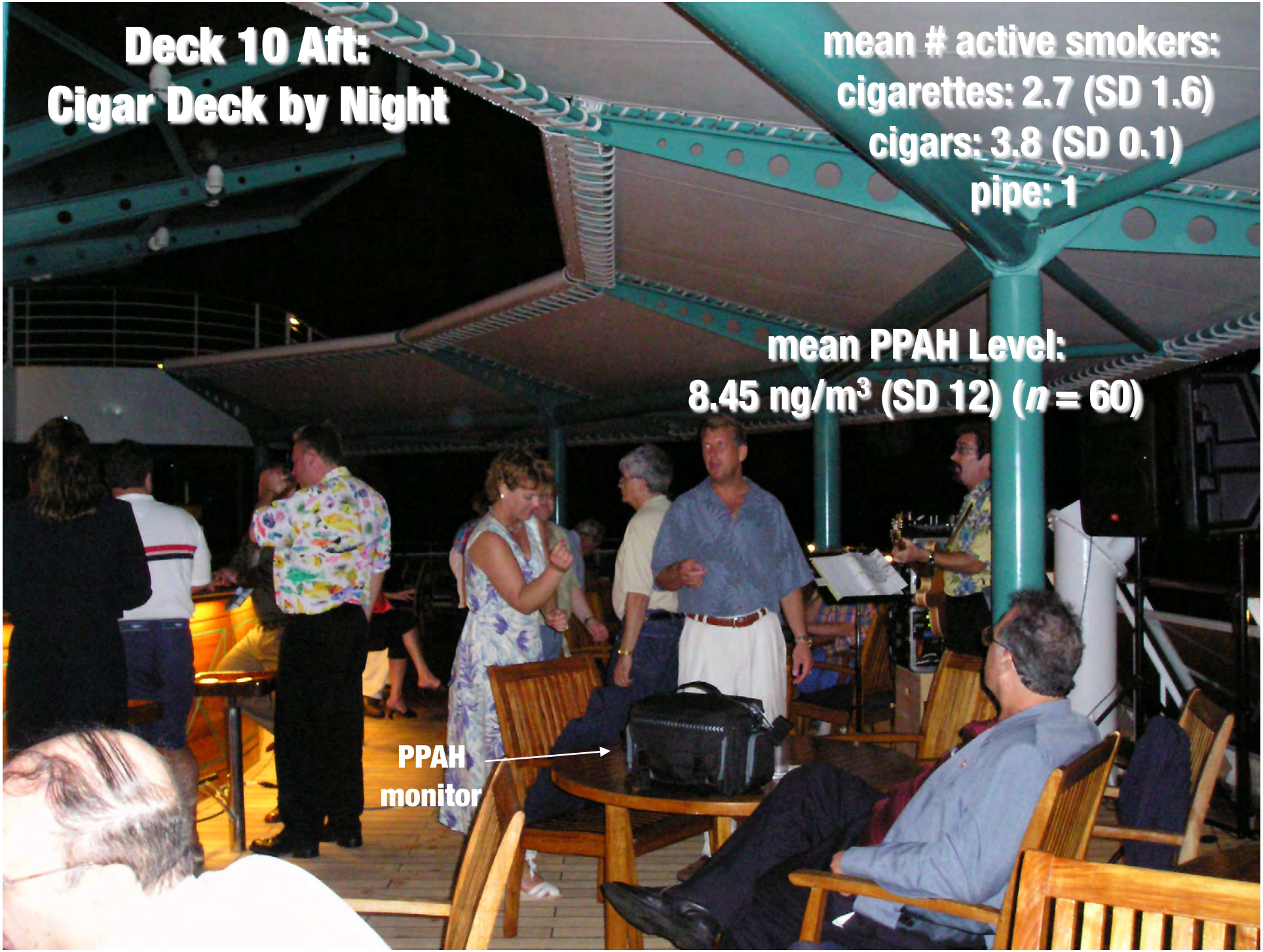
Outdoor Nonsmoking Location: Starboard Side Forward, Deck 11


Indoor Sampling Location 2:
Nonsmoking Restaurant
Deck 4
mean PPAH Level:
2.69 ng/m3 (SD 2.4) (n = 130)

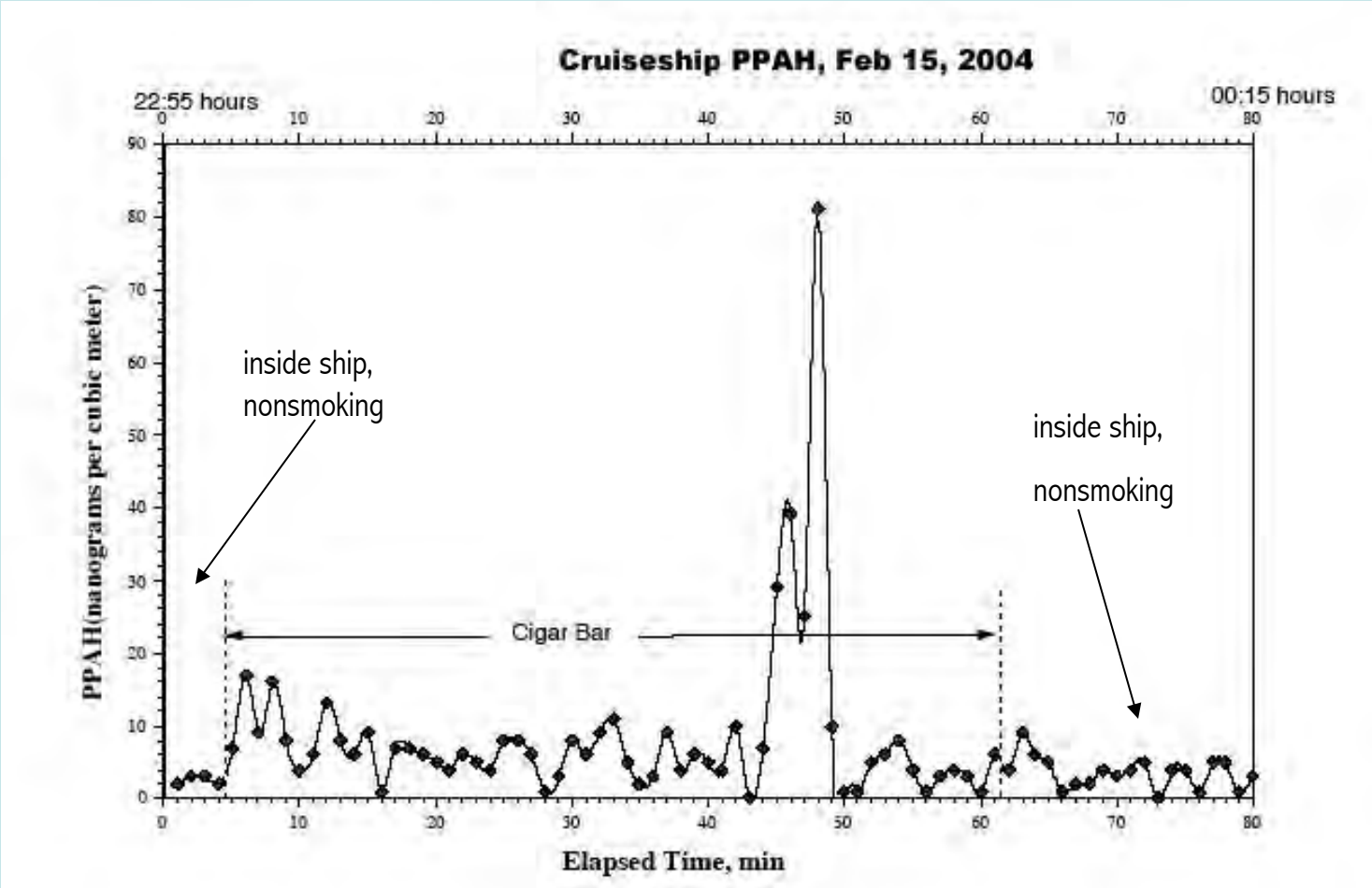

Indoor Sampling Location 1:
Nonsmoking Stateroom 7200
open
balcony
door
EcoChem
PPAH
Monitor
mean PPAH Level:
7.0 ng/m3 (SD 18) (n = 41)
4.3 ng/m3 (SD 3.0) (n = 40)*
*(removed 1 outlier from cigarette on adjacent balcony)


Ship's Corridors
mean PPAH Level:
6.2 ng/m3 (SD 10) (n = 40)
(smoking & nonsmoking)

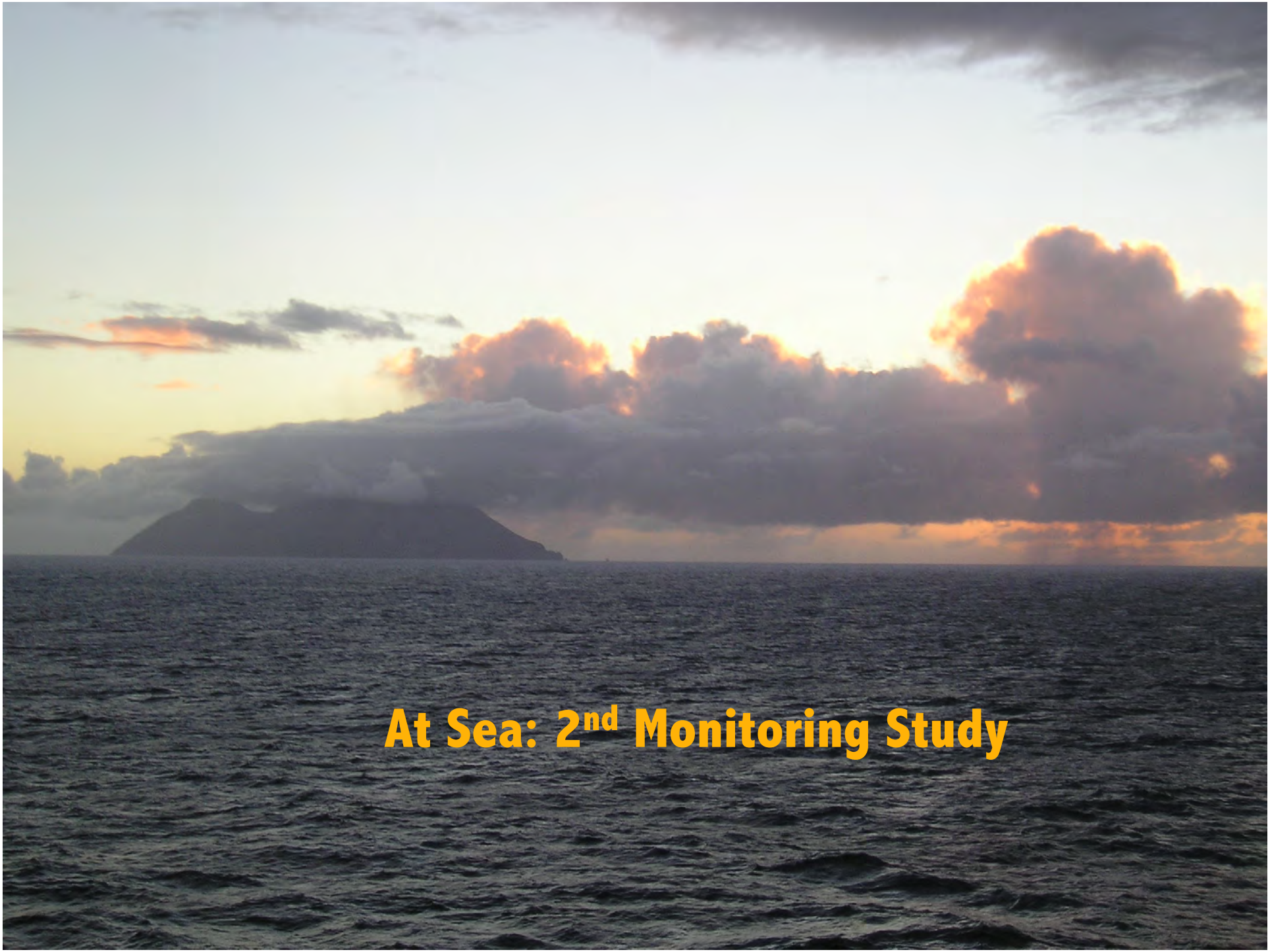

Deck 10 Aft:
By Day


Deck 10 Aft:
Cigar Deck by Night
mean # active smokers:
cigarettes: 2.7 (SD 1.6)
cigars: 3.8 (SD 0.1)
pipe: 1
mean PPAH Level:
8.45 ng/m3 (SD 12) (n = 60)
PPAH
monitor

REAL-TIME PPAH DATA before/after Cigar Bar



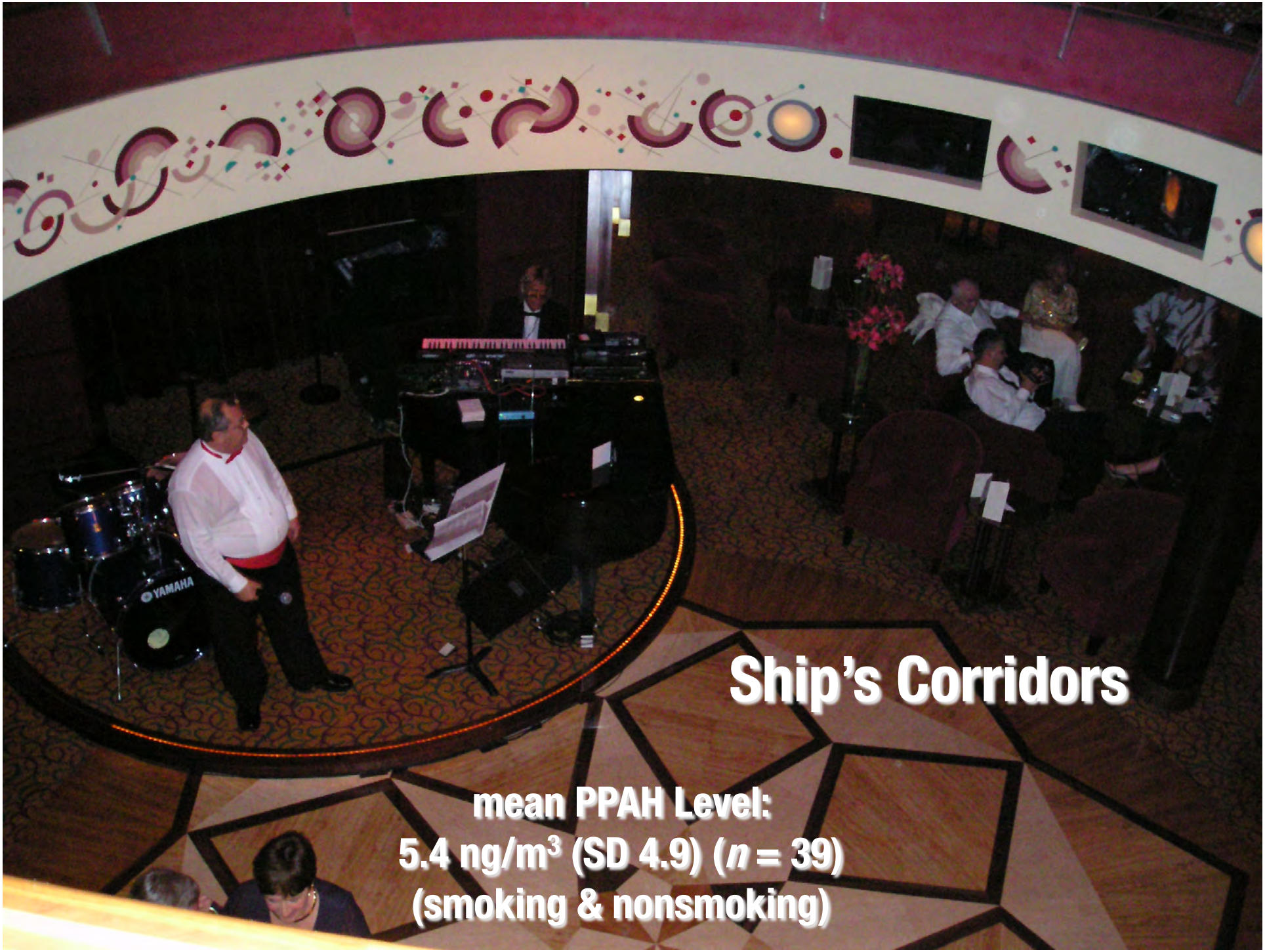

Deck 10 Pool Bar
Smoking
mean # active smokers:
cigarettes: 1.9 (SD 1.6)
PPAH
monitor
mean PPAH Level:
8.9 ng/m3 (SD 12) (n = 45)


At Sea: 2nd Monitoring Study


Indoor Sampling Location 1:
Nonsmoking Stateroom 7200
mean PPAH Level:
3.1 ng/m3 (SD 2.9) (n = 71)

Outdoor Control Location: Nonsmoking Side Deck 11


Indoor Sampling Location 2:
Nonsmoking Restaurant Deck 4
mean PPAH Level:
8.4 ng/m3 (SD 29) (n = 59)
2.4 ng/m3 (SD 2.6) (n = 55)*
*(removed 4 outliers from birthday candles)



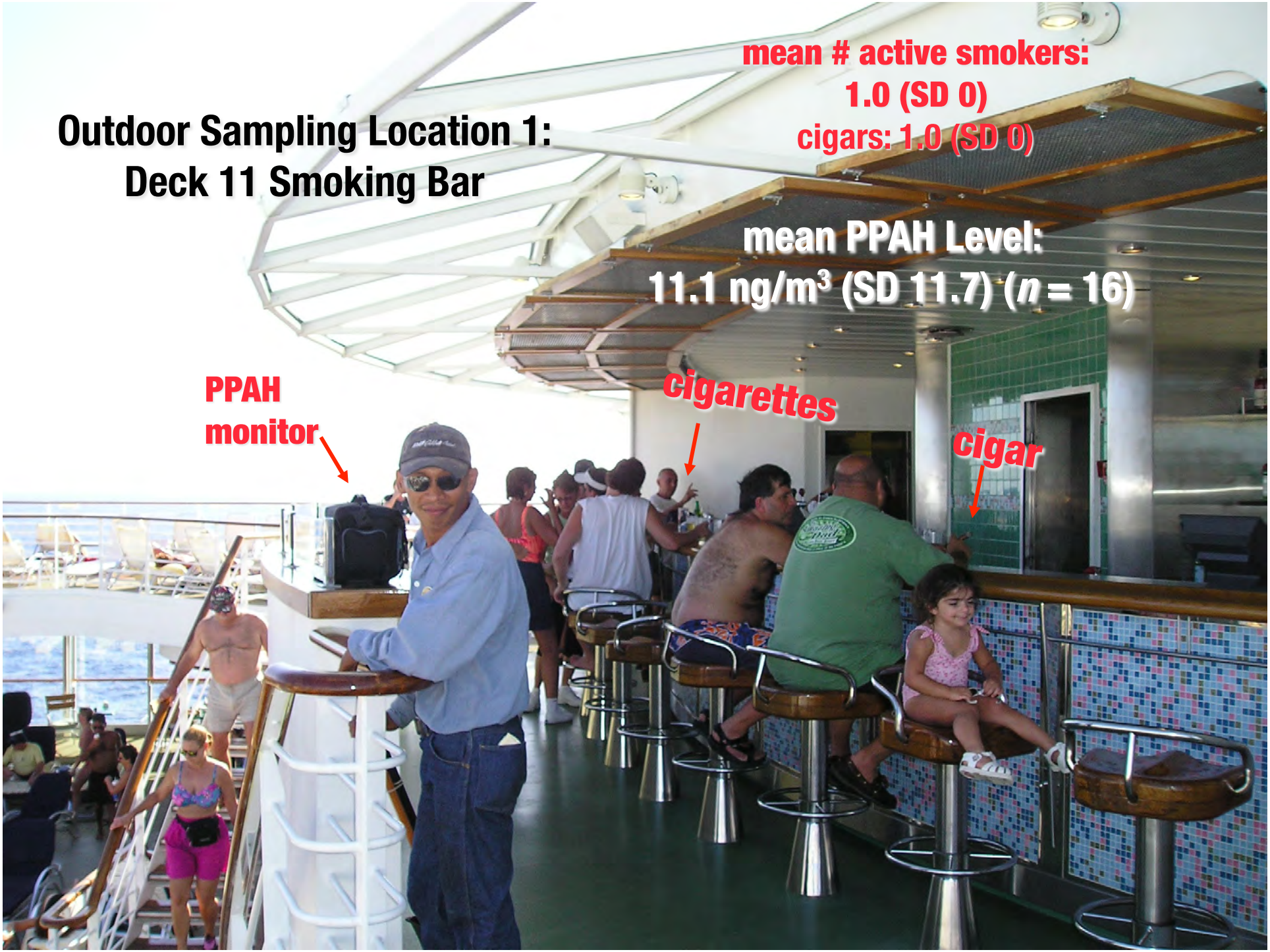
Ship's Corridors

mean PPAH Level:
5.4 ng/m^3 (SD 4.9) (n = 39)
(smoking & nonsmoking)

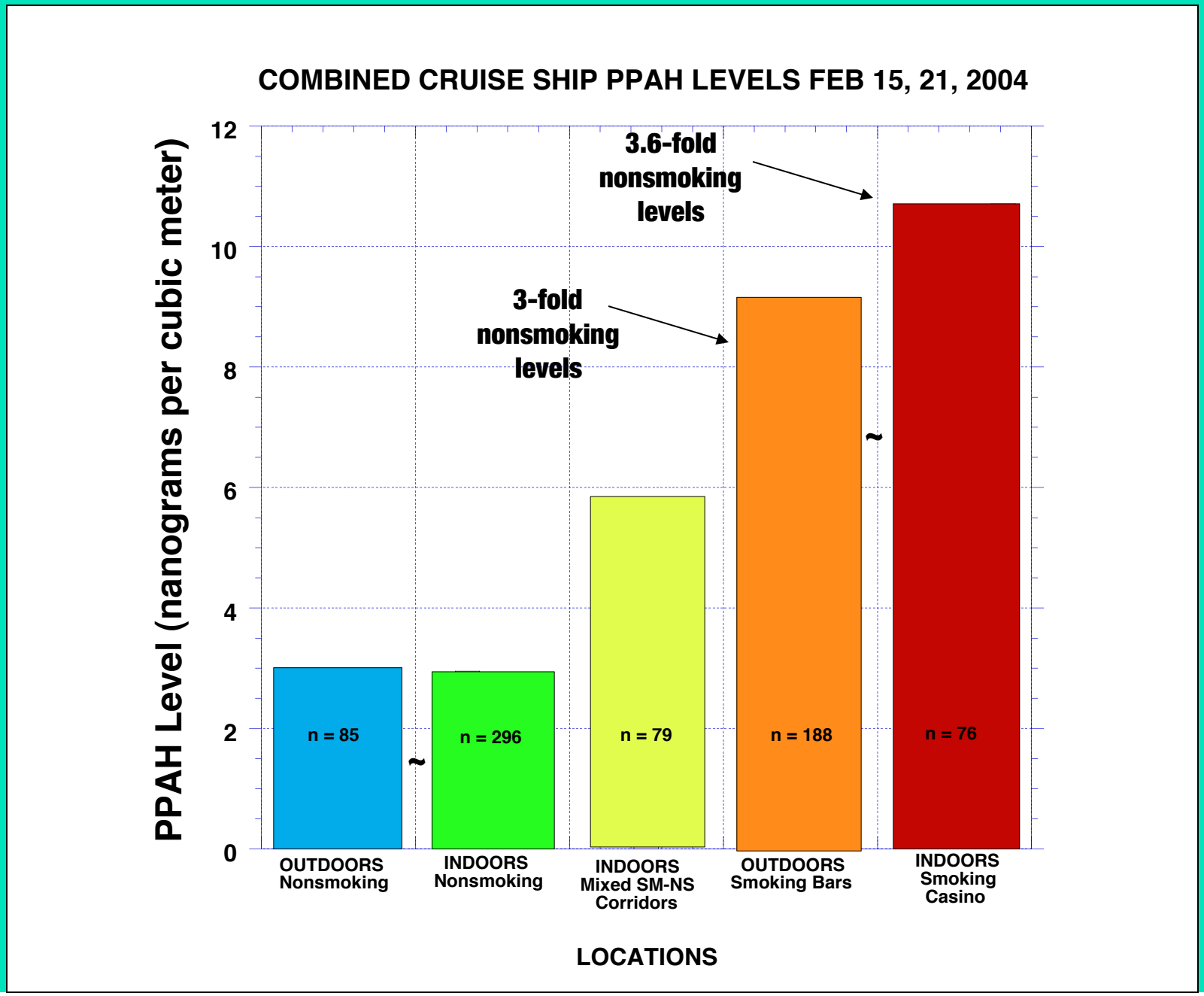

Deck 10 Aft:
Cigar Deck
mean # active smokers:
cigarettes: 1.4 (SD 0.52)
cigars: 3.8 (SD 0.52)
mean PPAH Level:
10.0 ng/m3 (SD 9.0) (n = 42)


mean # active smokers:
cigarettes: 2.2 (SD 2.4)
0.17 burning cigarettes per 100 m3
mean PPAH Level:
10.7 ng/m3 (SD 10.2) (n = 76)
Smoking Area in Casino

ASHRAE Casino: 120 Persons/1000 ft^2 @ 25.5% DPC smoking prevalence ≈ 31 HS/1000 ft^2 ≈ 10 AS/1000 ft^2
Summit Casino: 2.2 Active Smokers/5292 ft^2 = 0.42 AS/1000 ft^2, Ceiling Height: 8.6 ft; PPAH: 11 ng/m^3.
Summit Casino scaled to ASHRAE: (10/.42) (11 ng/m^3) = 262 ng/m^3. Summit Scaled to Delaware Park Casino
Ceiling Height: (8.6 ft/14 ft) (262 ng/m^3) = 161 ng/m^3. Meas. Delaware Park Casino (DPC) PPAH: 163 ng/m^3.
Delaware State smoking prevalence ≈ U.S. smoking prevalence of 23%.
INFERENCE: SMOKING PREVALENCE ON SHIP --indoors & outdoors-- IS LOWER THAN U.S. PREVALENCE.


Outdoor Sampling Location 1:
Deck 11 Smoking Bar
mean # active smokers:
1.0 (SD 0)
cigars: 1.0 (SD 0)
mean PPAH Level:
11.1 ng/m3 (SD 11.7) (n = 16)
PPAH
monitor
cigarettes
cigar

INDOOR & OUTDOOR PPAH COMPARABLE WHEN ETS IS PRESENT



Indoor and Outdoor Carcinogen Pollution on a Cruise Ship

Summary

1. PPAH measured in real-time using EcoChem PAS2000CE
2. Monitor calibrated under controlled conditions for ETS-PPAH
3. Cigarettes emit ~13 μg ETS PPAH/cig; 19 υg PPAH/g tobacco
4. ETS-PPAH emission factor in good agreement with other workers
5. Field Survey: PPAH measured indoors/outdoors on cruise ship at sea
6. Time-Activity Pattern Diary recorded location, presence of ETS
7. Number of cigarettes, pipes, cigars within ~10 meters recorded
8. Levels of PPAH tripled during smoking in Outdoor Bar Areas despite unlimited dispersion volume and strong breezes underway at sea…

Indoor and Outdoor Carcinogen Pollution on a Cruise Ship

Summary

9. Levels of PPAH comparable in outdoor bar areas and indoor casino during smoking
10. Levels of PPAH comparable indoors and outdoors in absence of smoking
11. Outdoor workers exposed to elevated PPAH levels from outdoor ETS, increasing exposure to carcinogenic and toxic compounds
12. Further research: characterize worker PPAH exposure in land-based outdoor cafés where smoking prevalence is higher.

The assistance of Hilarine Repace, BSc. is gratefully acknowledged.

This work is supported by the Flight Attendant Medical Research Institute

Table 1. Indoor/outdoor PPAH levels in nanograms per cubic meter (ng/m^3) on a cruise ship in the presence and absence of smoking. Sunday, Feb. 15, 2004, at sea

(unless otherwise specified, the number of active smokers refers to burning cigarettes only).

Microenvironment	Mean PPAH (SD)	Mean # of active smokers	Number of 1-min data points	Range	Ratio to Outdoor Nonsmoking
Outdoor Deck 11 Nonsmoking	2.62 (2.9)	0	58	0-13	1.00
Deck 4 Restaurant (NS)	2.69 (2.4)	0	130	0-11	1.03
Stateroom 7200	7.00 (18)	0	41	0-115	2.67
Stateroom 7200[a]	4.30 (3.0)	0	40	0-11	1.64
Ship Corridors	6.22 (10)	NR	40	0-49	2.37
Cigar Bar Outdoors C=cigars Breezy	8.45 (12)	**2.9 (1.61) C: 3.8 (0.1) Pipe-1 (0)**	60	0-81	3.23
Deck 10 Pool Bar Outdoors, Forward	8.91 (12)	1.87 (1.6)	45	0-60	3.40

[a]*Outlier removed: probably due to smoking on adjacent balcony; NR = not recorded*

Table 2. Indoor/outdoor PPAH levels in ng/m^3 on a cruise ship in the presence and absence of smoking. Sunday, Feb. 21, 2004, at sea (unless otherwise specified, the number of active smokers refers to burning cigarettes only).

Microenvironment	Mean PPAH (SD)	Mean # of active smokers	Number of 1-min data points	Range	Ratio to Outdoor Nonsmoking
Outdoor Deck 11 Nonsmoking*	3.96 (2.49)	0	27	0-8	1.00
Deck 4 Restaurant (NS)	8.44 (29)	0	59	0-197	2.13
Deck 4 Restaurant (NS)[a]	2.35 (2.6)	0	55	0-13	0.59
Stateroom 7200	3.11 (2.91)	0	71	0-18	0.78
Ship Corridors	5.44 (4.9)	NR	39	0-19	1.37
Cigar Bar Outdoors, Light wind; C=cigars	9.95 (8.96)	**1.62 (0.52) C: 1.4 (0.52)**	42	0-48	2.51
Deck 11 Bar Outdoors, Forward	11.12 (11.66)	**1.0 (0) C: 1 (0)**	16	3-52	2.81
Casino	10.71 (10.18)	2.2 (2.4)	76	0-54	2.70
Outdoors Smoking	8.60 (13.56)	1.33 (0.82)	25	0-58	2.17

*[a]Outliers removed:likely due to birthday cake candle smoke; *possibly biased upwards by proximity to door; NR = not recorded*

Table 3. Capacity of Public and Private Cruise ship Areas in which PPAH were measured.

Location	Capacity, Persons	Area	Volume
Stateroom 2169	2	-	28 m^3
Deck 4 Restaurant (NS)	1170	-	-
Stateroom 7200	2	-	36 m^3
Cigar Bar Outdoors, Aft	~105	2155 ft^2	12 ft partial overhead canopy
Deck 11 Bar Outdoors, Forward	~25	-	10ft partial canopy open to air 3 sides
Casino Indoors	270	5292 ft^2 (ceiling ht. 8.583′)	1286 m^3
Outdoors Deck 10 Smoking Port Side	~325	-	12 ft overhead canopy; in corner of pool area

Platform W1B Indoor Exposures & ETS
Abstract W1B-07
Indoor and Outdoor Carcinogen Pollution on a Cruise Ship

James L. Repace, Repace Associates, Inc. and Tufts University School of Medicine

A contribution to the exposure assessment of secondhand smoke (SHS) in outdoor microenvironments is made by measuring a class of carcinogenic compounds emitted during tobacco combustion, particulate polycyclic aromatic hydrocarbons (PPAH). Using a personal exposure monitor for PPAH, measurements were made on a gas-turbine-powered cruise ship underway in the South Atlantic to eliminate the omnipresent background of PPAH due to diesel emissions in urban environments. A controlled experiment was conducted using a human smoker in a well-ventilated inside stateroom to assess the PPAH emission from both exhaled mainstream and sidestream smoke from the most commonly smoked brand of cigarette, Marlboro. These cigarettes are estimated to emit ~**13** micrograms of PPAH when smoked, or ~**19** micrograms per gram of tobacco consumed. Peak levels of PPAH after 6.7 minutes of smoking increased 100-fold. Two field surveys were conducted indoors and outdoors on the ship in the presence and absence of tobacco smoking. The number of cigarettes, pipes, and cigars within 30 ft of the monitor were recorded. Steady tobacco smoking in various smoking-permitted outdoor areas of the ship tripled the level of PPAH to which nonsmokers were exposed relative to indoor and outdoor areas in which smoking did not occur, despite the strong breezes and unlimited dispersion volume. Moreover, outdoor smoking areas were contaminated with PPAH to nearly the same extent as a popular casino on board in which smoking was permitted. SHS PPAH in outdoor environments are readily detectable, and measurably increase the exposure of outdoor hospitality workers, such as waitstaff, bartenders, and musicians, to a class of compounds heavily implicated in tobacco carcinogenesis.