# Measuring Thirdhand Smoke in Indoor Environments: Challenges and Emerging Technologies

Lara Gundel and Hugo Destaillats
Lawrence Berkeley National Laboratory

***PUTTING THIRDHAND SMOKE ON THE POLICY AND RESEARCH AGENDA***

**Ontario Tobacco Research Unit**

**University Club, Toronto, 3 May 2012**

# Four R's of thirdhand tobacco smoke

**Residual tobacco smoke pollutants that:**

- **Remain** on surfaces & in dust long after smoking stops,
- **Re-suspend** from accumulated dust deposits,
- **Re-emit** into the gas phase, and/or
- **React** with other compounds in the environment to yield more pollutants

***Some challenges:***

**What's in THS? How different from SHS?**

**What to measure? Where is THS?**

**How long does it last?**

**How to clean it up?**

Matt et al. *Environ. Health Perspectives*, *119*, 1218-1226 (2011), with later addition of 'resuspend' as the fourth R

## *Prof. Matt's challenge to researchers:* **Things to be learned**

- Pathways of THS exposure
- THS of constituents
- Aging of constituents
- Interactions with other pollutants and oxidants
- Exposure to constituents
- Clean-up
- Markers of THS: tobacco specific, representative of THS pollutants
- Bio-markers of THS exposure: specific to THS, representative of exposure to THS pollutants
- Unique incremental health risks
- Cumulative health risks
- Individual differences in risks associated with exposure to pollutants
- Disentangle main and interaction effects in
    - Smokers: FHS x SHS x THS
    - Passive smokers: SHS x THS

From *Things to be Learned*

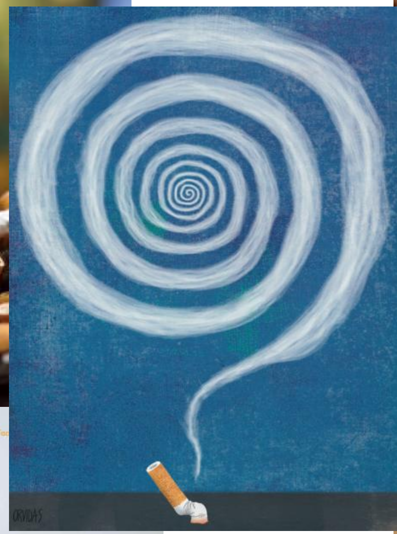
# Chemistry and environmental engineering

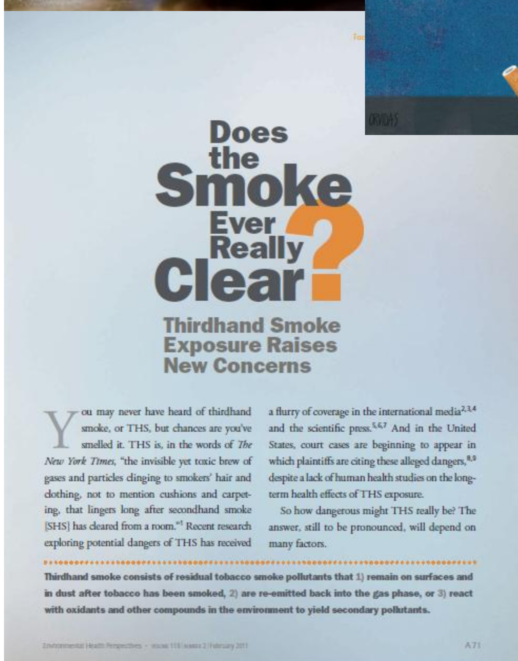
- How does SHS become THS?
  - Aging of constituents
  - Interactions with other pollutants and oxidants
- Partitioning among air, surfaces, particles (distribution indoors: on furniture, walls, people, clothes)
- Pathways of THS exposure
- Exposure to constituents
- Clean-up

**Lots of measurement challenges!**

**New approaches, methods and technologies!**

# Challenge: Predict carcinogen dose from THS



## Does the Smoke Ever Really Clear?

### Thirdhand Smoke Exposure Raises New Concerns

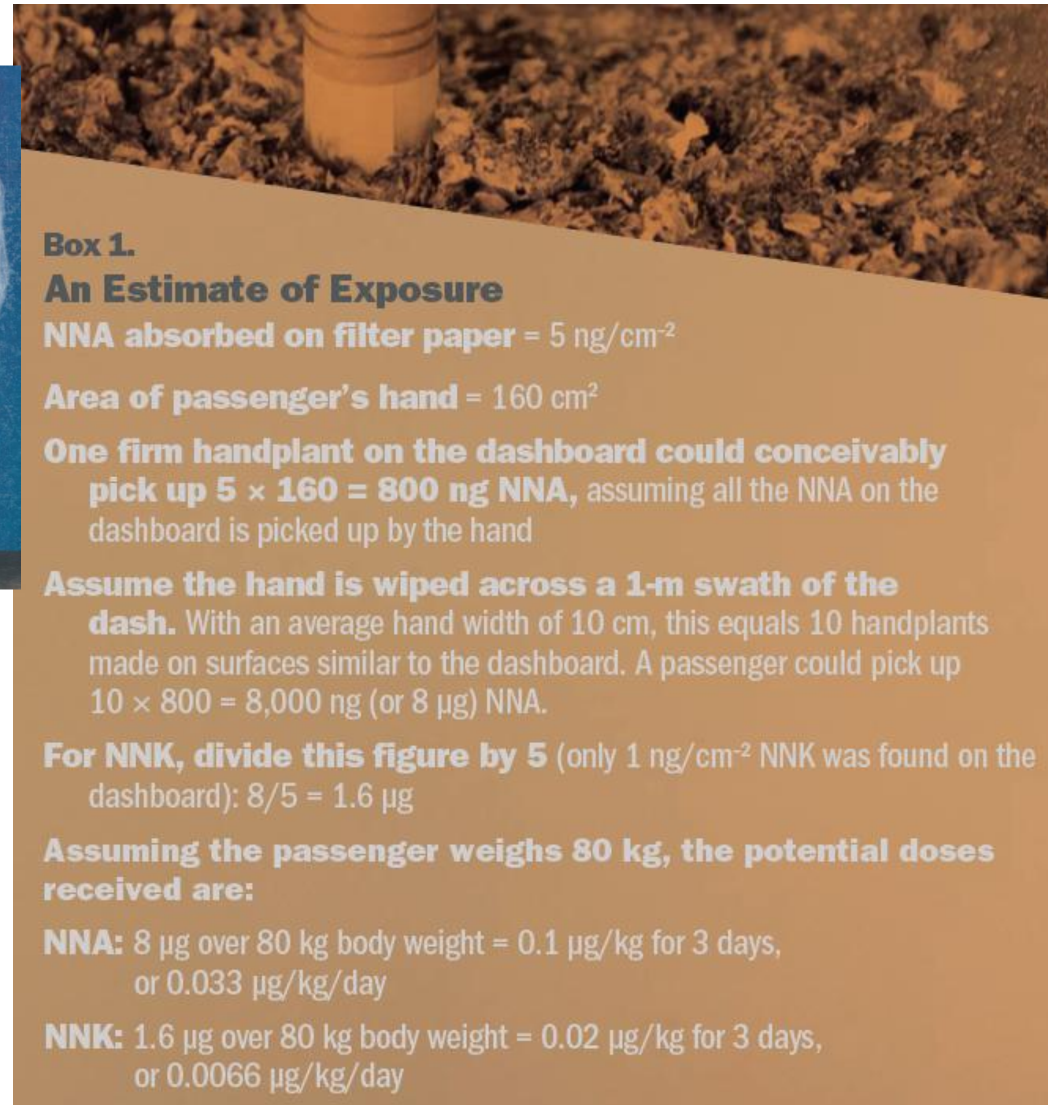
You may never have heard of thirdhand smoke, or THS, but chances are you've smelled it. THS is, in the words of *The New York Times*, "the invisible yet toxic brew of gases and particles clinging to smokers' hair and clothing, not to mention cushions and carpeting, that lingers long after secondhand smoke [SHS] has cleared from a room."[1] Recent research exploring potential dangers of THS has received a flurry of coverage in the international media[2,3,4] and the scientific press.[5,6,7] And in the United States, court cases are beginning to appear in which plaintiffs are citing these alleged dangers,[8,9] despite a lack of human health studies on the long-term health effects of THS exposure.

So how dangerous might THS really be? The answer, still to be pronounced, will depend on many factors.

**Thirdhand smoke consists of residual tobacco smoke pollutants that 1) remain on surfaces and in dust after tobacco has been smoked, 2) are re-emitted back into the gas phase, or 3) react with oxidants and other compounds in the environment to yield secondary pollutants.**



Burton, *EHP* - Feb. 2011



**Box 1.**

**An Estimate of Exposure**

**NNA absorbed on filter paper** = 5 ng/cm$^{-2}$

**Area of passenger's hand** = 160 cm$^2$

**One firm handplant on the dashboard could conceivably pick up 5 × 160 = 800 ng NNA,** assuming all the NNA on the dashboard is picked up by the hand

**Assume the hand is wiped across a 1-m swath of the dash.** With an average hand width of 10 cm, this equals 10 handplants made on surfaces similar to the dashboard. A passenger could pick up 10 × 800 = 8,000 ng (or 8 µg) NNA.

**For NNK, divide this figure by 5** (only 1 ng/cm$^{-2}$ NNK was found on the dashboard): 8/5 = 1.6 µg

**Assuming the passenger weighs 80 kg, the potential doses received are:**

**NNA:** 8 µg over 80 kg body weight = 0.1 µg/kg for 3 days, or 0.033 µg/kg/day

**NNK:** 1.6 µg over 80 kg body weight = 0.02 µg/kg for 3 days, or 0.0066 µg/kg/day

# Emerging research agenda

Review

*EHP* September 2011

**Thirdhand Tobacco Smoke: Emerging Evidence and Arguments for a Multidisciplinary Research Agenda**

*Georg E. Matt,[1] Penelope J. E. Quintana,[2] Hugo Destaillats,[3] Lara A. Gundel,[3] Mohamad Sleiman,[3] Brett C. Singer,[3] Peyton Jacob III,[4] Neal Benowitz,[4] Jonathan P. Winickoff,[5] Virender Rehan,[6] Prue Talbot,[7] Suzaynn Schick,[4] Jonathan Samet,[8] Yinsheng Wang,[9] Bo Hang,[10] Manuela Martins-Green,[11] James F. Pankow,[12] and Melbourne F. Hovell[2]*

[1]Department of Psychology, and [2]Graduate School of Public Health, San Diego State University, San Diego, California, USA; [3]Indoor Environment Department, Lawrence Berkeley National Laboratory, Berkeley, California USA; [4]San Francisco General Hospital Medical Center, University of California San Francisco, San Francisco, California, USA; [5]Center for Child and Adolescent Health Policy, Massachusetts General Hospital, Boston, Massachusetts, USA; [6]David Geffen School of Medicine, University of California Los Angeles, Los Angeles, California, USA; [7]Stem Cell Center, University of California Riverside, Riverside, California, USA; [8]Keck School of Medicine, University of Southern California, Los Angeles, California, USA; [9]Environmental Toxicology, University of California Riverside, Riverside, California, USA; [10]Department of Cancer and DNA Damage Responses, Lawrence Berkeley National Laboratory, Berkeley, California, USA; [11]University of California Riverside, Department of Cell Biology and Neuroscience, Riverside, California, USA; [12]Portland State University, Civil and Environmental Engineering and Chemistry, Portland, Oregon, USA

## California THS Consortium

UCSF, LBNL, UC Riverside, USC, SDSU

- chemistry, exposure, toxicology, and health effects
- behavioral, economic, and sociocultural implications
- role of THS in tobacco control efforts

http://www.trdrp.org/research_highights/ths.php

# Challenge: Different tobacco and nicotine uses

cigarette use in the US

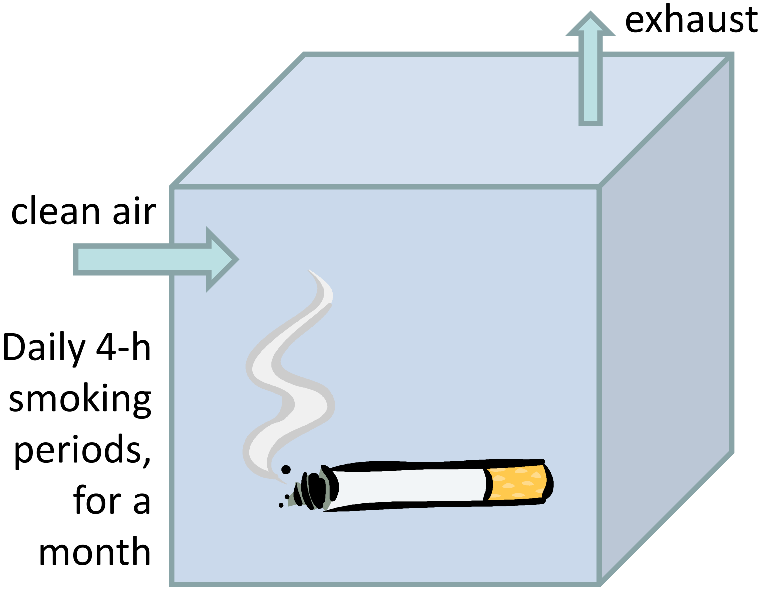

Colditz *et al.*, *Nat. Rev. Cancer.* 2006

hooka smoking

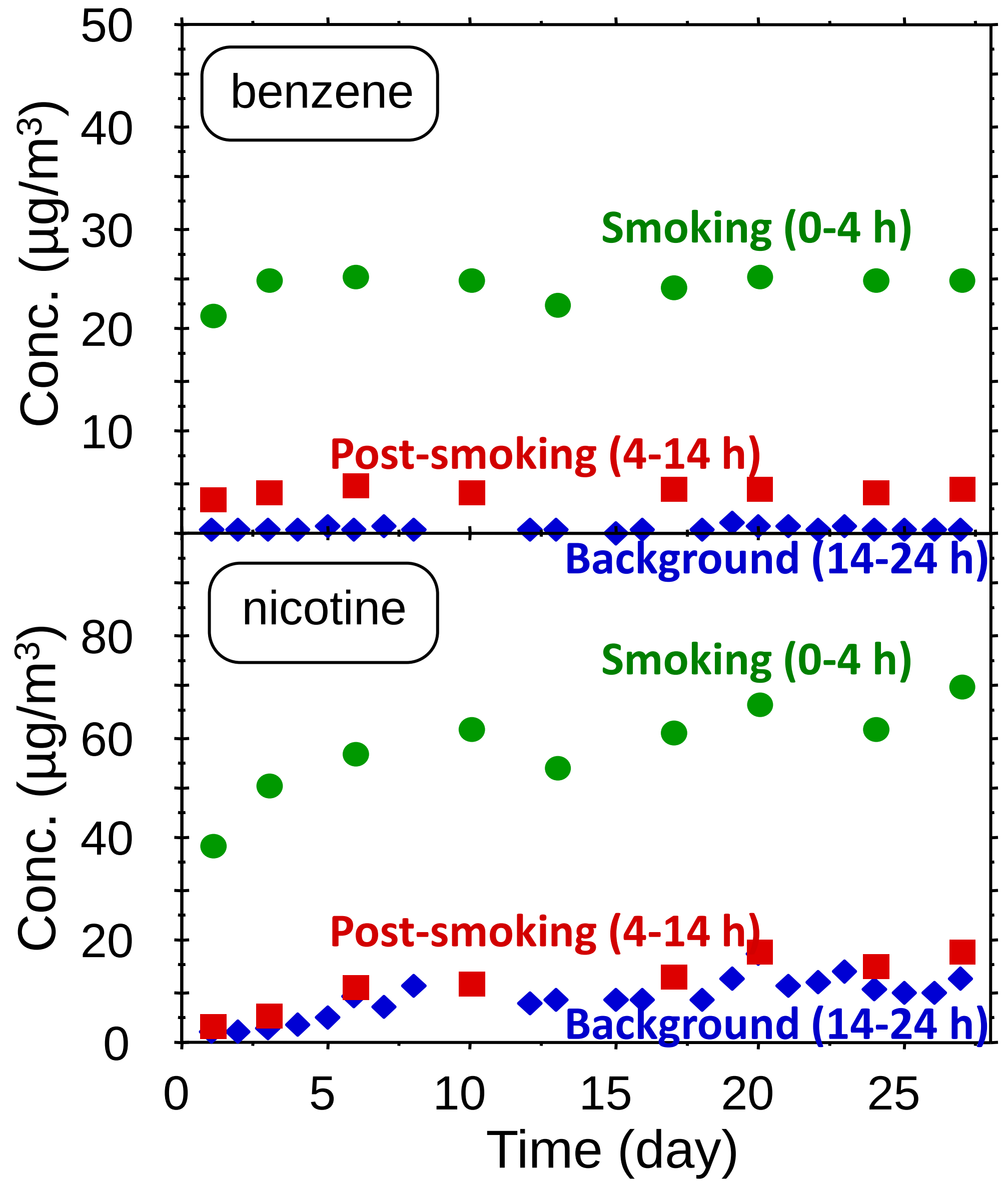


# Dynamics of secondhand smoke (SHS)

**Long term re-emission**




**Furnished**
**50-m³ chamber**

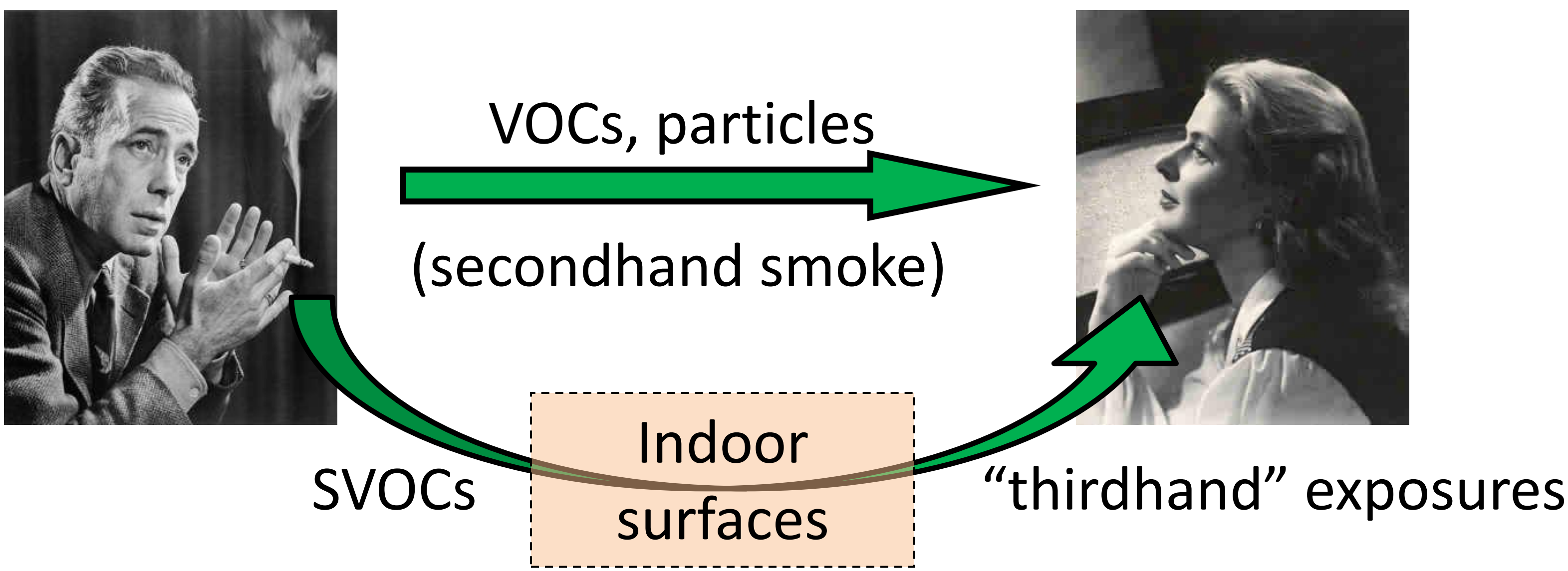



Singer et al, *Atmos. Environ.* 2004

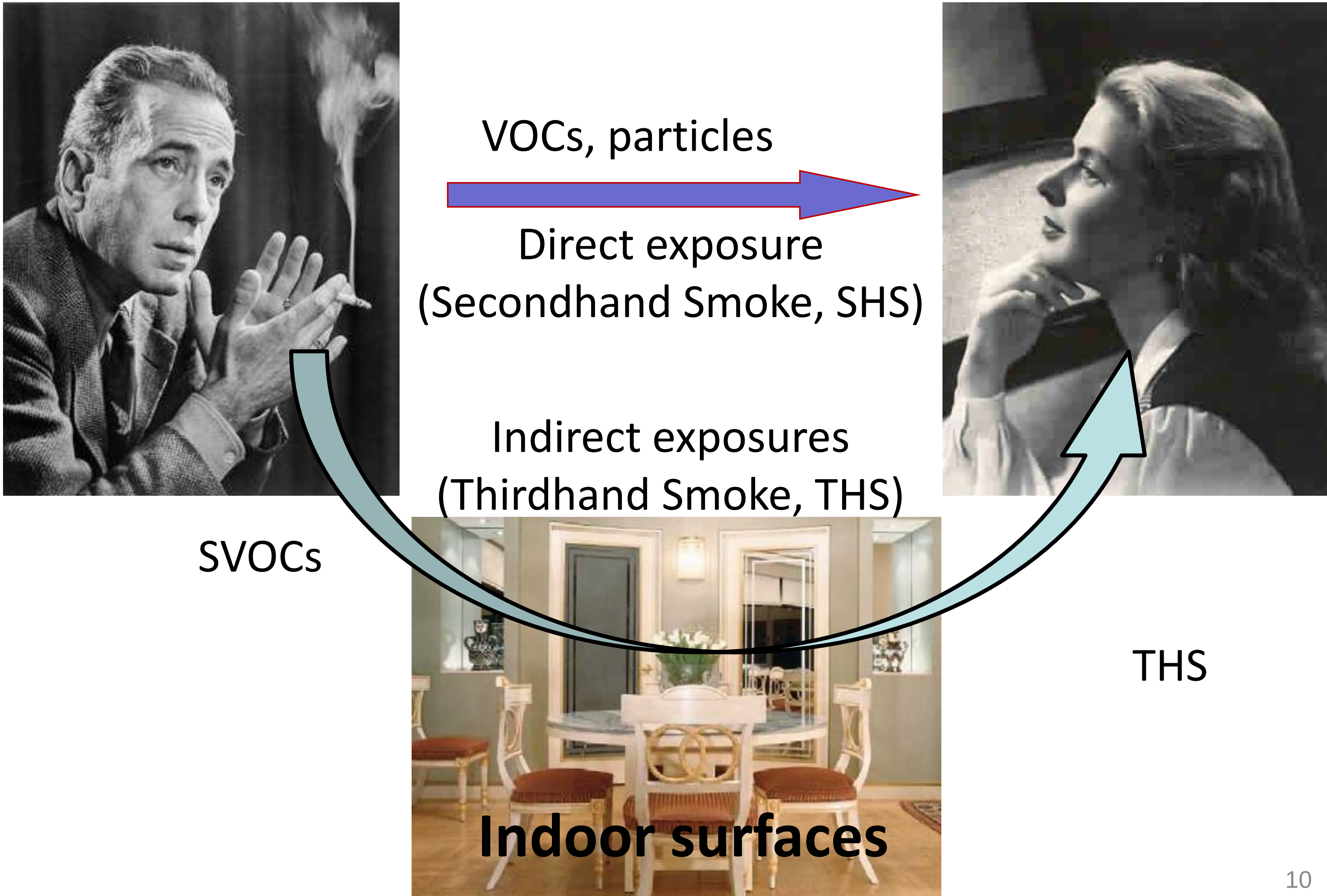
**How reactive are nicotine residues?**

# From secondhand to thirdhand smoke

| Gas phase | Particulate matter |
|---|---|
| CO, $NO_x$, HONO, HCN, $SO_2$ | nicotine, cotinine |
| formaldehyde, acrolein | polycyclic aromatic cpds (PAH) |
| aromatic (e.g., benzene) | tobacco-specific *N*-nitrosamines |
| 1,3-butadiene | phenolic compounds |
| volatile *N*-nitrosamines | sterols, fatty acids |
| volatile amines (e.g., pyridine) | polymeric combustion byproducts |
| nicotine (1-5 mg/cig) | metals: As, Pb, Cr, Cd |



# Tobacco smoke residues in the indoor environment



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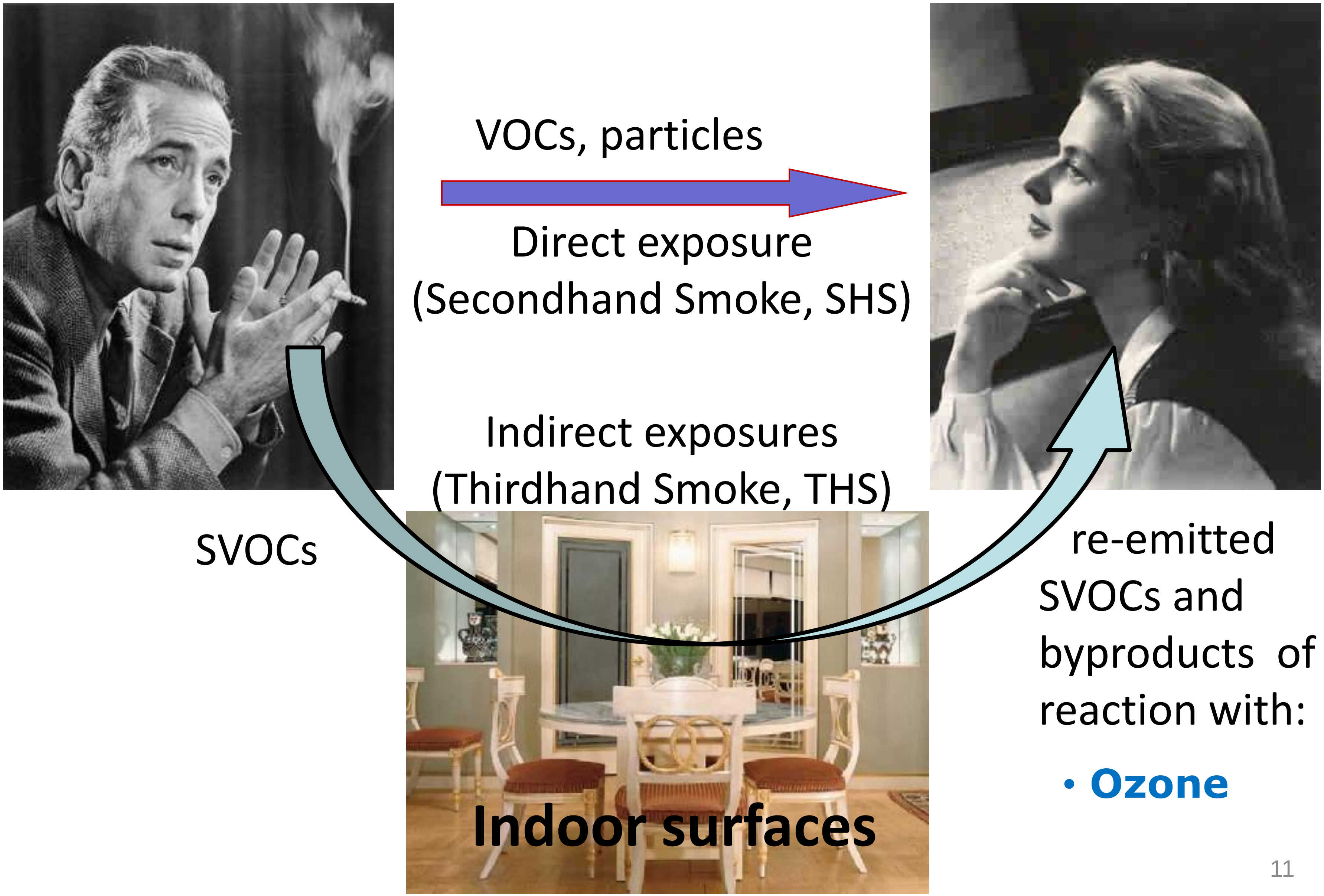
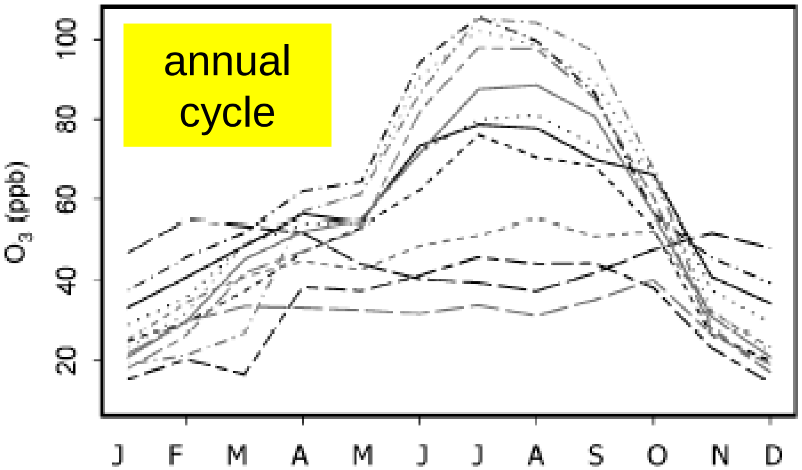


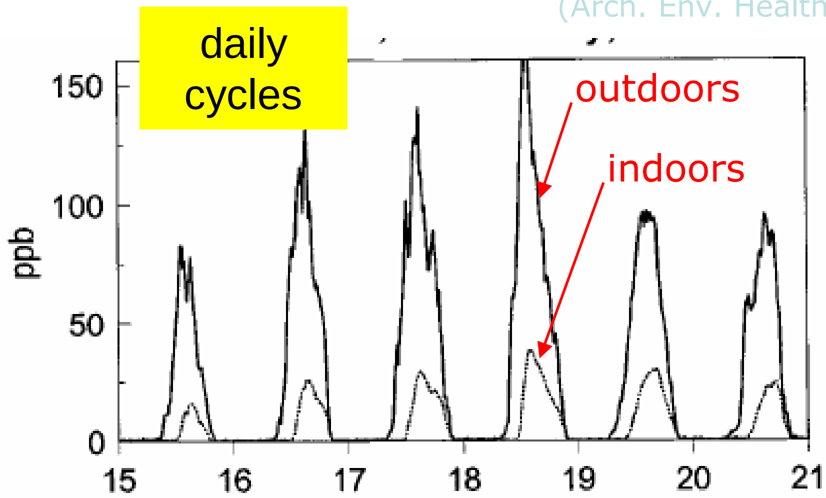
# Indoor ozone

**Main source: outdoor air**




Southern California

Millstein et al, 2004
(Arch. Env. Health)

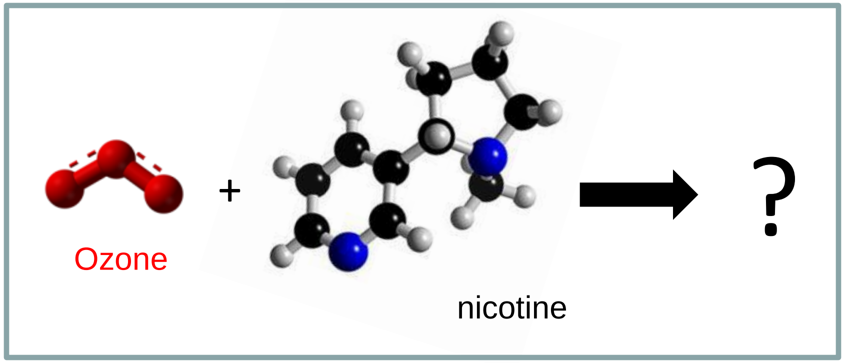



Burbank, July, 1992

Weschler, 2000
(Indoor Air)

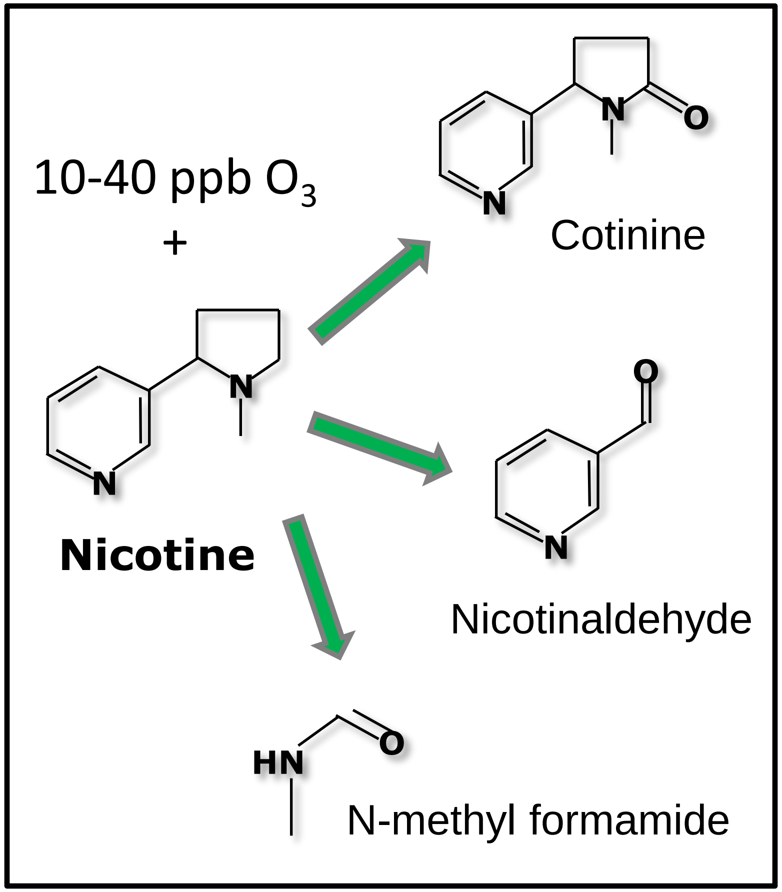
**High levels: "air purifiers"**


- used to remove tobacco odors
- up to hundreds of ppb

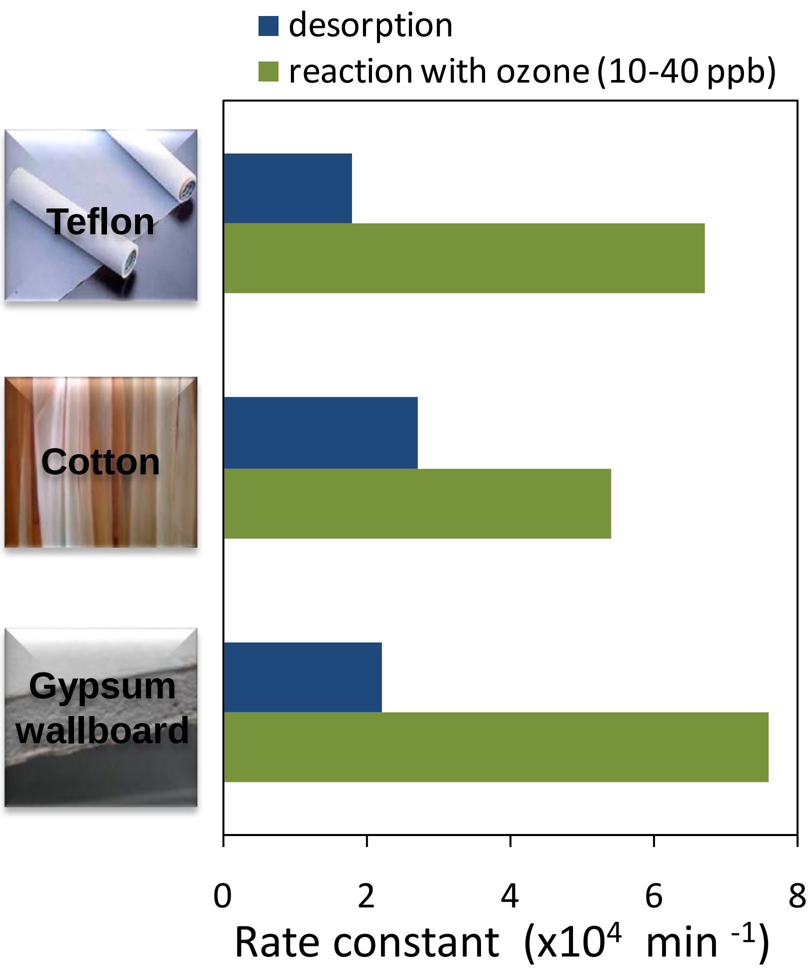


# Nicotine oxidation on indoor surfaces

**Formation of gaseous pollutants; oxidation rates comparable to desorption**



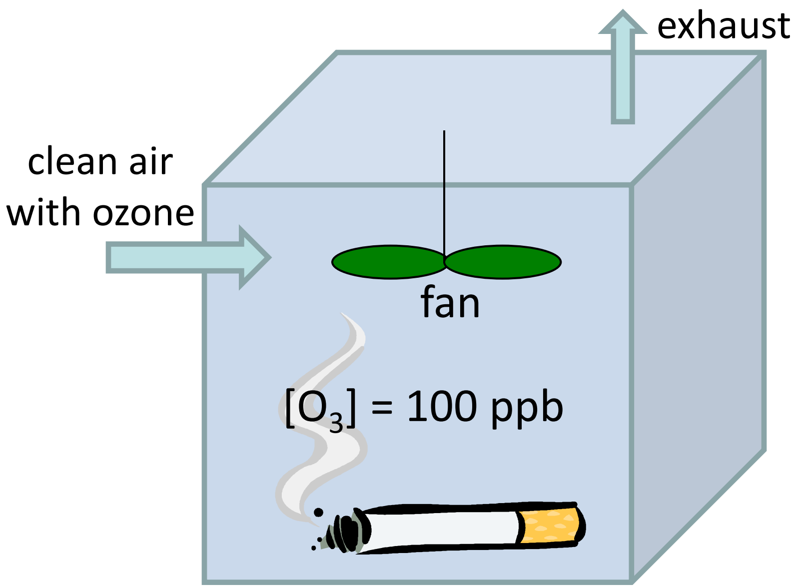

- sampled on Tenax sorbent
- detected by GC/NPD

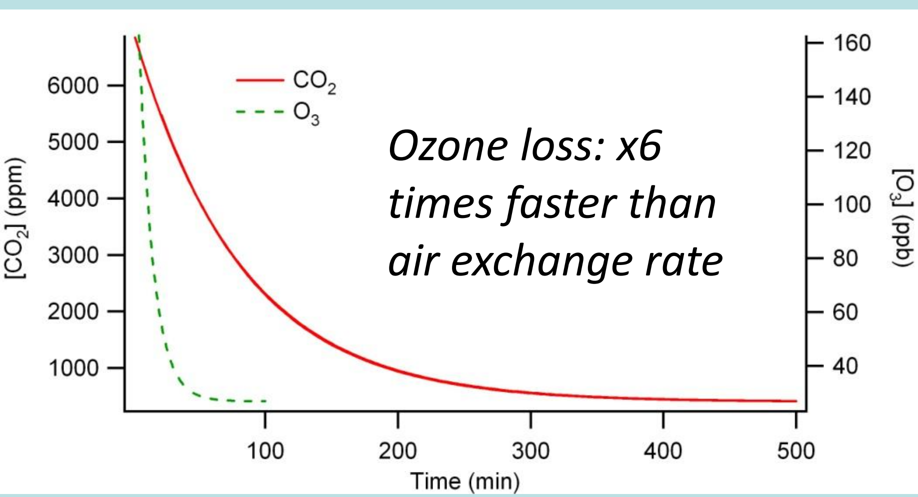


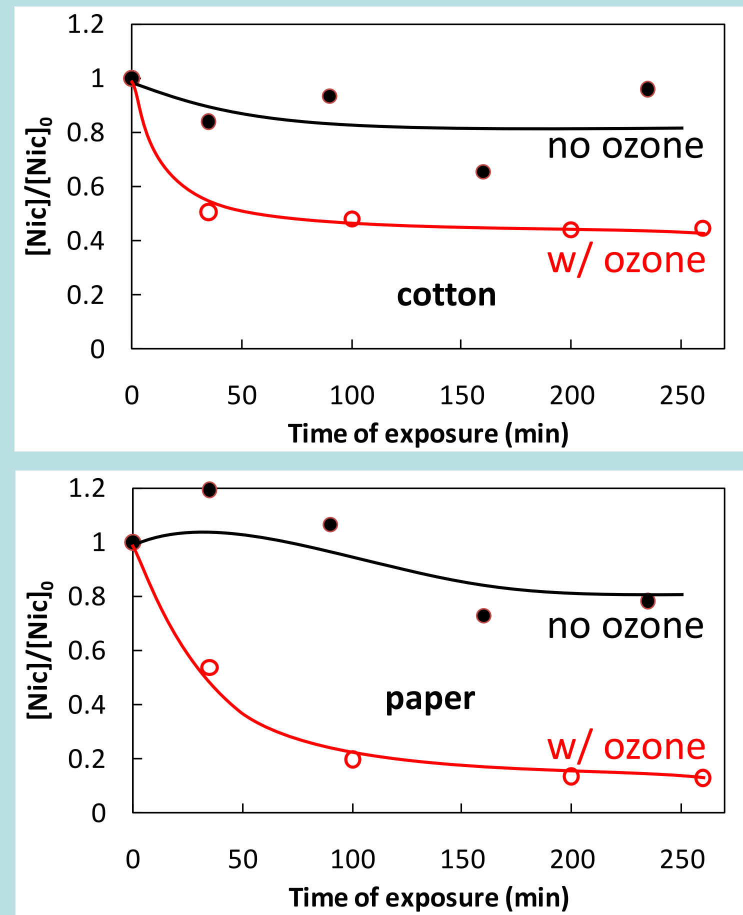

Destaillats et al. *Environ. Sci. Technol*. 2006

# Reaction of $O_3$ with SHS in room-sized chamber (20 $m^3$)

**Ozone uptake by surfaces; depletion of sorbed nicotine**



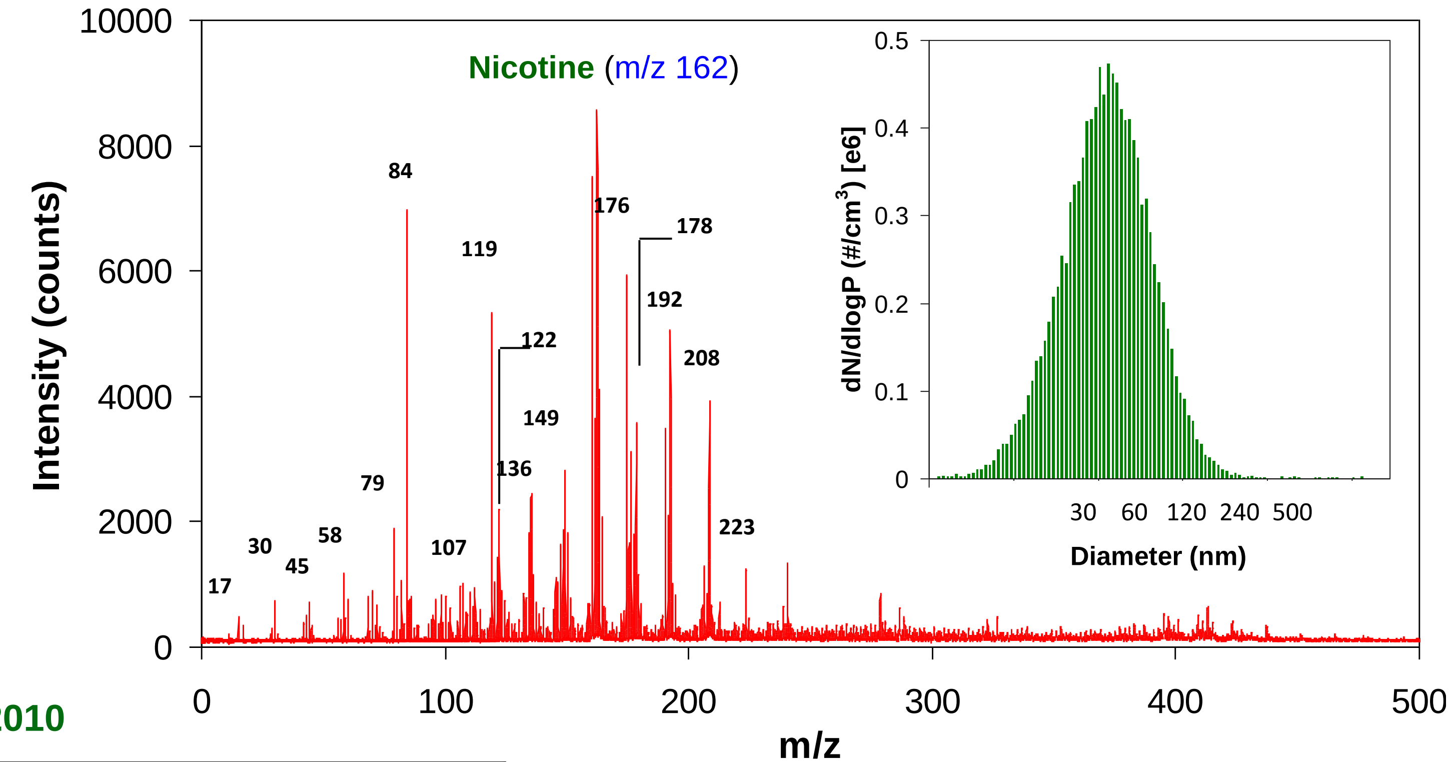




Petrick et al., *Atmos. Environ*. 2011

# Ozonolysis of nicotine

**Formation of ultrafine particles (< 100 nm) with aerosol yields of 4 - 9%**




**Sleiman et al.,**
***Atmos. Environ.*, 2010**

| | Dry air (RH < 1%) | Humid air (RH: 50%) |
|---|---|---|
| **Aerosol yield (%)** | 3.8 | 9.2 |
| **Concentration ($\mu g\ m^{-3}$)** | 56 | 186 |
| **Diameter (nm)** | 65 | 70 and 120 |

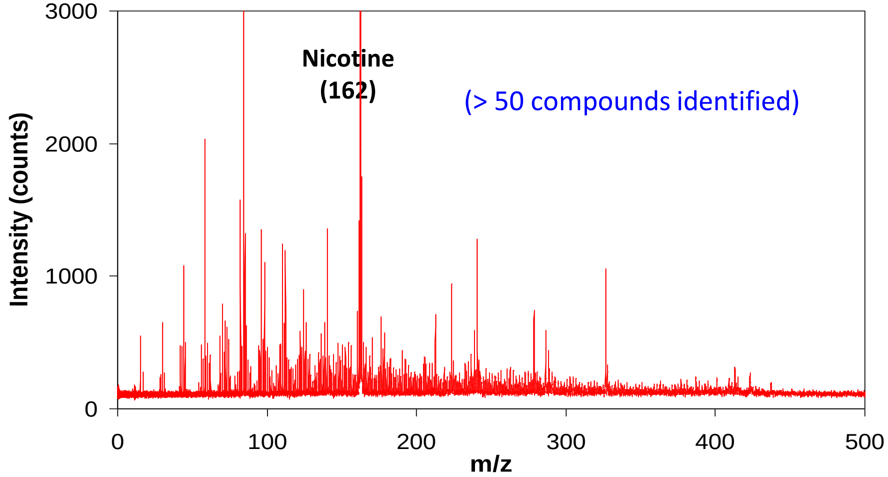
$$\text{Yield} = \frac{\text{total aerosol mass}}{\text{amount of reacted organics}}$$

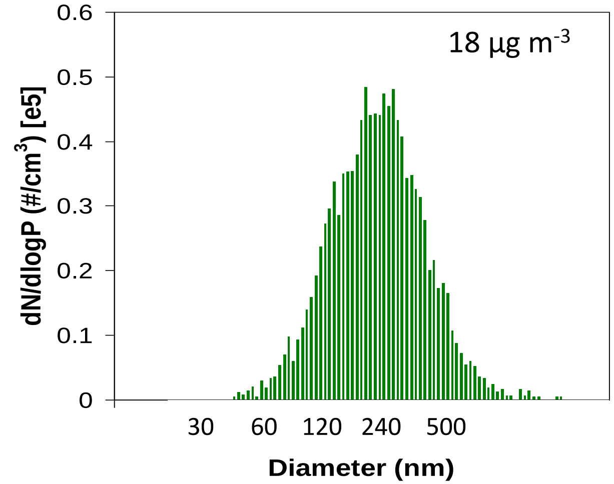
**What species can we identify?**

# Ozone reactions with secondhand smoke (SHS)

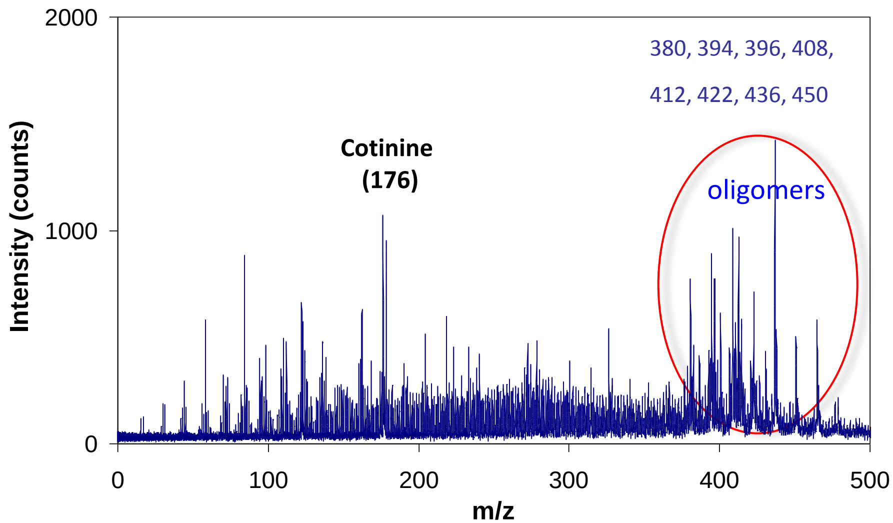
**Formation of ultrafine particles with HMW (N, O - containing oligomers)**

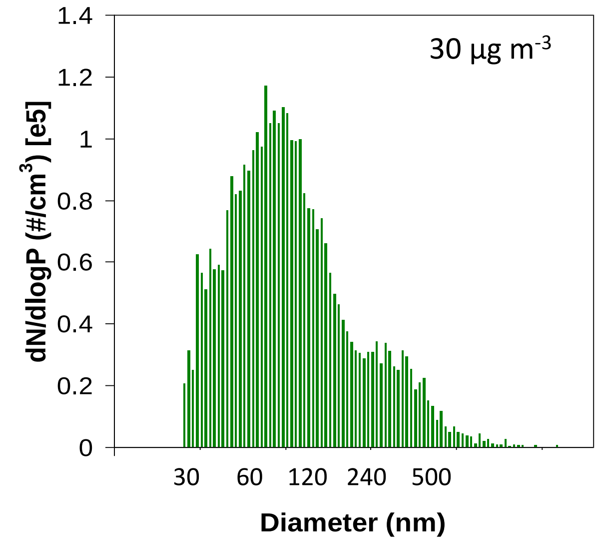
**SHS before exposure to $O_3$**



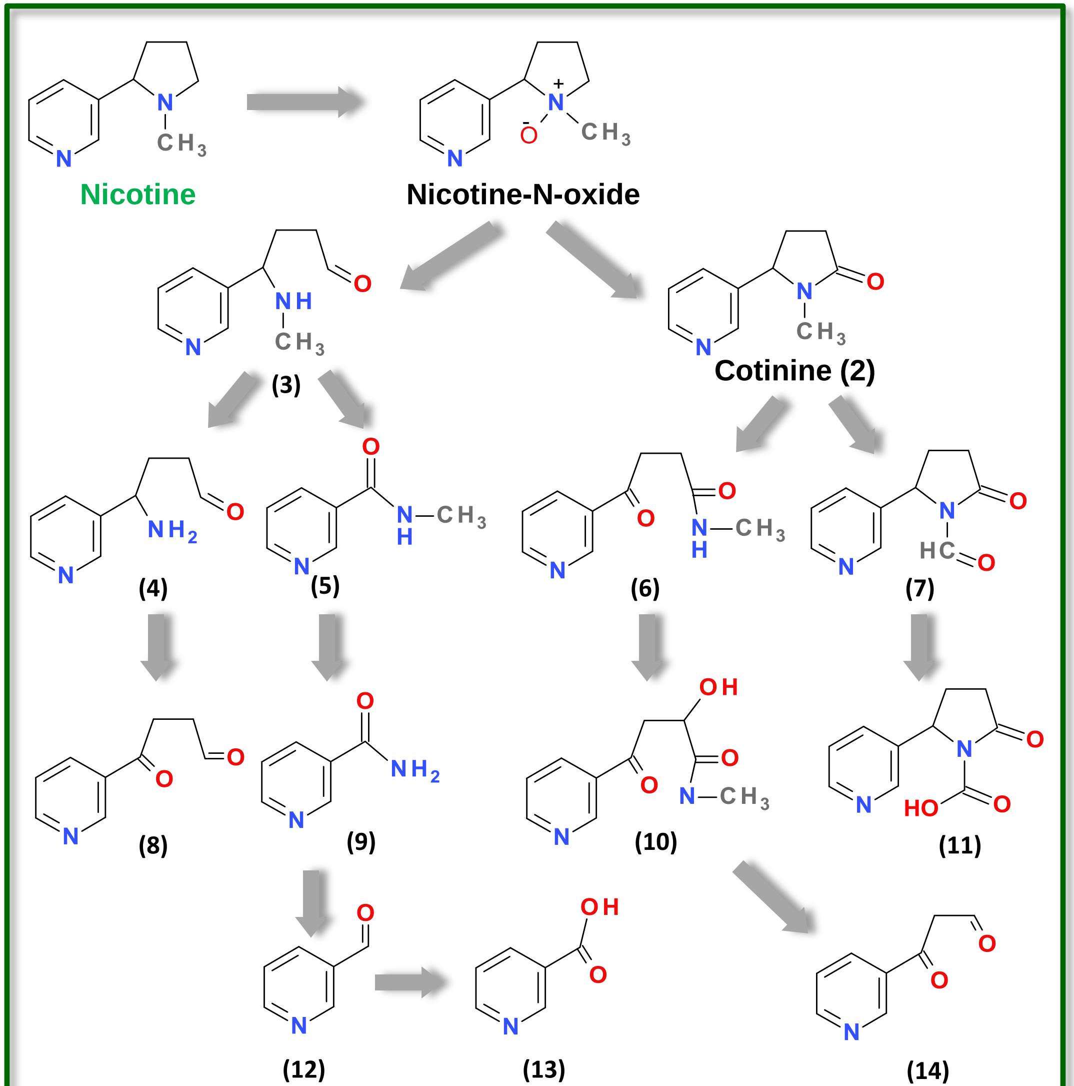

**SHS after 1 hour of exposure to $O_3$ (< 100 ppbv)**




Sleiman et al., *Atmos. Environ.*, 2010

# Oxidation products in SOA and their Asthma Hazard Index




| Product No. | Asthma Hazard index ([a, b]) |
|---|---|
| **Nicotine** | **0.64** |
| (1) Nicotine-N-oxide | 0.57 |
| (2) Cotinine | 0.76 |
| (3) | 0.94 |
| (4) | 0.92 |
| (5) | 0.61 |
| (6) | 0.87 |
| (7) | 0.85 |
| (8) | 0.86 |
| (9) | 0.53 |
| (10) | 0.99 |
| (11) | 0.94 |
| (12) | 0.59 |
| (13) | 0.92 |
| (14) | 0.83 |

**Sleiman et al., *Atmos. Environ.*, 2010**

[a] Jarvis et al. Occupational and Environmental Medicine, 2005

[b] http://www.coeh.man.ac.uk/hazassess/

# Summary #1: indoor ozone chemistry

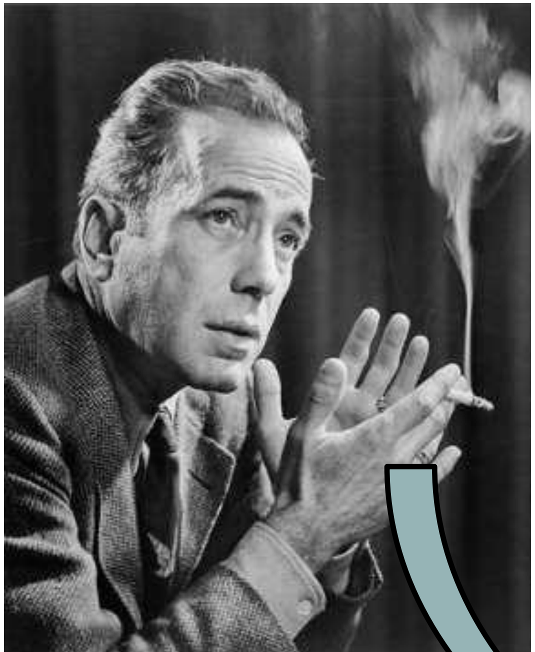
## Conclusions

- ❑ Ozone reacts with adsorbed nicotine at rates that are relevant indoors
- ❑ It can reduce nicotine levels originating in re-emission
- ❑ Formation of gas phase byproducts and ultrafine (secondary) organic aerosols
- ❑ Several byproducts have higher Asthma Hazard Index than nicotine

## Perspectives

- ❑Pending: measurement of byproducts (gas phase and aerosols) in full-size chamber, and evaluate implications for exposure.

# Tobacco smoke residues in the indoor environment



VOCs, particles

Direct exposure
(Secondhand Smoke, SHS)

Indirect exposures
(Thirdhand Smoke, THS)

SVOCs


re-emitted SVOCs and byproducts of reaction with:

**$NO_x$/HONO**

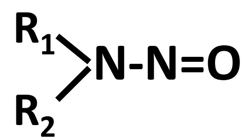
# Reaction of nicotine with nitrous acid (HONO)

## Sources of HONO and NOx

- ❑ combustion (indoor and outdoor)
- ❑ heterogeneous conversion of NOx on indoor surfaces yielding HONO (g)
- ❑ typical indoor HONO levels are 10-40 ppb (higher than outdoors)

## Formation of nitrosamines

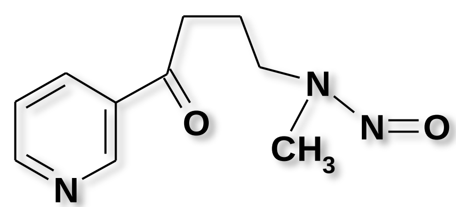
- ❑ HONO reaction with amines in air produces volatile *N*-nitrosamines




*Pitts et al. Environ. Sci. Technol. (1978)*

- ❑ Nicotine nitrosation in acidic $NaNO_2$ solution forms tobacco-specific nitrosamines

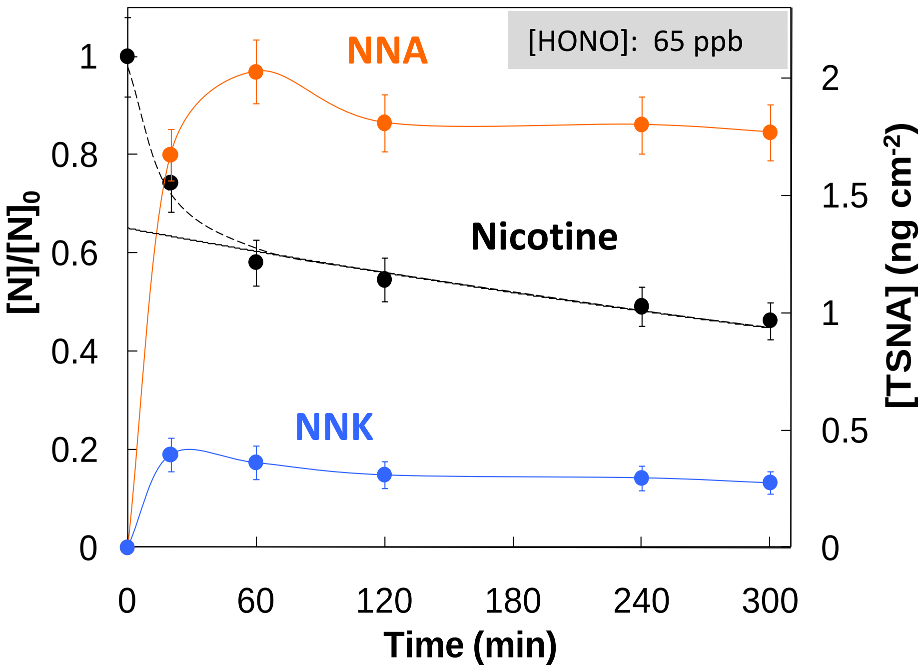
*Hecht et al. J. Org. Chem. (1978)*

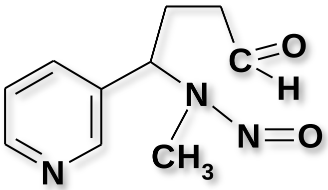



**4-(methylnitrosamino)-1-(3-pyridinyl)-1-butanone (NNK)**

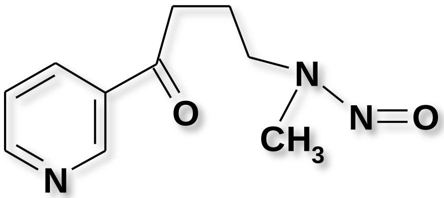
# Laboratory experiments

## Formation of carcinogens: tobacco-specific nitrosamines (NNA and NNK)




1-(N-methyl-N-nitrosamino)-1-(3-pyridinyl)-4-butanal




4-(methylnitrosamino)-1-(3-pyridinyl)-1-butanone

- ❑ TSNA yield (ϕ): $\phi_{TSNA}$ = 6.7 to 9.1%
- ❑ Nicotine loss rate: $k_N = 1.25\ \text{x}10^{-3}\ \text{min}^{-1}$
- ❑ HONO uptake rate: $R_{HONO} = 5.5\ \mu\text{mol m}^{-2}\ \text{h}^{-1}$

**Are NNA and NNK also formed on real indoor surfaces ?**

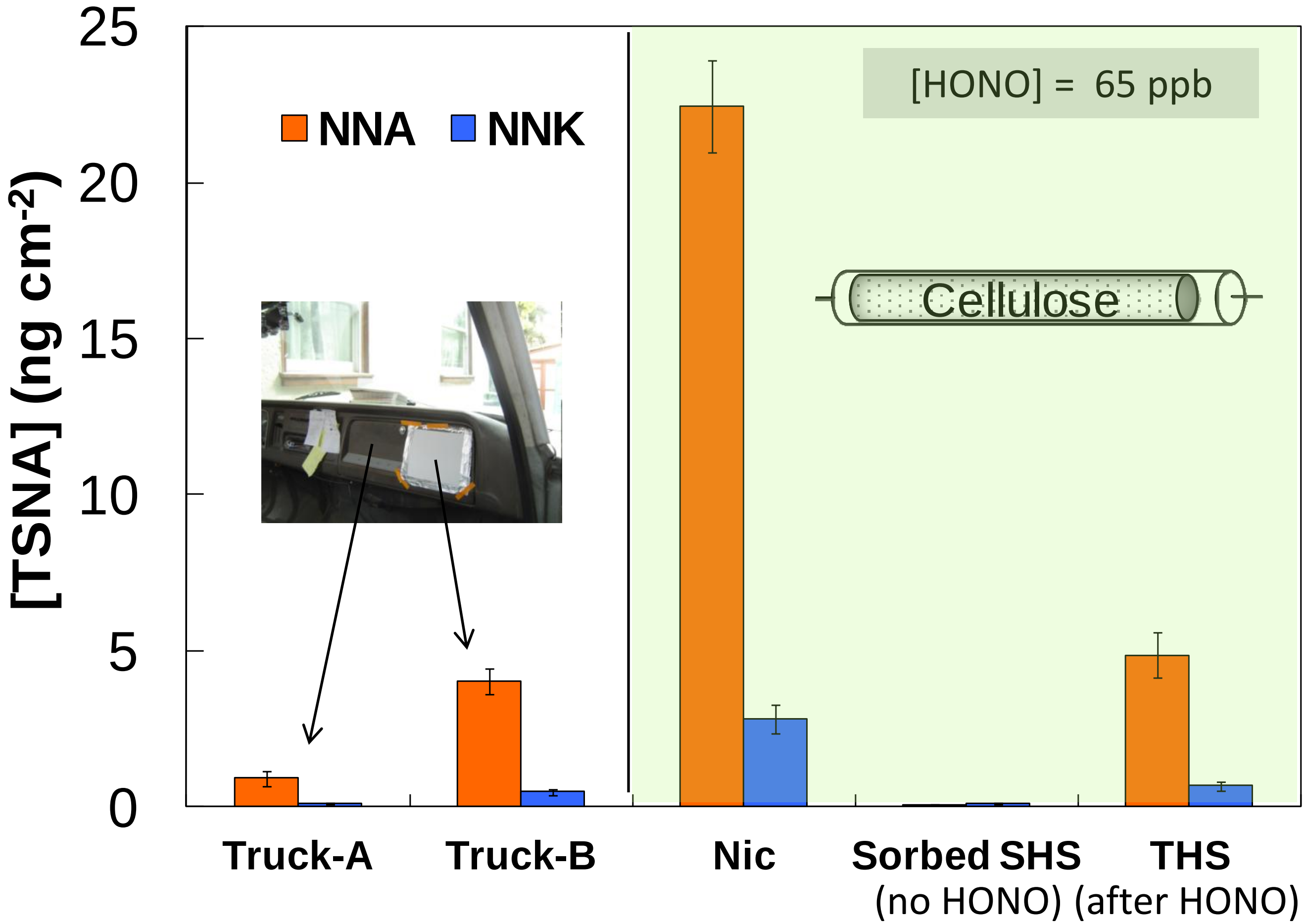
Sleiman et al., *PNAS* 2010

# Field sampling

**NNA and NNK found in field samples with similar NNA/NNK ratio**

Vehicle's cabin
(3 days of smoking+aging)

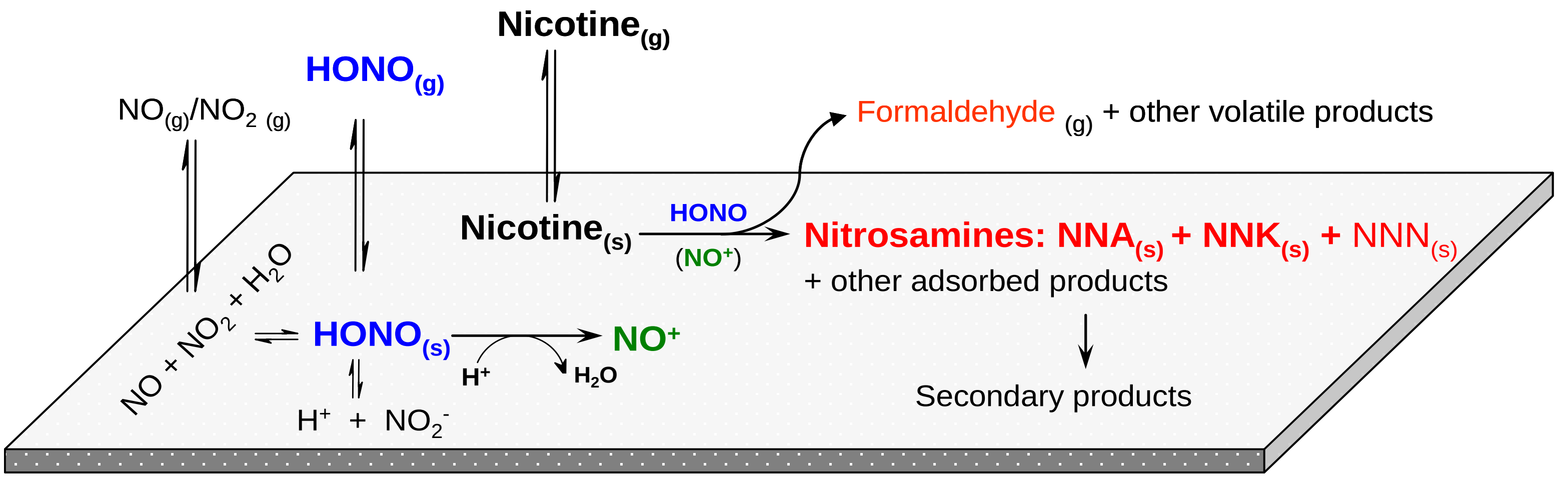
$$\frac{[TSNA]}{[Nic]} = \frac{1}{320}$$

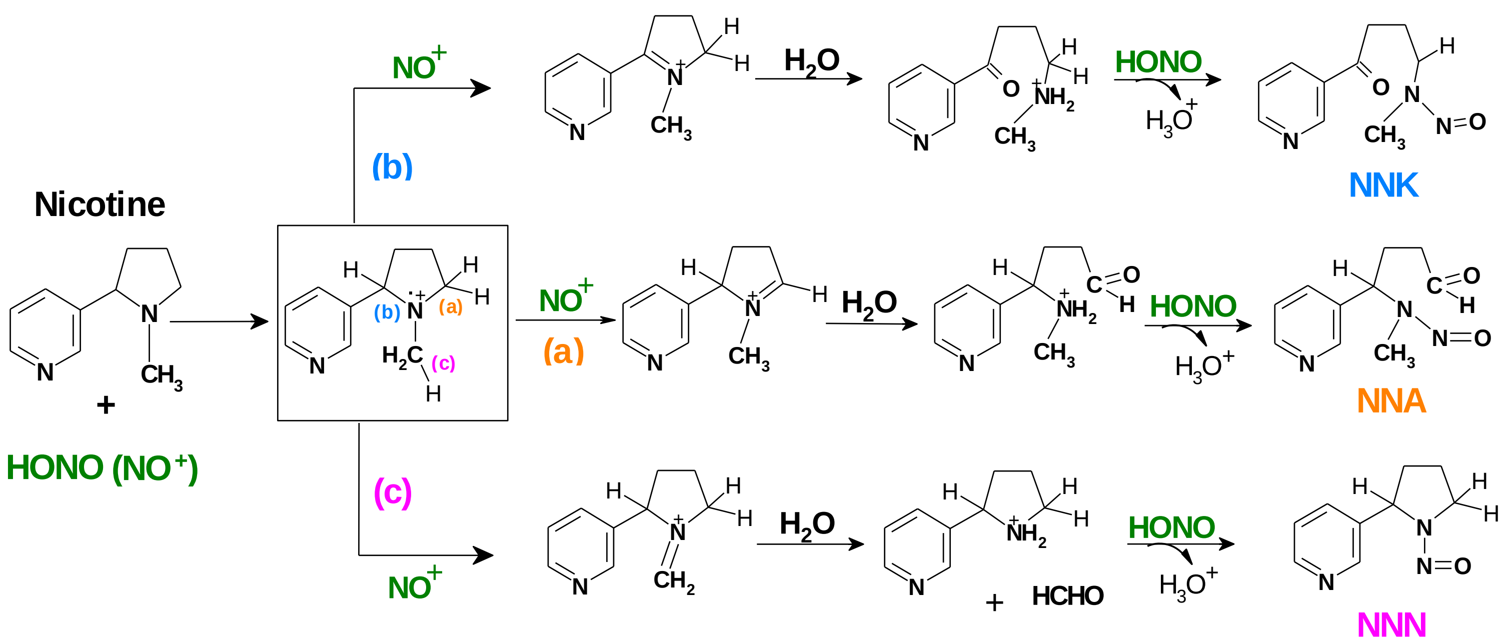



**Sleiman et al., *PNAS* 2010**

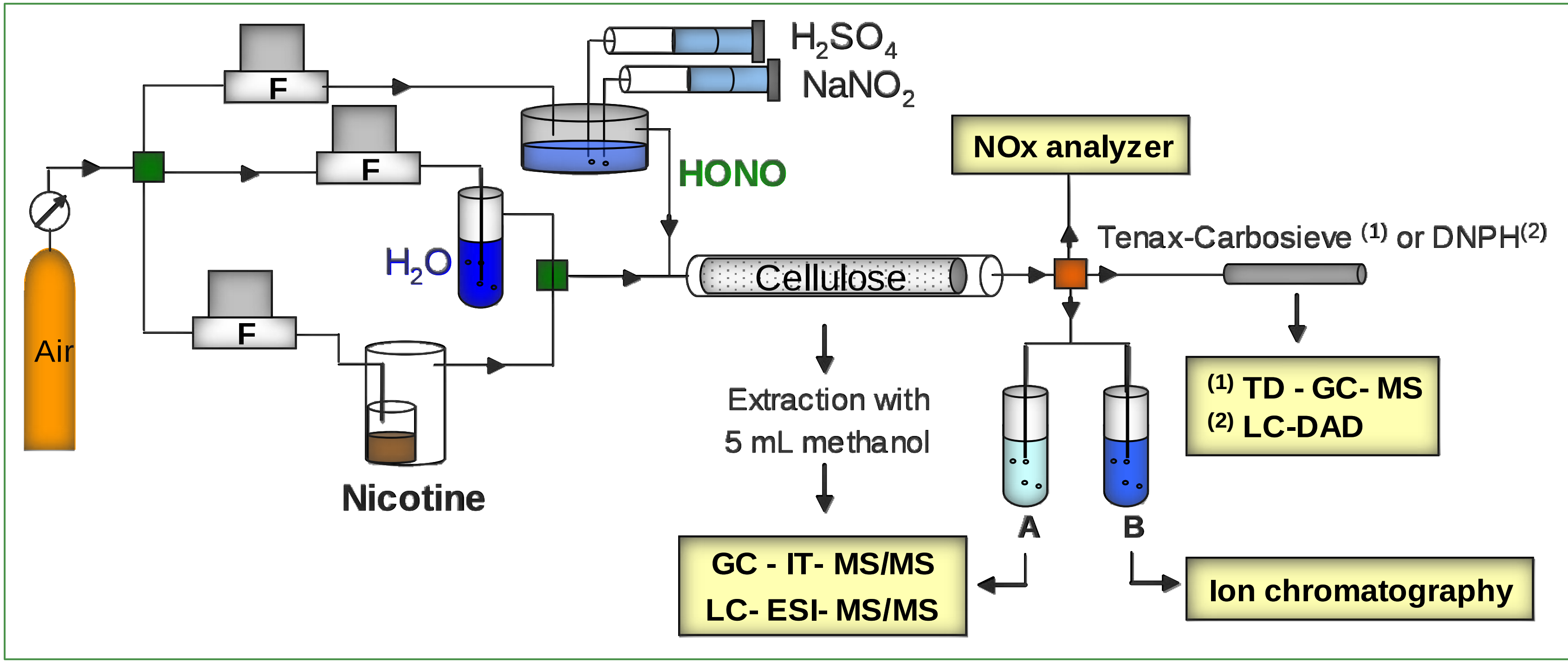
**How stable are NNA and NNK?**

# How TSNA are formed: reaction mechanisms



# Setup for heterogeneous reactions of HONO + nicotine




- ❑ [HONO] : 50 – 100 ppb
- ❑ Total air flow = 0.5 $L.min^{-1}$
- ❑ Nicotine loadings : 1 – 10 $\mu g.cm^{-2}$
- ❑ RH = 45 ± 5 % and T = 23 ± 2 C

Sleiman et al., *J. Chromat. A* 2009

# Implications for indoor exposure

- Exposure pathways: dermal contact, inhalation and ingestion of TSNA-loaded dust

| Surface | | [Nicotine] (µg m$^{-2}$) | [TSNA] (ng m$^{-2}$) |
|---|---|---|---|
| Households | Furniture [(a)] | 11 – 73 | 42 – 300 |
| | Dust [(a)] | 0.89 – 4.4 | 3.5 – 17 |
| Vehicles | Dashboard [(a)] | 5.0 – 8.6 | 18 – 35 |
| | Dust [(a)] | 11 – 30 | 47 – 78 |
| Skin & clothing | Skin [(a)] | > 80 | > 320 |
| | Skin [(b)] | 0.63 – 63 | 2.5 – 250 |
| | Cotton [(c)] | 1000 | 4000 |

$$M_N = K_{oa} \delta [N]_g S_H$$

$M_N$ : surface concentration of nicotine

$K_{oa}$ : octanol-air partition

$\delta$: thickness of organic film on skin (10 nm)

$[N]_g$ : gas phase nicotine concentration

$S_H$ : exposed surface of the human skin (0.4 m$^2$)

[(a)] Matt et al., *Nicotine & Tobacco Research*, 2008
[(b)] Weschler & Nazaroff, *Atmos. Environ.*, 2008
[(C)] Destaillats et al, *Environ. Sci. Technol*. 2006

**Do these TSNA levels pose a significant health hazards ?**

# Summary #2: HONO

## Conclusions

- ❑ Reactivity of indoor nicotine with HONO makes it potentially more hazardous than has been recognized previously

- ❑ Heterogeneous chemistry play a key role in the aging and the exposure to tobacco smoke pollutants

## Perspectives

- ❑ We need more information on exposure and health risk assessment

  - ✓ Field data
  - ✓ Biomarkers and environmental tracers of THS
  - ✓ Dermal uptake, indirect transport routes (via partitioning to aerosols), dust ingestion
  - ✓ Genotoxicity of aged second-hand smoke
  - ✓ Asthma, airway irritation by oxidation byproducts

# Reactive oxygen species (ROS)

- Unstable molecules/radicals/ions containing O atoms
- Short-lived (microseconds to hours)
- Generated often as a mixture
- Difficult to detect in the environment

"stealth pollutants"

- Organic radicals ($R^{\bullet}$)
- Hydroxyl radicals ($HO^{\bullet}$)
- Superoxide ($O_2^{\bullet -}$)
- Hydrogen peroxide ($H_2O_2$)
- Organic peroxides
- Hydroperoxides (ROOH)

VOCs, particles, ROS

(secondhand smoke)

SVOCs, ROS

Indoor surfaces

ROS

"thirdhand" exposures

From *Things to be Learned*

# Chemistry and environmental engineering

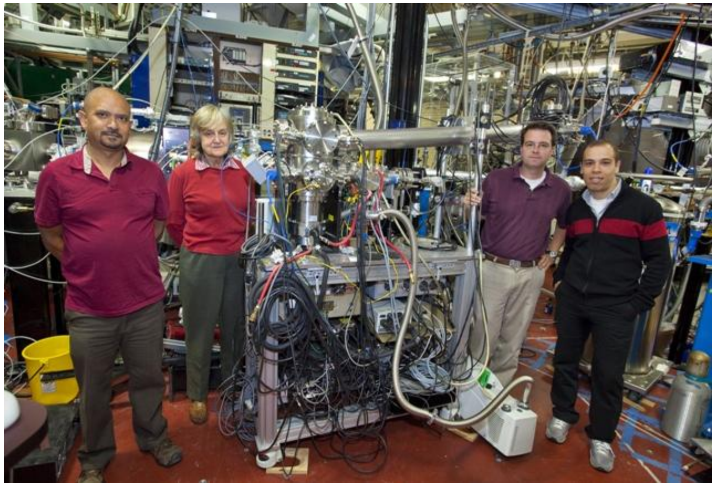
- How does SHS become THS?
  - Aging of constituents
  - Interactions with other pollutants and oxidants
- Partitioning among air, surfaces, particles (distribution indoors: on furniture, walls, people, clothes)
- Pathways of THS exposure
- Exposure to constituents
- Clean-up

**Lots of measurement challenges!**

**New approaches, methods and technologies!**

# Acknowledgements

❑ LBNL:
Randy Maddalena, Al Hodgson, Marion Russell, Emma Smith, Musahid Ahmed, Kevin Wilson



❑ Portland State U.:
James Pankow

❑ U. of California San Francisco:
Peyton Jacob, Suzaynn Schick

❑ Technion (Israel):
Yael Dubowski, Lauren Petrick

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UC Tobacco-Related Diseases Research Program
US-Israel Binational Science Foundation

# Goals of TRDRP's THS Initiative

1. Identify the health effects of exposure to THS and develop science-based policies to prevent such exposures.

2. Develop sufficient understanding of exposure to and mechanisms of action by THS to build the framework for future research.

# Specific Aims: THS Exposure & Health Effects

1. Identify and quantify THS constituents and candidates for biomarkers of exposure to THS;
2. Identify the most relevant pathways for exposure; measure human exposure under controlled conditions and in field studies;
3. Delineate cellular, molecular, toxicological, physiologicaland pathological effects of THS;
4. Conduct health risk assessments, particularly among vulnerable populations; and
5. Describe policy and economic implications of the results.

# THS Chemistry

LBNL and Portland State University:

- Identify and characterize THS
- Constituents that may affect health
- Characterize indoor chemical reactions
- and partitioning between indoor air, dust
- and surfaces.

# THS Exposure

LBNL, UCSF, USC, SDSU

- Generate THS samples under controlled laboratory conditions for use consortium-wide
- Develop indoor partitioning models to evaluate pollutant\fate and to predict human exposures
- Develop novel analytical methods for biomarkers and tracers to measure THS exposure
- Provide quantitative analysis of biofluid samples and synthesis of THS constituents for use by other investigators
- Human exposure (controlled conditions; Schick et al.)
- Exposure assessment (field work; Matt et al.)

# THS Health Impacts

LBNL, UCR

- Genotoxicity; DNA adducts generated by THS samples
- Effects on female reproduction
- Effects on human embryonic stem cells
- Effects on wound healing

# Economic and Policy Research

USC, SDSU, UCSF

- Develop & test protocols for characterizing exposure in homes and work places
- Estimate prevalence of exposure in California
- Develop and apply a policy framework for approaches to reducing risks from THS.

# Synthesis of Findings and Integration for Risk Assessment and Policy

**THS Exposure**

- Identification of THS constituents and data on their partitioning (LBNL)
- Measurement of THS in dust and wipe samples (LBNL, UCSF, SDSU, USC)
- Biomarker studies, and data on population level exposure (UCSF)

**Risk Assessment**

- Hazard identification and exposure assessment elements (UCSF, USC)
- Dose-response evaluation and risk characterization (by population, particularly susceptible and vulnerable groups e.g infants and children, workers (UCR, UCSF, USC)

**Policy Framework**

- Policy analysis and consideration of economic costs (USC)
- Policy approaches to reduce the population burden of risk (USC)
- Workshop that includes scientific experts and stakeholders to develop policy actions

NBC NEWS

C&EN CHEMICAL & ENGINEERING NEWS

# AFTER THE SMOKE CLEARS

**INDOOR CHEMISTRY:** Tobacco residues react with chemicals in air to form dangerous products

**NONSMOKERS** may have a new worry—thirdhand smoke. Nicotine residues on indoor surfaces can react with nitrous acid in the air to form carcinogenic nitrosamines not present in fresh tobacco smoke, chemists at Lawrence Berkeley National Laboratory have demonstrated.

"The residual smoke on surfaces appears to become even more toxic through reactions with other atmospheric chemicals," says K. Michael Cummings, a secondhand-smoke expert at Roswell Park Cancer Institute in Buffalo. "The assumption was with time the material would become less, not more, harmful."

More than 30 years ago, Stephen S. Hecht and coworkers of the University of Minnesota first showed that nicotine reacts with nitrous acid in aqueous solution. A new study shows that such reactions can also happen with nicotine left behind from tobacco smoke and nitrous acid in the air. "We are describing a system in which these reactions can take place on indoor surfaces," says Hugo Destaillats, a chemist at LBNL (*Proc. Natl. Acad. Sci. USA*, DOI: 10.1073/pnas.0912820107).

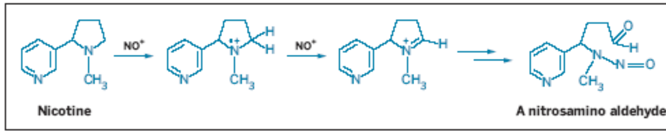
Destaillats, Lara A. Gundel, Mohamed Sleiman, and coworkers measured nitrosamines formed by the reaction of nicotine adsorbed on surfaces with nitrous acid in the air. They took samples from a nicotine-coated model cellulose surface and from surfaces in the cab of a smoker's truck. Three tobacco-specific nitrosamines were the main products of the reaction.

The researchers propose the following mechanism for the reaction: $NO^+$ removes an electron from the pyrrolidine nitrogen of nicotine to form an unstable cation. Then, a second $NO^+$ abstracts H from one of the three α-carbons to form an iminium ion. Subsequent reactions with adsorbed water and nitrous acid vapors yield the nitrosamines.

In addition, they found secondary products resulting from decomposition of the nitrosamines. One of these compounds, a stable pyrazole formed from the decomposition of one of the nitrosamines that has not been observed in fresh tobacco smoke, could serve as a tracer for thirdhand smoke, the authors suggest.

"Since nicotine readily adsorbs to surfaces and nitrogen oxides are ubiquitous, their findings may have some relevance to contamination by thirdhand smoke," Hecht says. "Research would be necessary to demonstrate whether, for example, infants in homes that permitted smoking were receiving significant exposures by this route. I personally feel that exposure by this route would be minimal, but the studies need to be carried out."

Destaillats emphasizes that this study addresses only the chemistry. "Our study should incite some of our colleagues to determine whether exposure to these reactive residues and by-products of these reactive residues can be harmful," he says.—CELIA ARNAUD




*Reaction of surface-bound nicotine with nitrous acid can form one of three tobacco-specific nitrosamines. The nitrosamino aldehyde shown is the primary product.*

BBC

## 'Third-hand smoke' could damage health

**Lingering residue from tobacco smoke which clings to upholstery, clothing and the skin releases cancer-causing agents, work in PNAS journal shows.**

Nicotine residues from tobacco smoke hang around for weeks or months

Berkeley scientists in the US ran lab tests and found "substantial levels" of toxins on smoke-exposed material.

They say while banishing smokers to outdoors cuts second-hand smoke, residues will follow them back inside and this "third-hand smoke" may harm.

TF1 NEWS

Accueil TF1

## Le tabac froid, dangereux pour la santé

Par TF1 News (d'après agence), le 09 février 2010 à 14h12, mis à jour le 09 février 2010 à 14:43

**Une étude américaine montre que la fumée de cigarette est mauvaise pour la santé même sous forme de résidu déposé sur les murs ou les meubles.**

15 Commentaires | 63

Article suivant dans Santé : Les secrets du grand âge sont dans les gènes

On connaissait les dangers du tabagisme, y compris passif, mais une nouvelle étude américaine montre que la fumée de cigarette est mauvaise pour la santé même sous forme de résidu déposé sur les murs ou les meubles. Lorsque une cigarette est allumée, la nicotine est libérée sous forme de fumée qui se dépose sur les surfaces de la maison (murs, moquettes, rideaux, meubles), où elle peut rester des mois, rappelle cette étude publiée dans les Annales de l'Académie américaine des Sciences (PNAS).

DER SPIEGEL

## Forscher warnen vor Nikotin-Rückständen

EL PAÍS

ELPAIS.com > Sociedad

## Un nuevo peligro del tabaco: el 'humo de tercera mano'

La nicotina puede reaccionar con productos químicos y posarse en la superficie de objetos cotidianos