The Unfinished Health and Research Agendas of Incomplete Combustion Particles

Kirk R. Smith
Tyler Laureate 2012
Professor of Global Environmental Health
University of California, Berkeley

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Doha, Qatar
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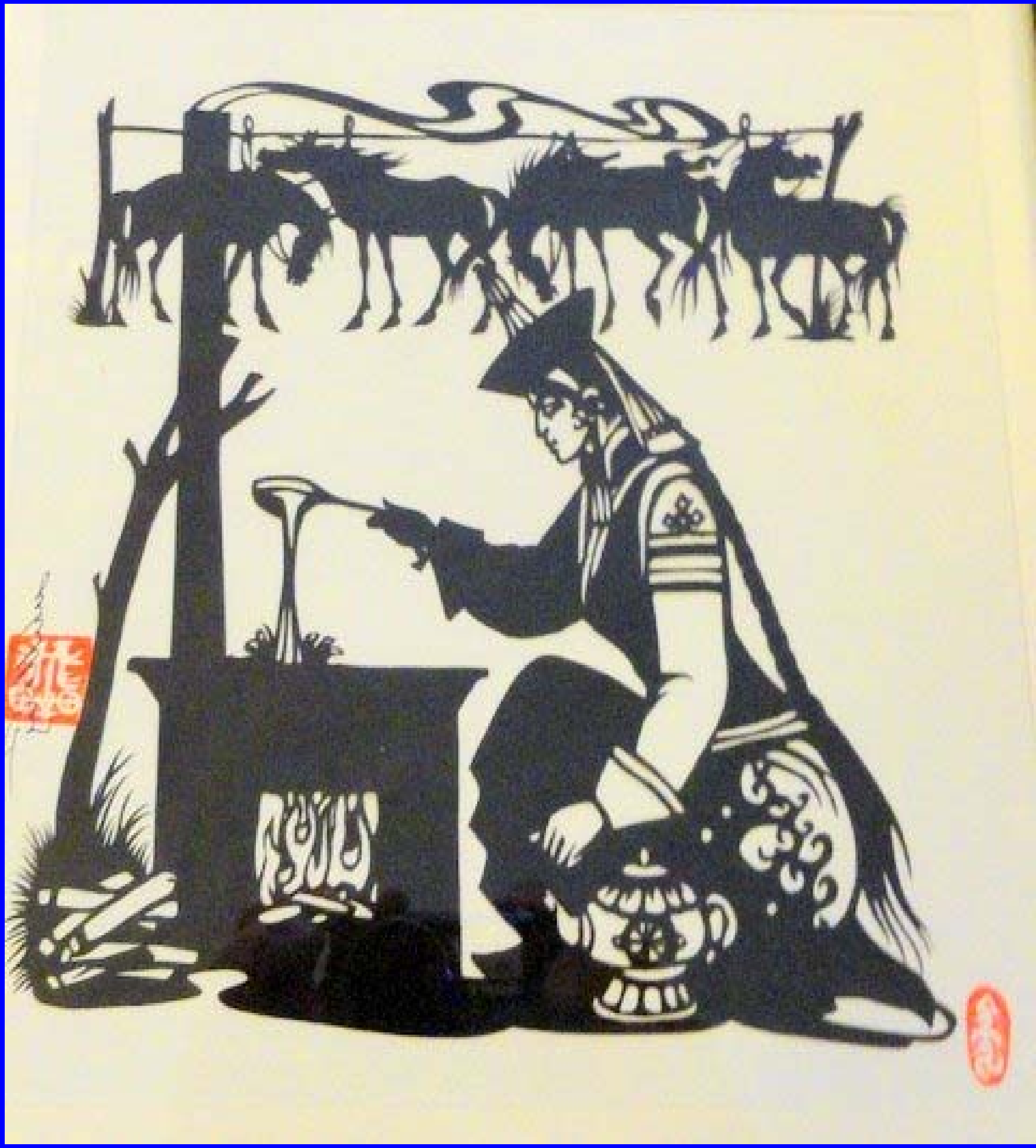
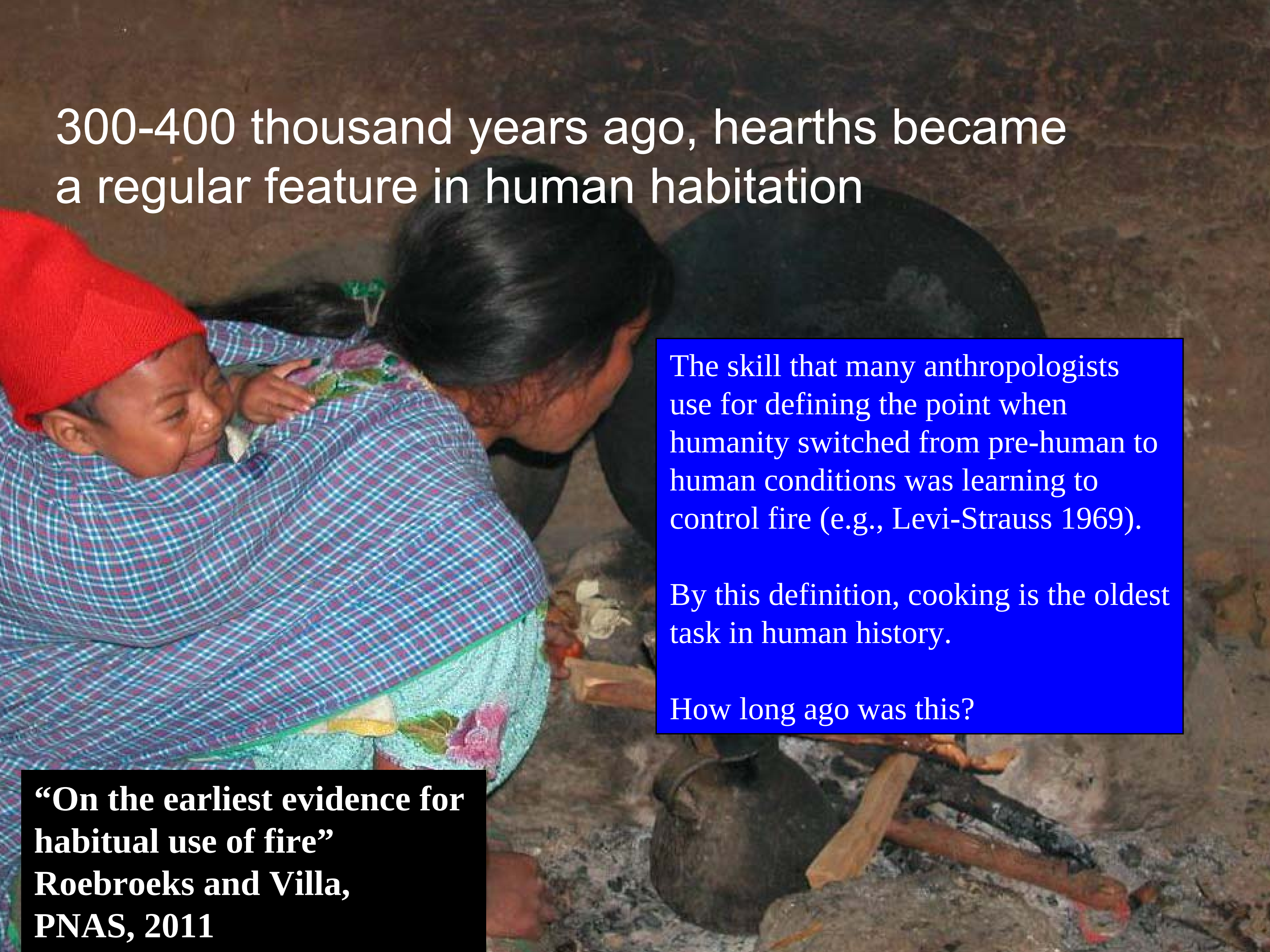


300-400 thousand years ago, hearths became a regular feature in human habitation



The skill that many anthropologists use for defining the point when humanity switched from pre-human to human conditions was learning to control fire (e.g., Levi-Strauss 1969).

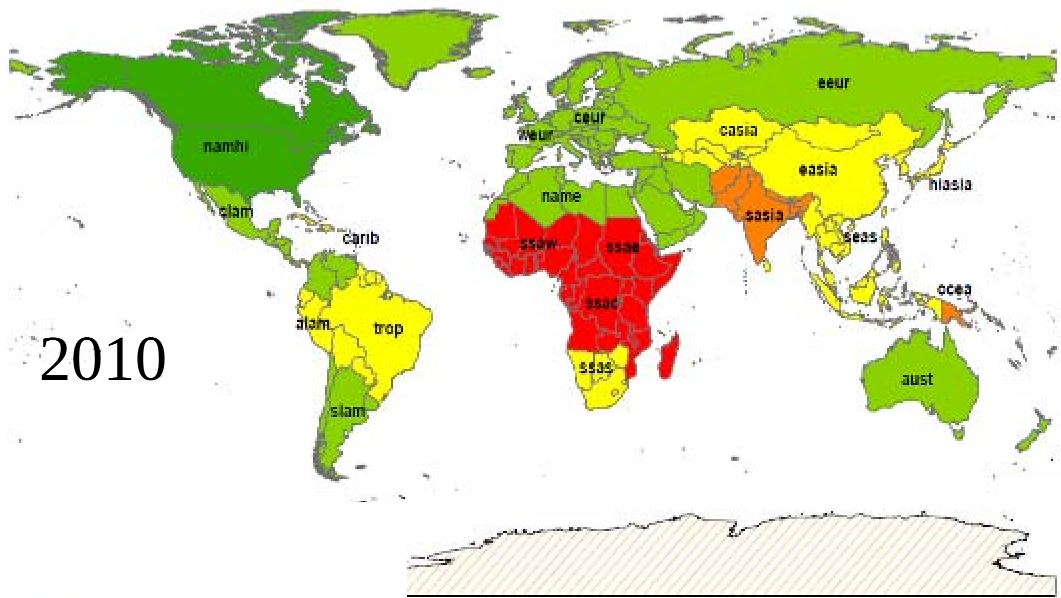
By this definition, cooking is the oldest task in human history.

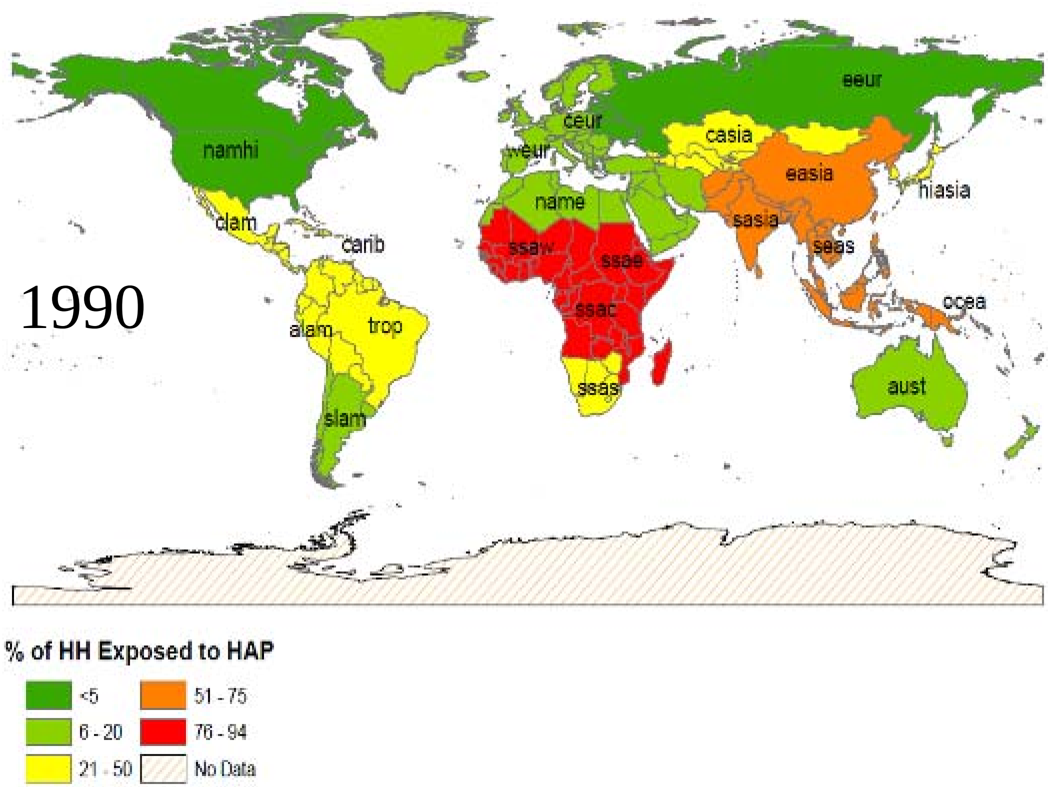
How long ago was this?

“On the earliest evidence for habitual use of fire”
Roebroeks and Villa, PNAS, 2011


The three major solid fuels

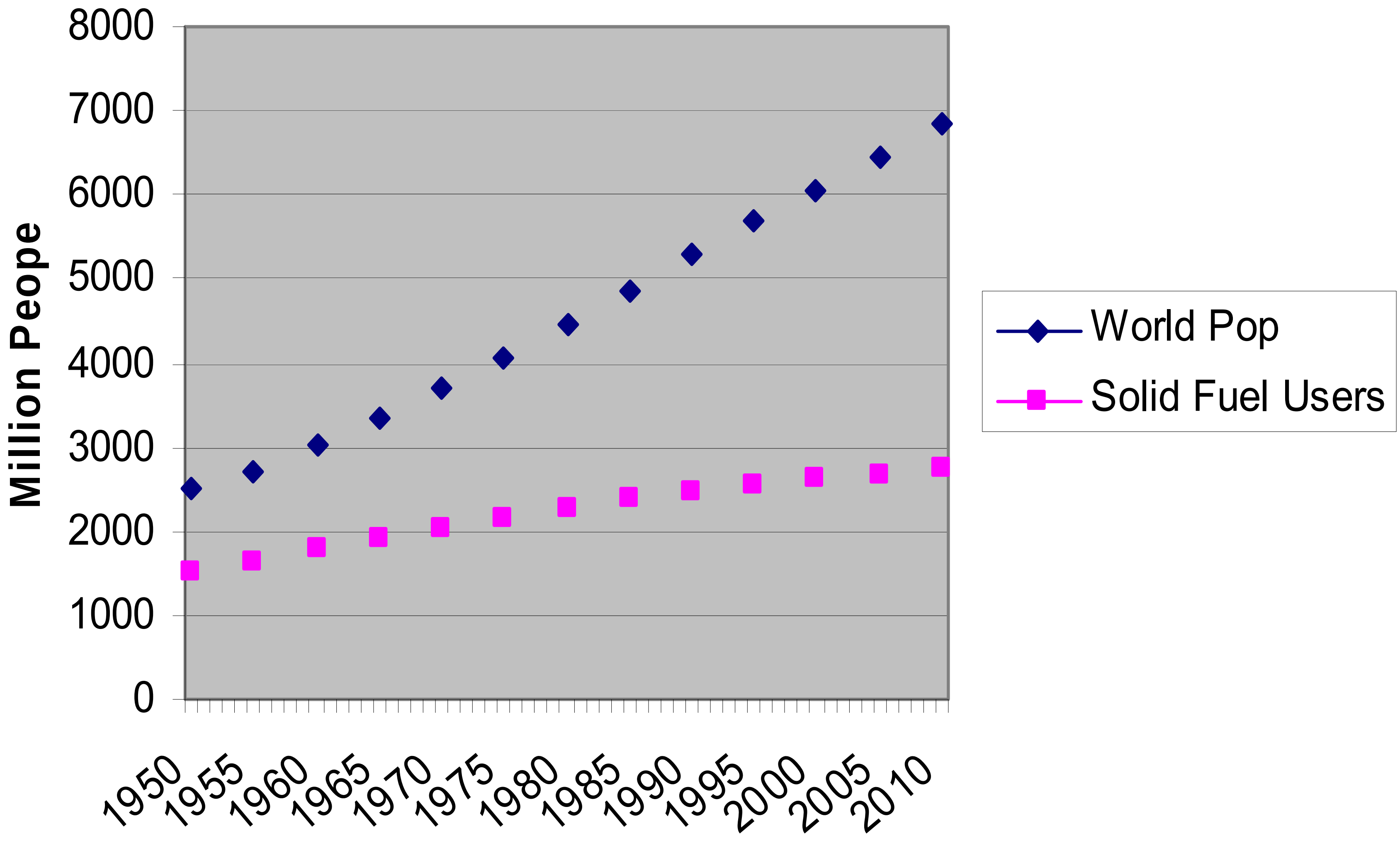
Households using biomass or coal to cook





Comparative Risk Assessment (CRA) 2012

World Population Using Solid Fuels



Woodsmoke is natural – how can it hurt you?

Or, since wood is mainly just carbon, hydrogen, and oxygen, doesn't it just change to CO_2 and H_2O when it is combined with oxygen (burned)?

Reason: the combustion efficiency is far less than 100%

Energy flows in a well-operating traditional wood-fired Indian cooking stove

A Toxic Waste Factory!!

Typical biomass cookstoves convert 6-20% of the fuel carbon to toxic substances

Into Pot	In PIC	Waste Heat
2.8 MJ	1.2 MJ	11.3 MJ
18%	8%	74%

PIC = products of incomplete combustion = CO, HC, C, etc.

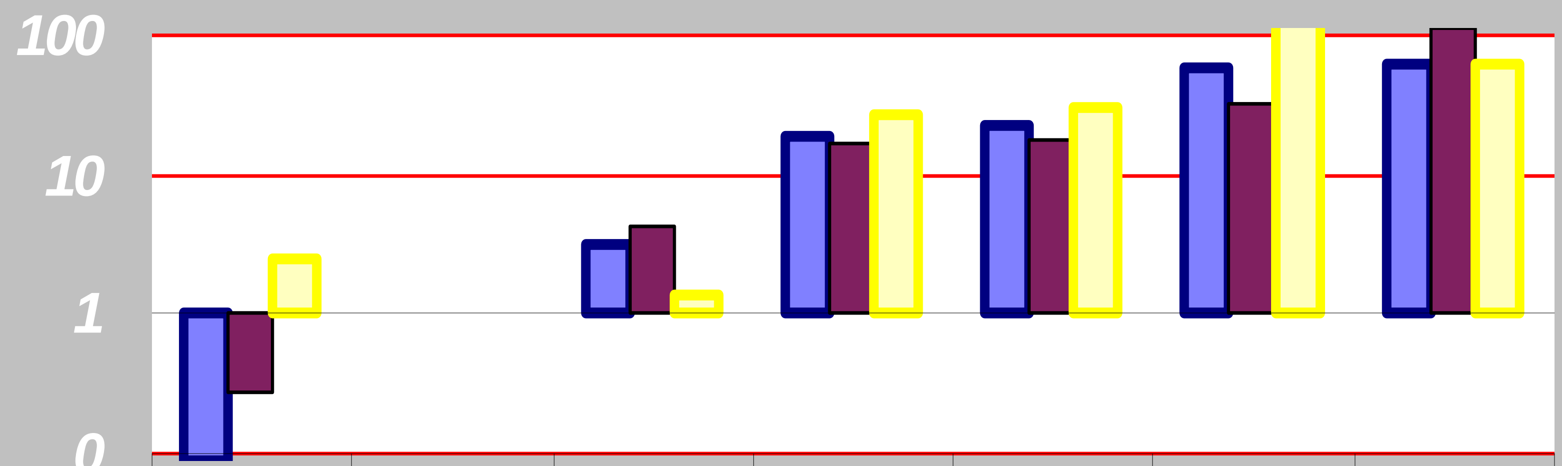
Source: Smith, et al., 2000

Toxic Pollutants in Biomass Fuel Smoke from Simple (poor) Combustion

- Small particles, CO, NO_2
- Hydrocarbons
  - 25+ saturated hydrocarbons such as *n-hexane*
  - 40+ unsaturated hydrocarbons such as *1,3 butadiene*
  - 28+ mono-aromatics such as *benzene & styrene*
  - 20+ polycyclic aromatics such as *benzo(α)pyrene*
- Oxygenated organics
  - 20+ aldehydes including *formaldehyde* & *acrolein*
  - 25+ alcohols and acids such as *methanol*
  - 33+ phenols such as *catechol* & *cresol*
  - Many quinones such as *hydroquinone*
  - Semi-quinone-type and other radicals
- Chlorinated organics such as *methylene chloride* and *dioxin*

Source: Naeher et al, *J Inhal Tox*, 2007

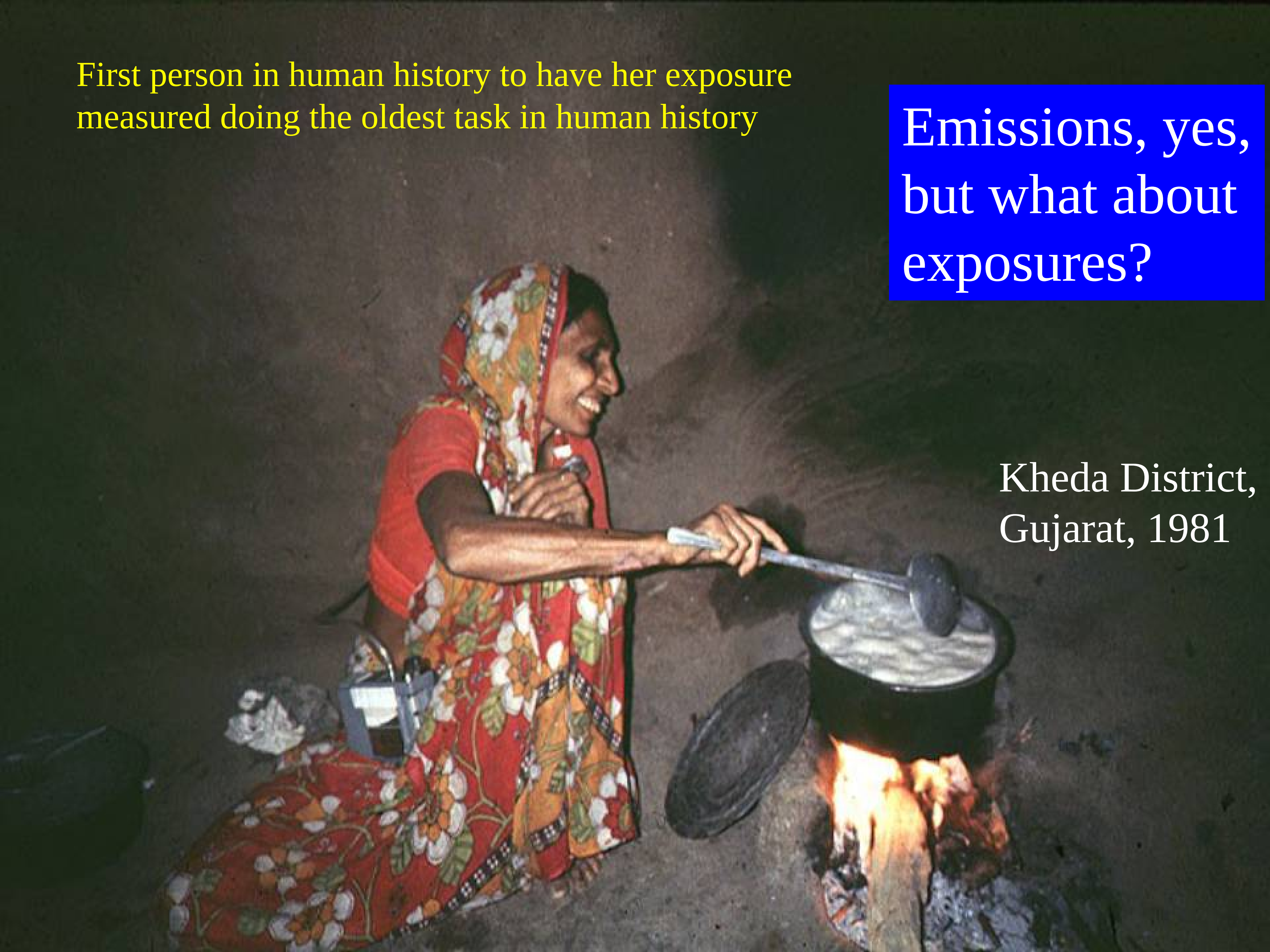
Health-Damaging Pollutants per Unit Energy Delivered
Ratio of Emissions to LPG



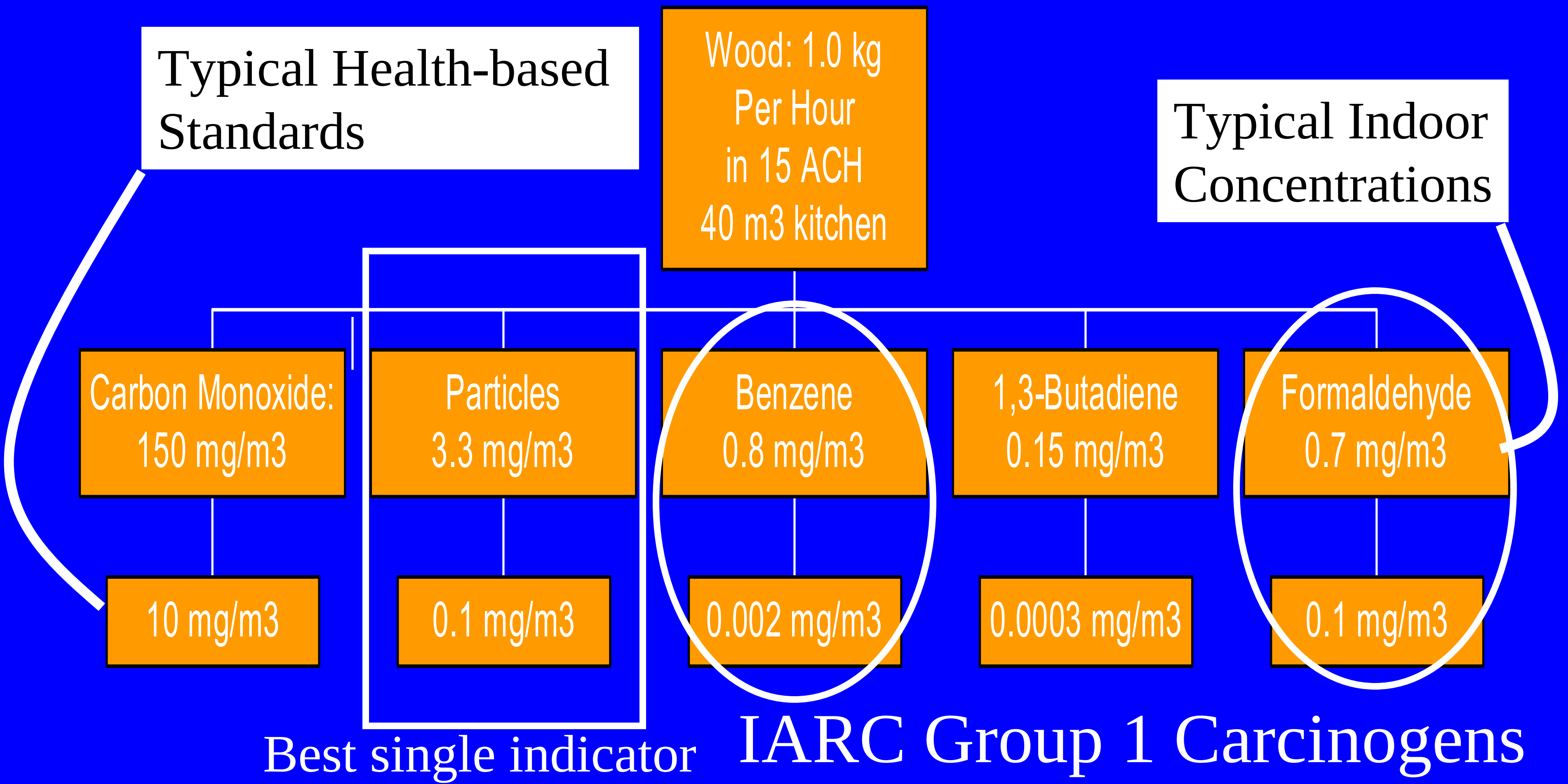
	Biogas	LPG	Kerosene	Wood	Roots	Crop Residues	Dung
CO	0.1	1.0	3	19	22	60	64
Hydrocarbons	0.3	1.0	4.2	17	18	32	115
PM	2.5	1.0	1.3	26	30	124	63

CO Hydrocarbons PM

Smith, et al., 2005


First person in human history to have her exposure
measured doing the oldest task in human history
Emissions, yes,
but what about
exposures?
Kheda District,
Gujarat, 1981

Health-Damaging Air Pollutants From Typical Woodfired Cookstove in India.



WORLD HEALTH ORGANIZATION
INTERNATIONAL AGENCY FOR RESEARCH ON CANCER

IARC Monographs on the Evaluation of Carcinogenic Risks to Humans

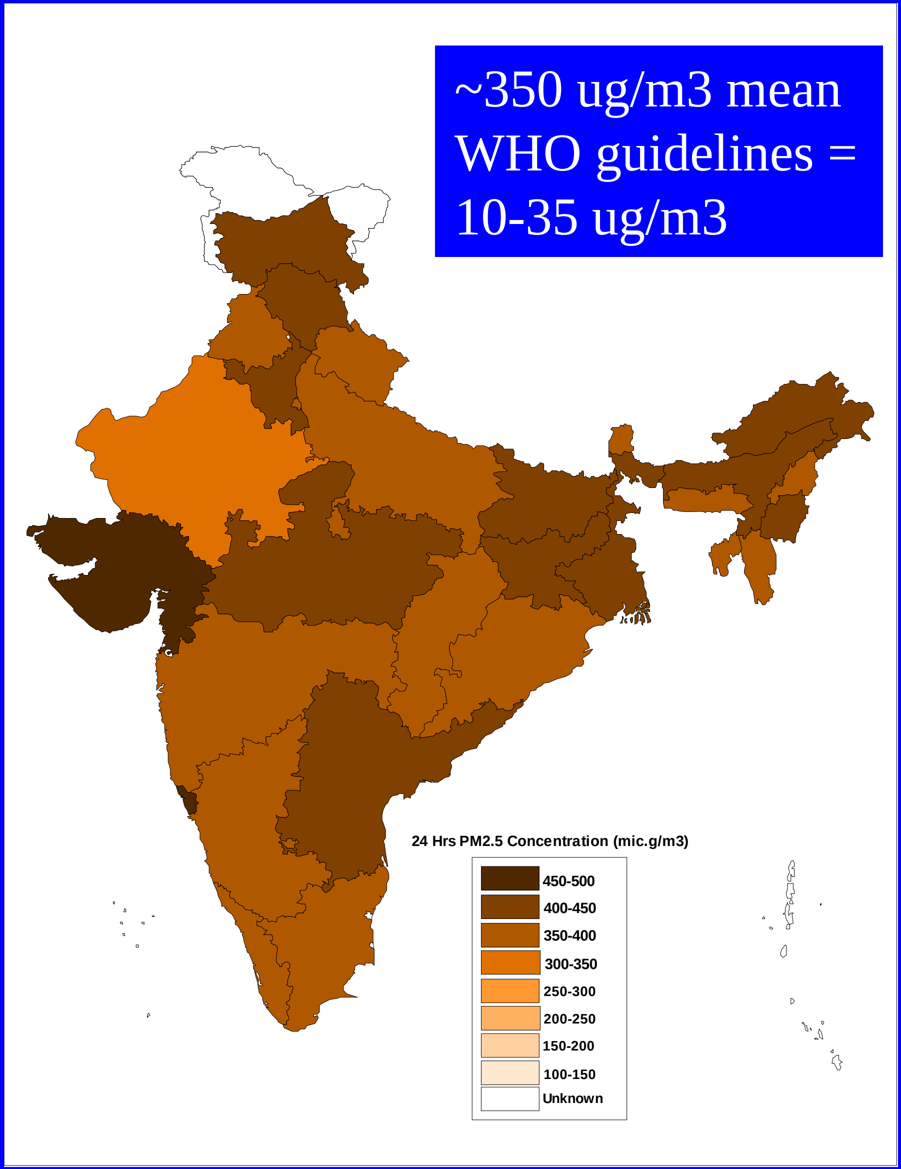
VOLUME 95

Household Use of Solid Fuels and High-temperature Frying

Published in 2010, but conducted in 2006.
Woodsmoke found to be 2A – probable human carcinogen
(Not Group #1 due to weak epidemiological evidence)

Exposure Model for India based on measurements in ~1000 households

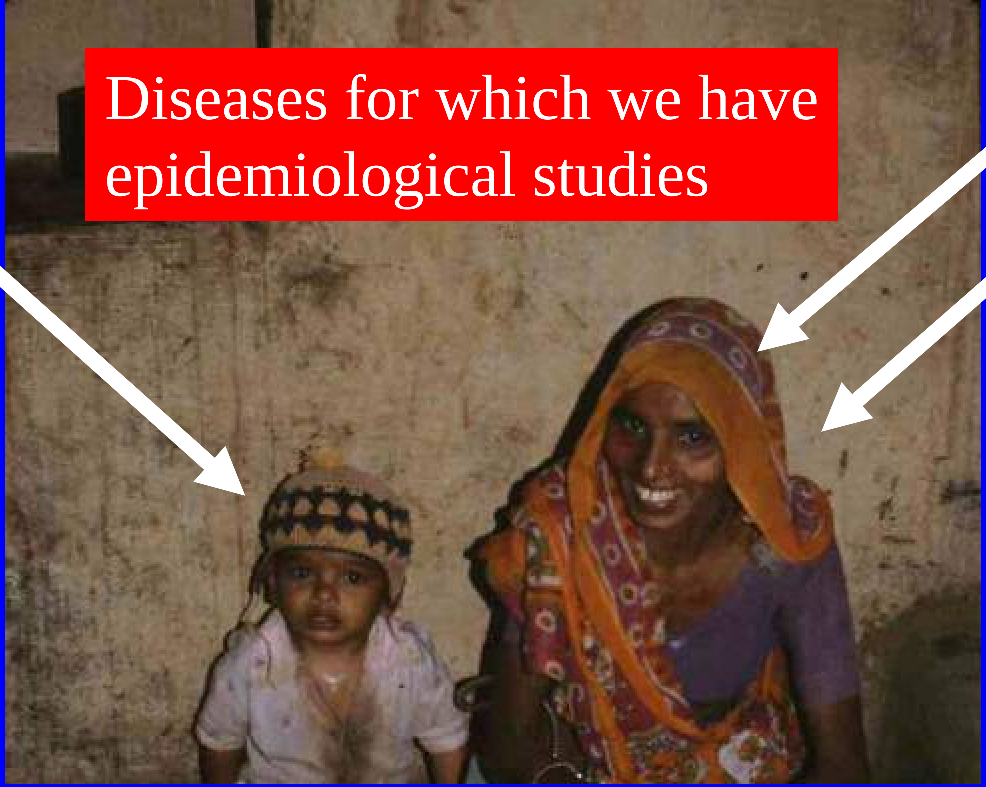
Estimated PM2.5 for <u>only</u> solid-fuel-using households



~350 ug/m3 mean
WHO guidelines = 10-35 ug/m3

Household Air Pollution Comparative Risk Assessment, 2012

ALRI/
Pneumonia

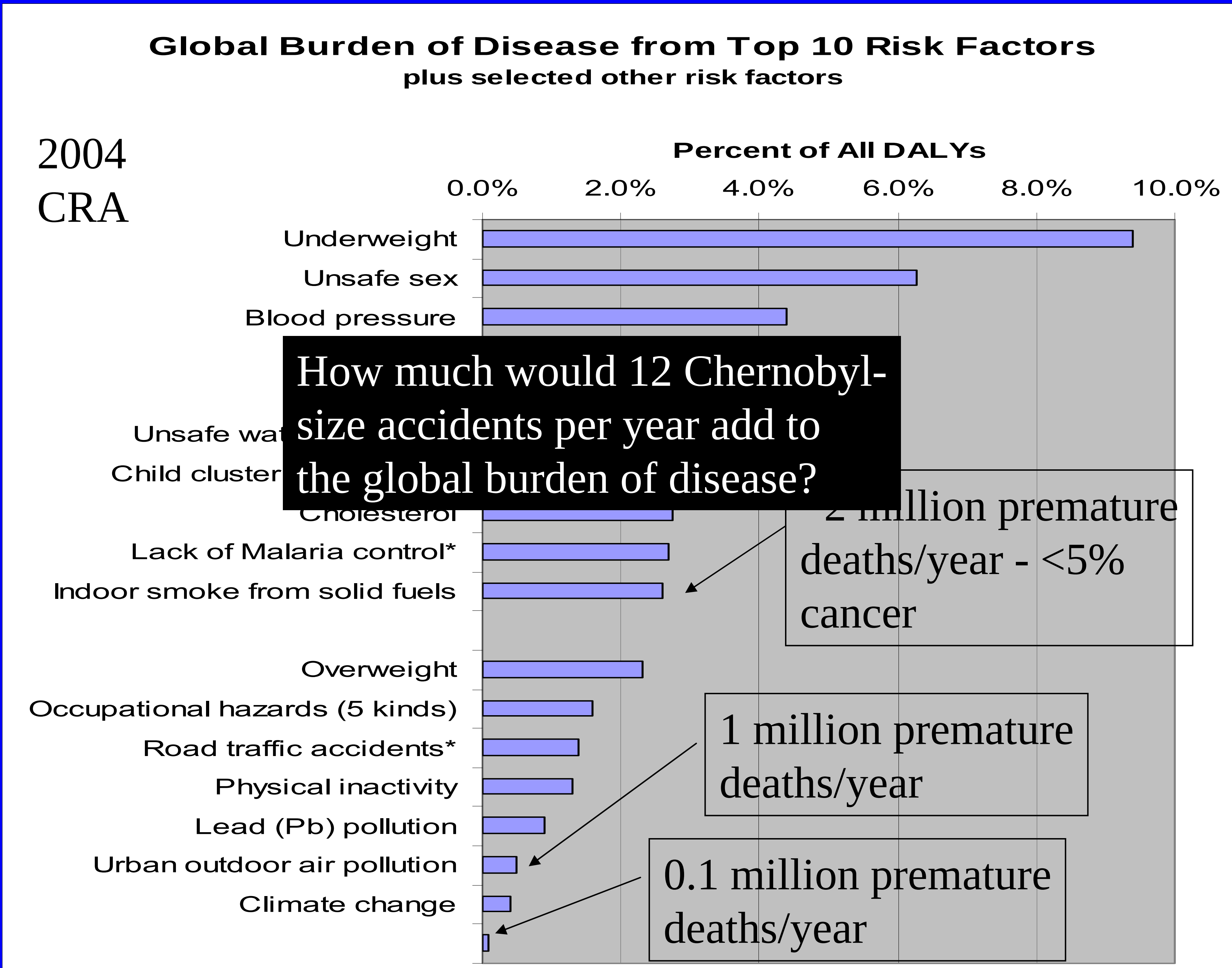


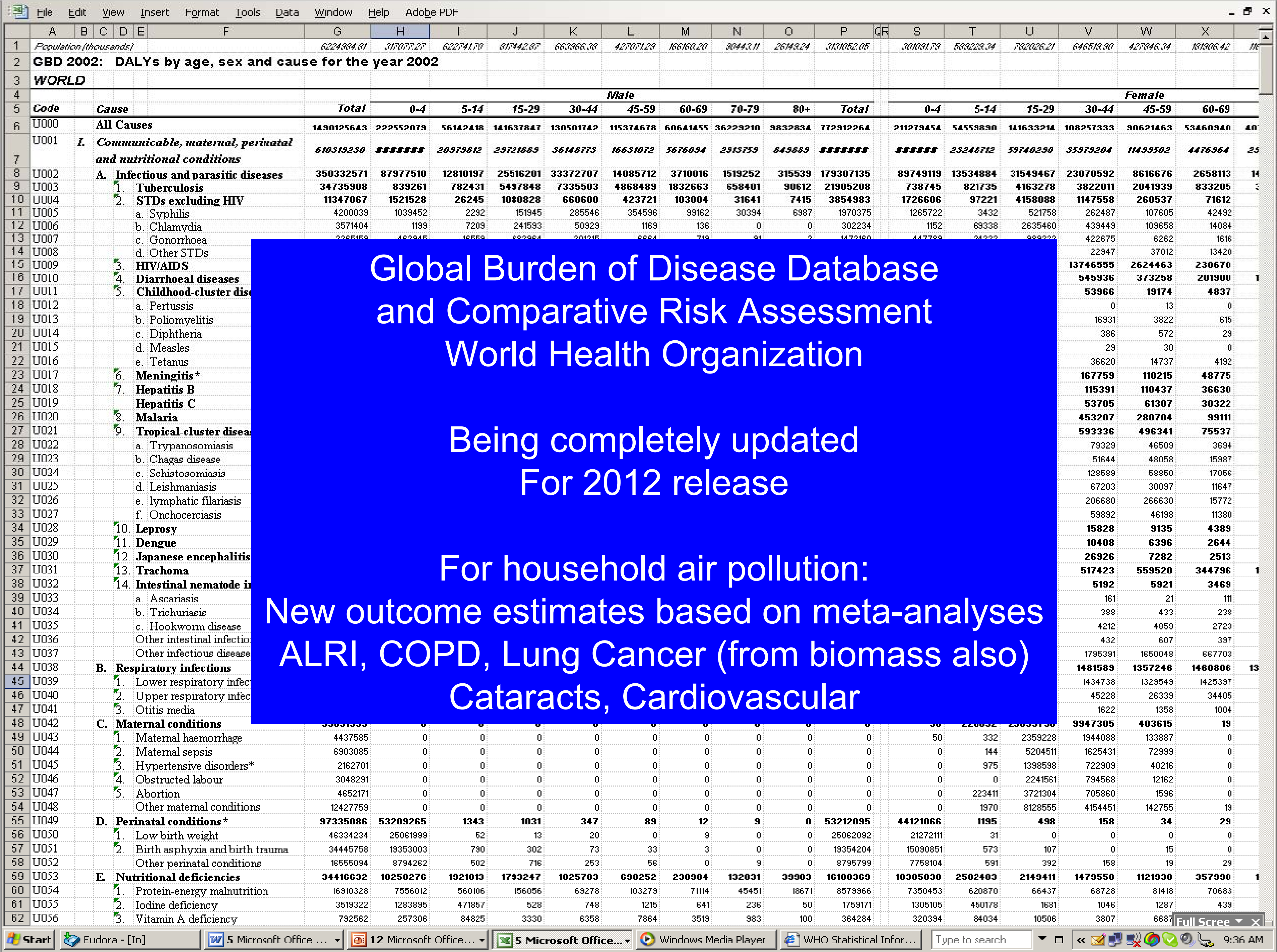
COPD

Lung cancer
(coal)

These three diseases were included in the
2004 Comparative Risk Assessment
Managed and published by WHO

First ever comprehensive risk assessment
with consistent rules of evidence
and common databases


Global Burden of Disease from Top 10 Risk Factors
plus selected other risk factors
2004
CRA
Percent of All DALYs
0.0%
2.0%
4.0%
6.0%
8.0%
10.0%
Underweight
Unsafe sex
Blood pressure
Child cluster
Lack of Malaria control*
Indoor smoke from solid fuels
Overweight
Occupational hazards (5 kinds)
Road traffic accidents*
Physical inactivity
Lead (Pb) pollution
Urban outdoor air pollution
Climate change
How much would 12 Chernobyl-size accidents per year add to the global burden of disease?
million premature deaths/year - <5% cancer
1 million premature deaths/year
0.1 million premature deaths/year



Global Burden of Disease Database
and Comparative Risk Assessment
World Health Organization

Being completely updated
For 2012 release

For household air pollution:
New outcome estimates based on meta-analyses
ALRI, COPD, Lung Cancer (from biomass also)
Cataracts, Cardiovascular

Diseases for which we now have epidemiological studies

ALRI/ Pneumonia

Low birth weight

Stillbirth

COPD

Lung cancer (coal)

Lung cancer (biomass)

Blindness (cataracts, opacity)

CV disease
Blood pressure
ST-segment

These additional diseases will be included in the 2010 Comparative Risk Assessment – being published 2012

In addition, using evidence from other exposure sources, CVD will be included

There is epi evidence for these other diseases, but considered insufficient to include in the 2010 Comparative Risk Assessment

Cognitive Impairment

Birth defects

Asthma?

Tuberculosis

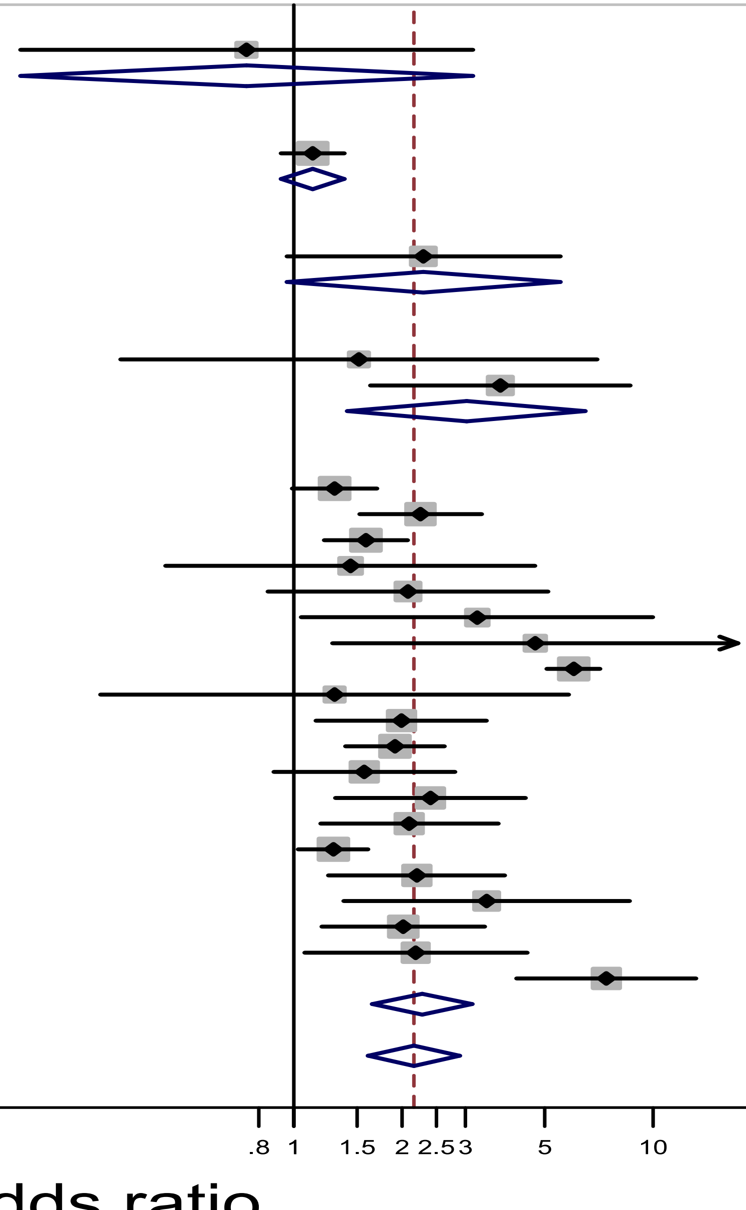
ALRI

Other cancers
(cervical, NP, upper airway)

Burns and the health/safety impacts of fuel gathering

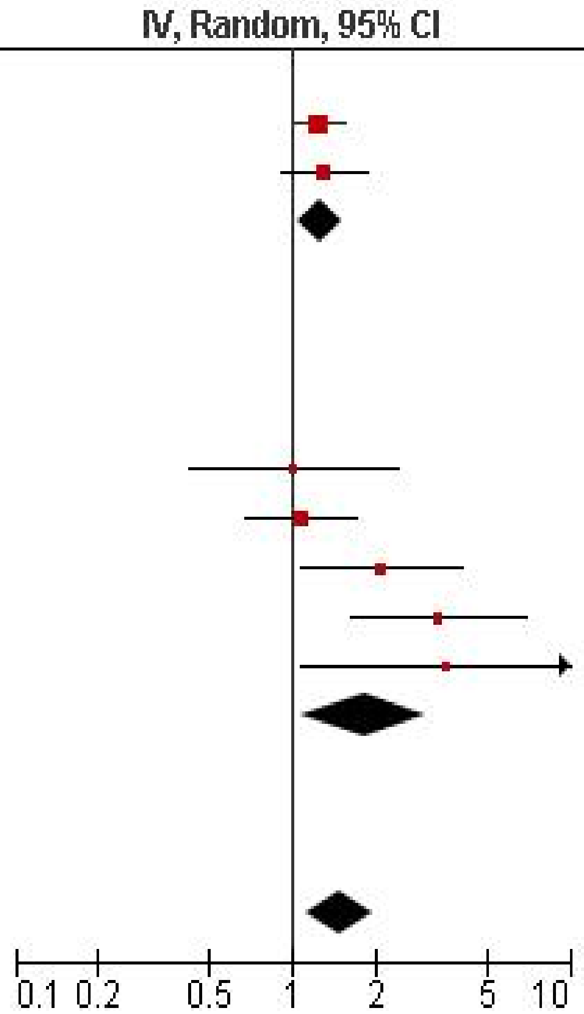
Systematic Review and Meta-analysis of lung cancer and household coal combustion

study	studyyear	casenum	contnum	ES (95% CI)
Africa				
Sasco(2002)	1996-1998	118	235	0.74 (0.17, 3.14)
Subtotal (I-squared = .%, p = .)				0.74 (0.17, 3.14)
.				
Europe				
Lissowska(2005)	1998-2001	2861	3118	1.13 (0.93, 1.38)
Subtotal (I-squared = .%, p = .)				1.13 (0.93, 1.38)
.				
North America				
Wu(1985)	1981-1982	220	220	2.30 (0.96, 5.50)
Subtotal (I-squared = .%, p = .)				2.30 (0.96, 5.50)
.				
India				
Gupta(2001)	1995-1997	265	525	1.52 (0.33, 6.98)
Sapkota(2008)	2001-2004	793	718	3.76 (1.64, 8.63)
Subtotal (I-squared = 4.4%, p = 0.307)				3.02 (1.42, 6.46)
.				
Mainland China and Taiwan				
Wu-Williams(1990)	1985-1987	965	959	1.30 (0.99, 1.70)
Sun(1991)	1985-1987	418	398	2.26 (1.53, 3.33)
Chengyu(1992)	1990-1991	135	135	1.59 (1.22, 2.07)
Ger(1993)	1990-1991	131	524	1.44 (0.44, 4.69)
Li(1993)	1986-1992	161	161	2.08 (0.85, 5.08)
Lin(1996)	1985-1990	122	122	3.24 (1.05, 9.94)
Dai(1996)	1992-1993	120	120	4.70 (1.29, 17.18)
Luo(1996)	1990-1991	102	306	6.00 (5.07, 7.10)
Ko(1997)	1992-1993	117	117	1.30 (0.29, 5.80)
Hao(1998)	1981-1986	220	440	1.99 (1.16, 3.43)
Huang(1999)	1993-1996	122	244	1.92 (1.40, 2.62)
Wu(1999)	1997	258	258	1.58 (0.89, 2.80)
Lan(2000)	1995-1996	122	122	2.40 (1.31, 4.40)
Lee(2001)	1993-1999	527	805	2.10 (1.19, 3.70)
Kleinerman(2002)	1994-1998	832	1724	1.29 (1.03, 1.61)
Sun(2002)	1996-1999	206	618	2.20 (1.25, 3.86)
Lu(2003)	1998-2001	445	445	3.44 (1.38, 8.57)
Liang(2004)	2001-2002	152	152	2.02 (1.20, 3.39)
Galeone(2008)	1987-1990	218	436	2.19 (1.08, 4.46)
Lan(2008)	1985-1990	498	498	7.40 (4.18, 13.10)
Subtotal (I-squared = 90.3%, p = 0.000)				2.28 (1.66, 3.13)
.				
Overall (I-squared = 90.4%, p = 0.000)				2.16 (1.62, 2.90)



Lung Cancer: Biomass vs. clean fuel

Study or Subgroup	IV, Random, 95% CI
2.7.1 Male	
Lissowska2005	1.24 [1.00, 1.54]
Sapkota2008	1.30 [0.90, 1.87]
Subtotal (95% CI)	**1.26 [1.04, 1.52]**
Heterogeneity: $Tau^2 = 0.00$; $Chi^2 = 0.05$, df = 1 ($P = 0.83$); $I^2 = 0\%$	
Test for overall effect: $Z = 2.37$ ($P = 0.02$)	
2.7.2 Female	
Sapkota2008	1.01 [0.42, 2.41]
Lissowska2005	1.07 [0.67, 1.71]
Ko1997	2.08 [1.06, 4.07]
Lee2001	3.36 [1.62, 6.96]
Behera 2005	3.59 [1.08, 11.97]
Subtotal (95% CI)	**1.81 [1.07, 3.06]**
Heterogeneity: $Tau^2 = 0.21$; $Chi^2 = 10.21$, df = 4 ($P = 0.04$); $I^2 = 61\%$	
Test for overall effect: $Z = 2.20$ ($P = 0.03$)	
Total (95% CI)	**1.48 [1.12, 1.97]**
Heterogeneity: $Tau^2 = 0.06$; $Chi^2 = 12.14$, df = 6 ($P = 0.06$); $I^2 = 51\%$	
Test for overall effect: $Z = 2.75$ ($P = 0.006$)	
Test for subgroup differences: $Chi^2 = 1.89$, df = 1 ($P = 0.17$), $I^2 = 47.1\%$	



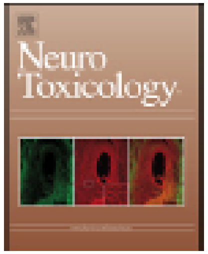
CRA, Imran et al. submitted

Other outcomes

- Intriguing but with insufficient evidence to date to include as primary outcomes. Among them are:
  - Cognitive impacts in children
  - Cervical cancer

Contents lists available at SciVerse ScienceDirect

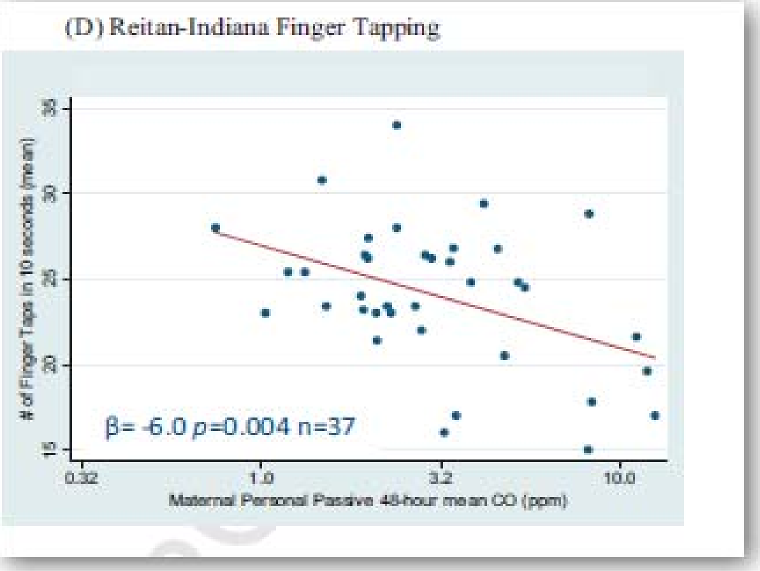
NeuroToxicology

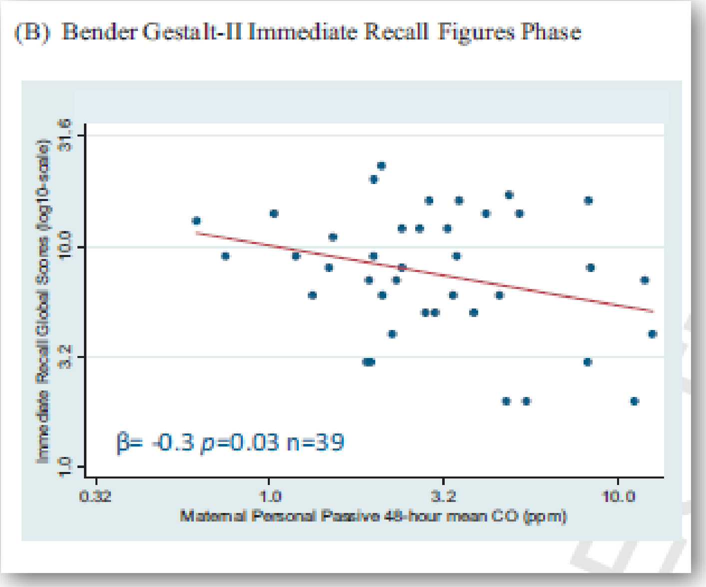


Neurodevelopmental performance among school age children in rural Guatemala is associated with prenatal and postnatal exposure to carbon monoxide, a marker for exposure to woodsmoke

Linda Dix-Cooper[a], Brenda Eskenazi[b], Carolina Romero[c], John Balmes[a,d], Kirk R. Smith[a,*]

[a] Division of Environmental Health Sciences, School of Public Health, University of California, Berkeley, CA 94720-7360, USA
[b] Center for Environmental Research and Children's Health (CERCH), School of Public Health, University of California, Berkeley, CA, USA
[c] Centro de Estudios en Salud Universidad Del Valle, Guatemala
[d] Division of Occupational and Environmental Medicine, Department of Medicine, University of California, San Francisco, CA, USA





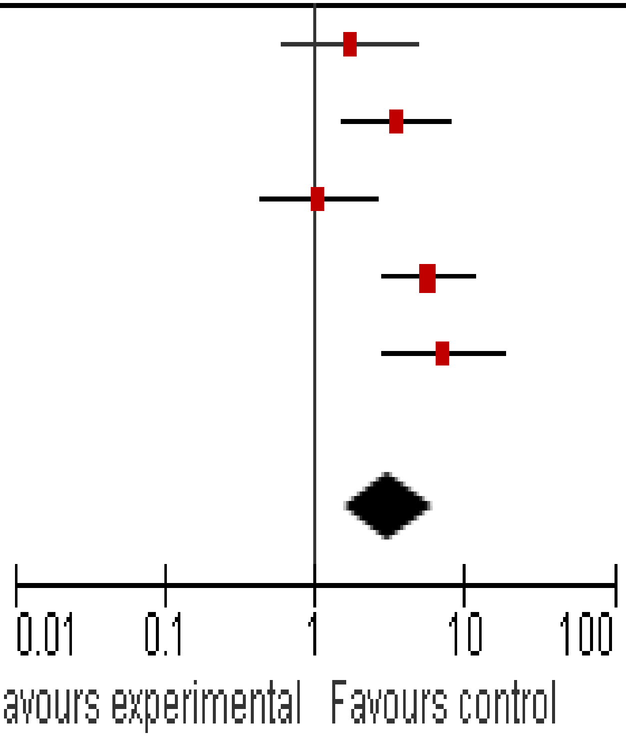
Cervical Cancer and Household Air Pollution

Study or Subgroup	log[Odds Ratio]	SE	Weight	Odds Ratio IV, Random, 95% CI
Ferrera 2000(a)	0.54232429	0.53624989	17.6%	1.72 [0.60, 4.92]
Ferrera 2000(b)	1.24990174	0.41614175	20.9%	3.49 [1.54, 7.89]
Velema 2002(a)	0.06765865	0.45514155	19.8%	1.07 [0.44, 2.61]
Velema 2002(b)	1.75093748	0.36626585	22.4%	5.76 [2.81, 11.81]
Sierra Torres 2006	1.98787435	0.47618897	19.2%	7.30 [2.87, 18.56]
Total (95% CI)			**100.0%**	**3.14 [1.57, 6.30]**

Heterogeneity: $Tau^2 = 0.43$; $Chi^2 = 12.71$, df = 4 (P = 0.01); $I^2 = 69\%$

Test for overall effect: Z = 3.23 (P = 0.001)

Odds Ratio
IV, Random, 95% CI



Three papers; two done in Honduras, one in Columbia

Issues with the Cervical Cancer Studies.

- Problems
  - Poor exposure assessment
  - Not all adjusted for smoking
  - Doubtful control selection
  - Interaction with HPV not clear
- Strengths
  - Large effects
  - Exposure-response shown
  - Known effects of tobacco smoke

Does a chimney reduce exposure enough?

THELANCET-D-09-06268R3

S0140-6736(11)60921-5

Embargo: [add date when known]

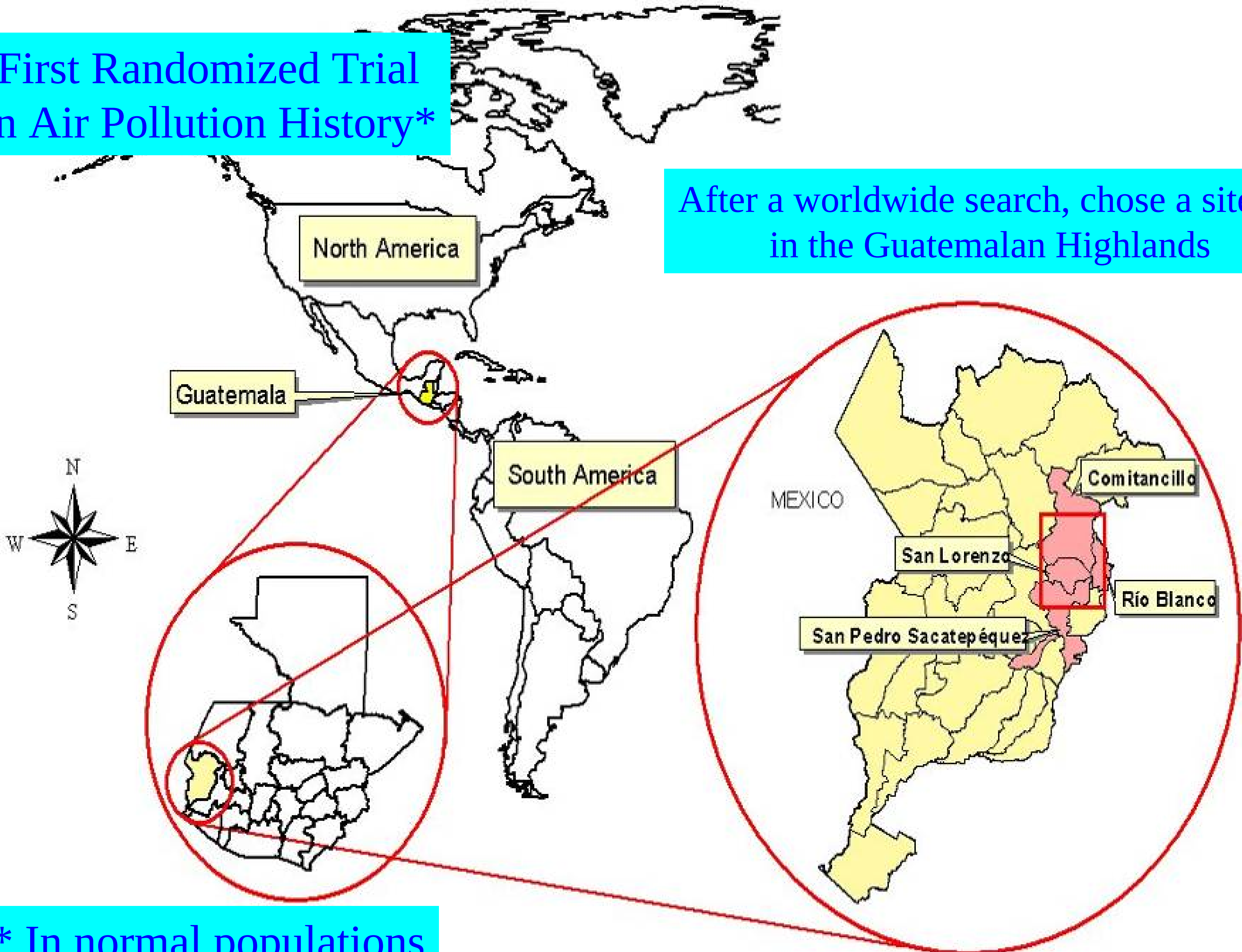
Effect of reduction in household air pollution on childhood pneumonia in Guatemala (RESPIRE): a randomised controlled trial

Kirk R Smith, John P McCracken, Martin W Weber, Alan Hubbard, Alisa Jenny, Lisa M Thompson, John Balmes, Anaite Diaz, Byron Arana, Nigel Bruce

Published Nov 2011

First Randomized Trial In Air Pollution History*

After a worldwide search, chose a site in in the Guatemalan Highlands



* In normal populations

RESPIRE – Randomized trial (n=518)

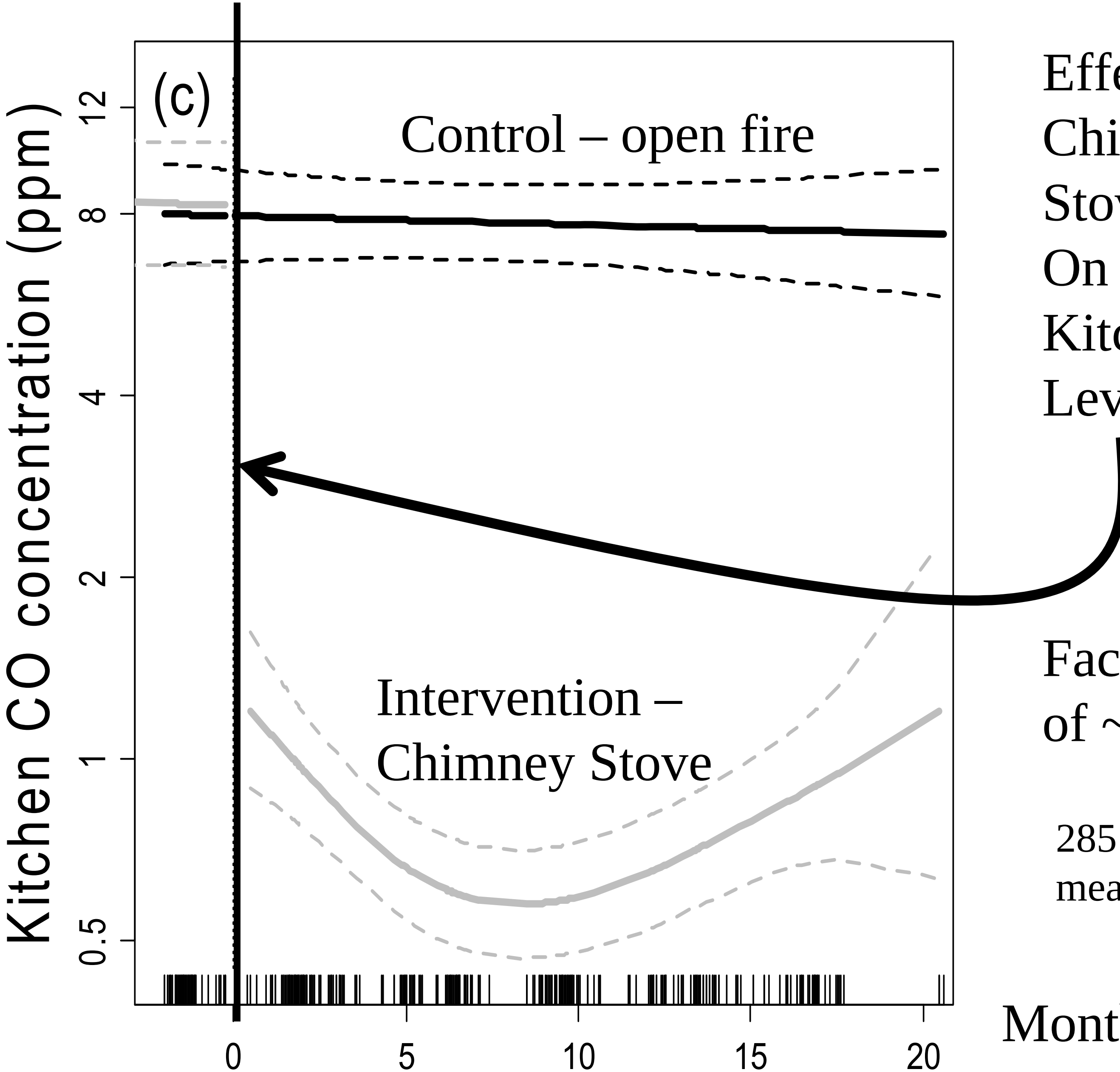
Impact on pneumonia up to 18 months of age

Traditional open 3-stone fire: kitchen 48-hour $PM_{2.5}$ levels of 600 - 1200 µg/m^3

Chimney wood stove, locally made and popular with households


CO monitor
CO monitor

Guatemala RCT: Kitchen Concentrations



Effect of Chimney Stove On Kitchen CO Levels

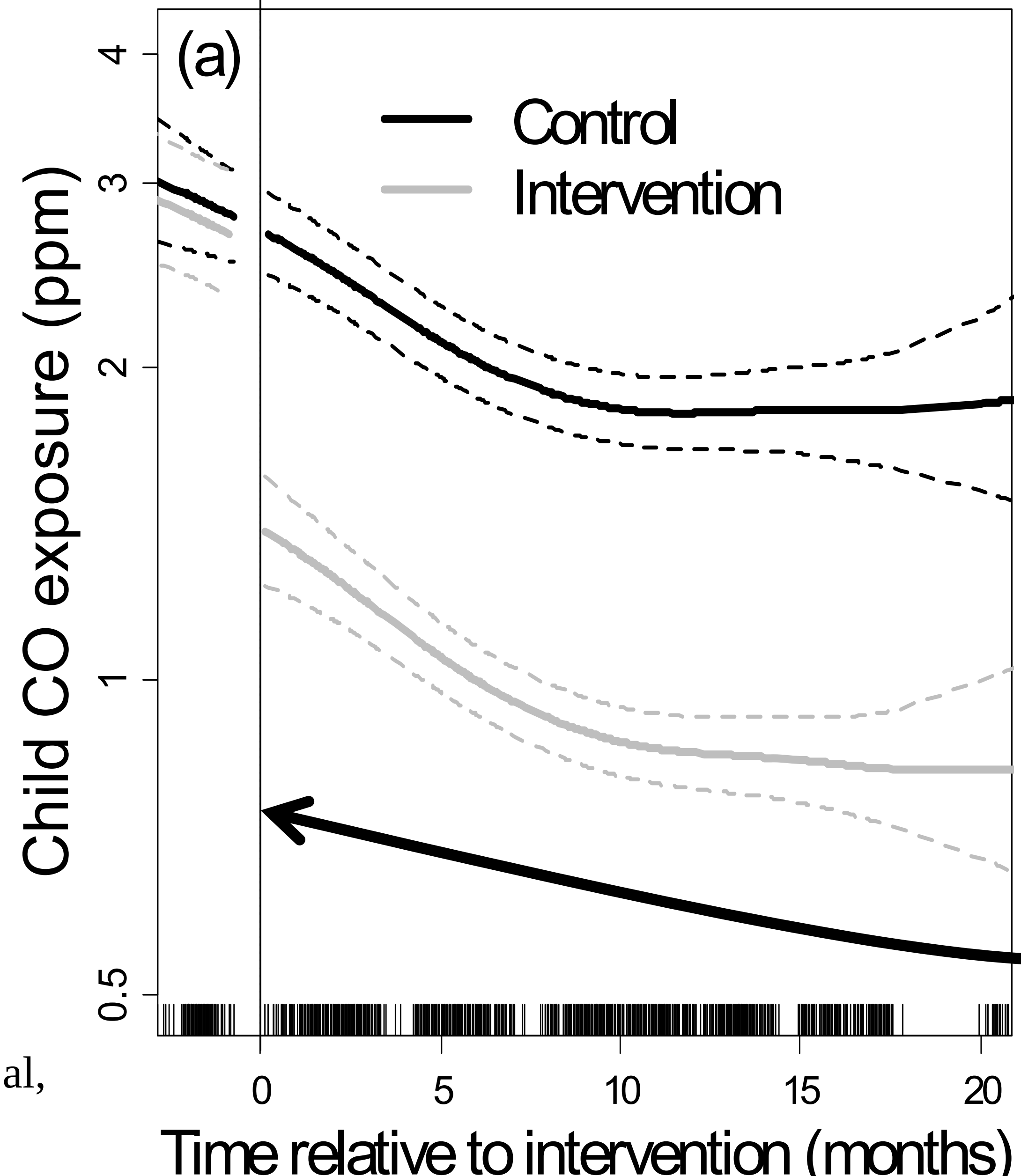
Factor of ~10 less

285 48-h measurements

Months

Smith, et al, 2010

Infant Exposures



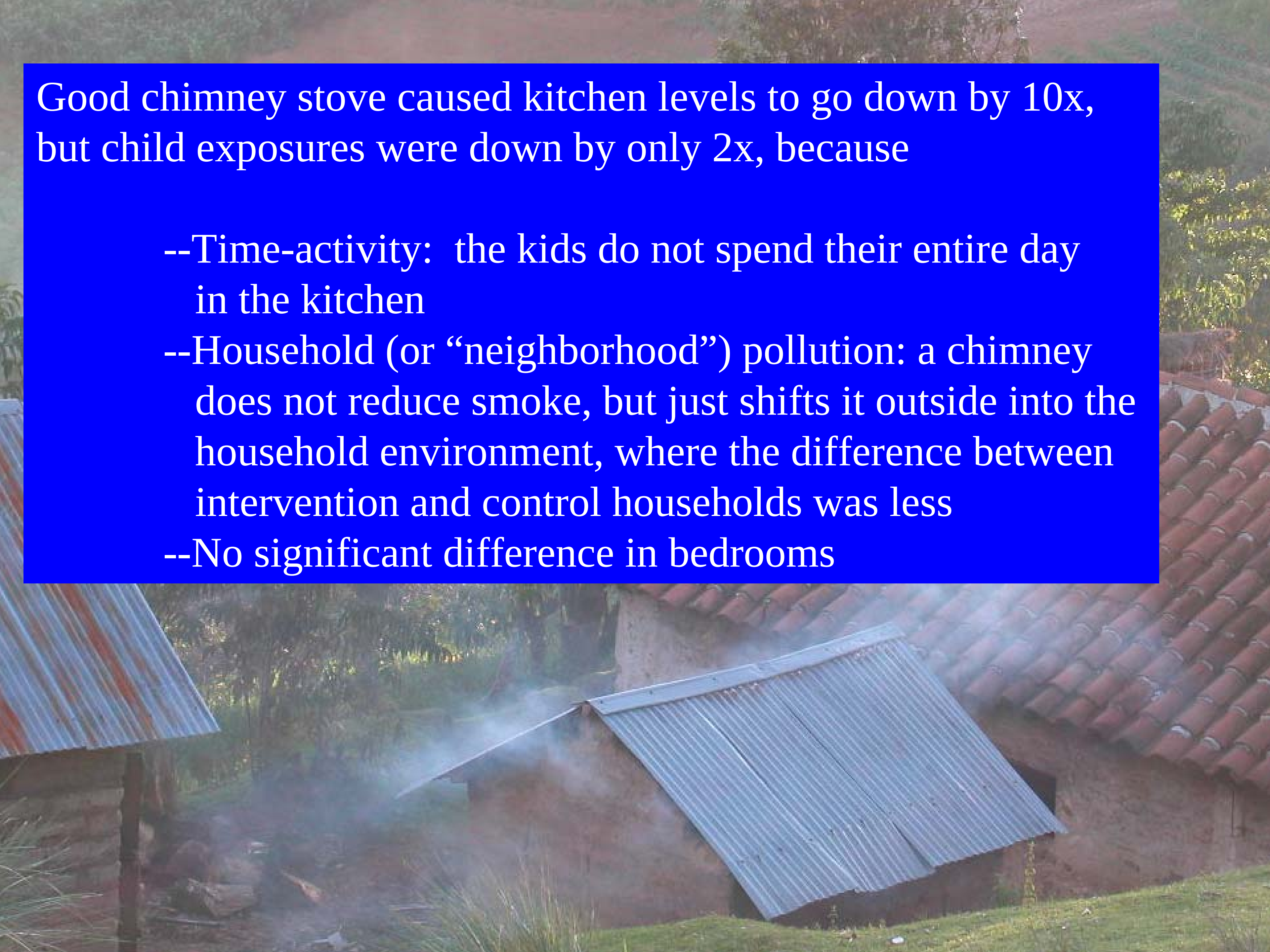
1888 48-h measurements

Effect of Chimney Stove On Infant Exposures - 2x less

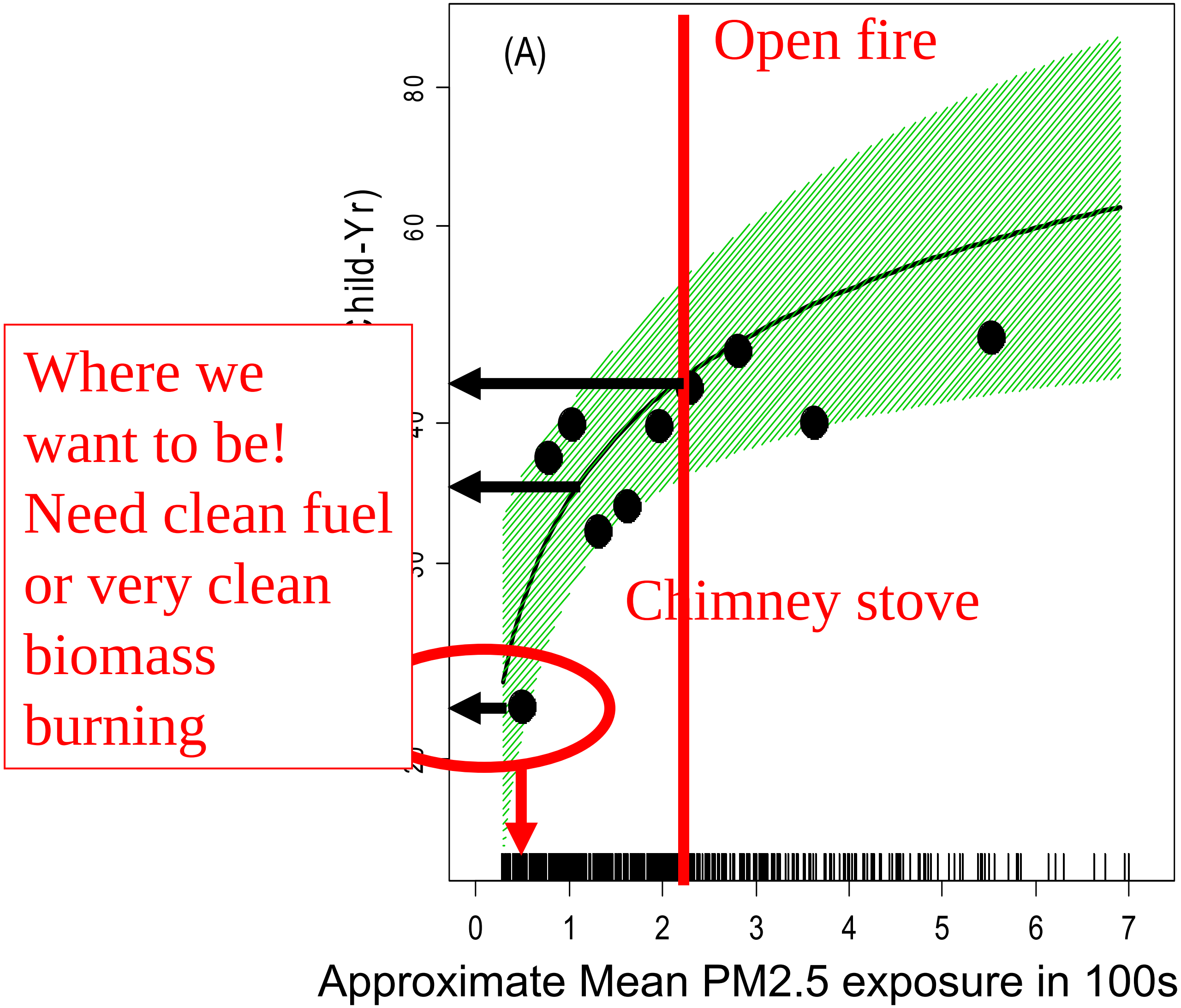
Smith, et al, 2010

Good chimney stove caused kitchen levels to go down by 10x, but child exposures were down by only 2x, because

- --Time-activity: the kids do not spend their entire day in the kitchen
- --Household (or "neighborhood") pollution: a chimney does not reduce smoke, but just shifts it outside into the household environment, where the difference between intervention and control households was less
- --No significant difference in bedrooms



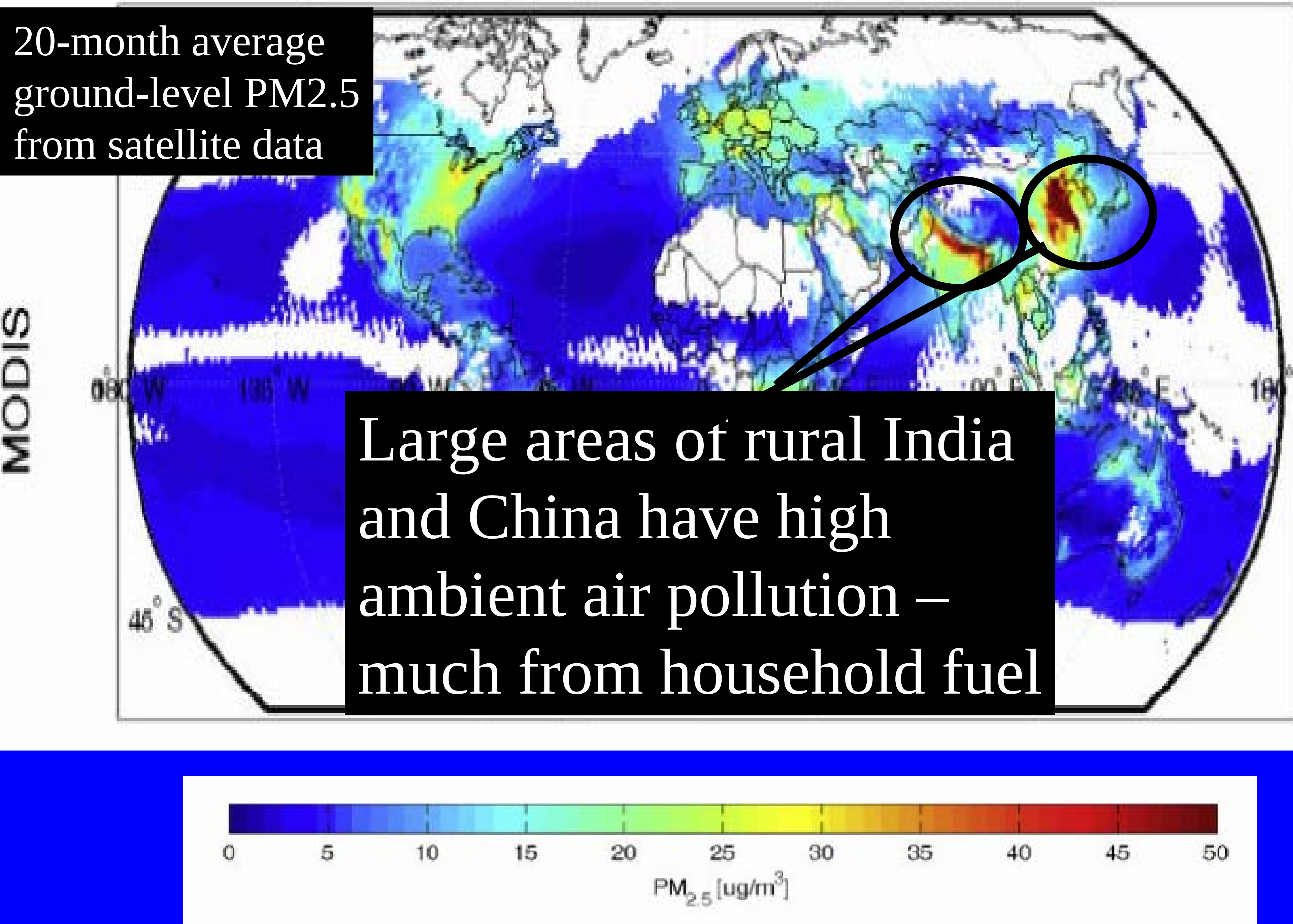
MD-diagnosed Acute Lower Respiratory Infection



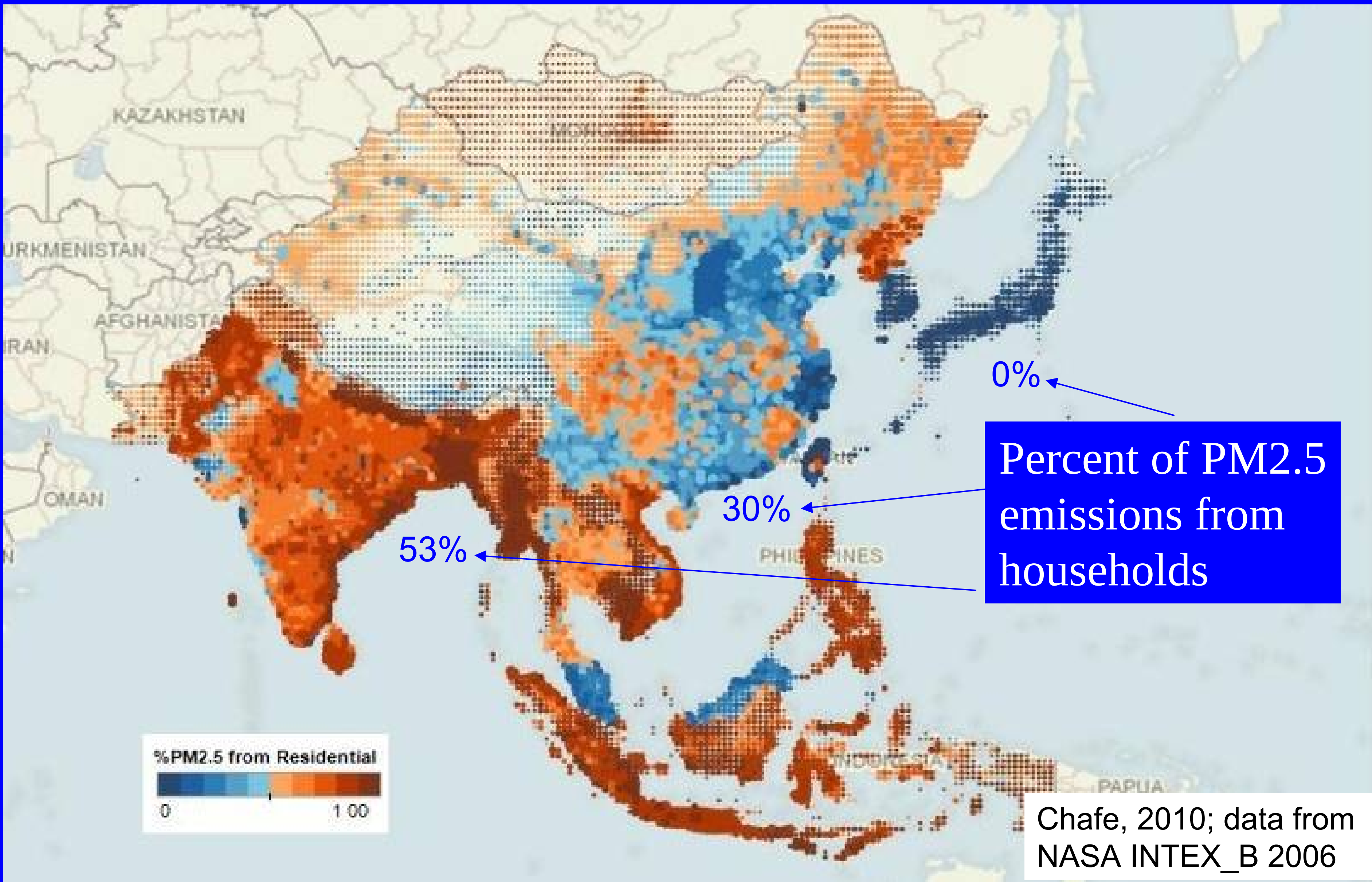
RESPIRE-Guatemala

You have heard of secondhand smoke – from tobacco burning

But there is another kind – from cookfires


20-month average ground-level PM2.5 from satellite data
Large areas of rural India and China have high ambient air pollution – much from household fuel
MODIS
45° S
0
5
10
15
20
25
30
35
40
45
50
PM2.5 [ug/m3]

Percent $PM_{2.5}$ emissions from households



Chafe, 2010; data from NASA INTEX_B 2006

Combustion Particles

The Generalized Exposure Response

(GER)

Heart Disease and Combustion Particle Doses

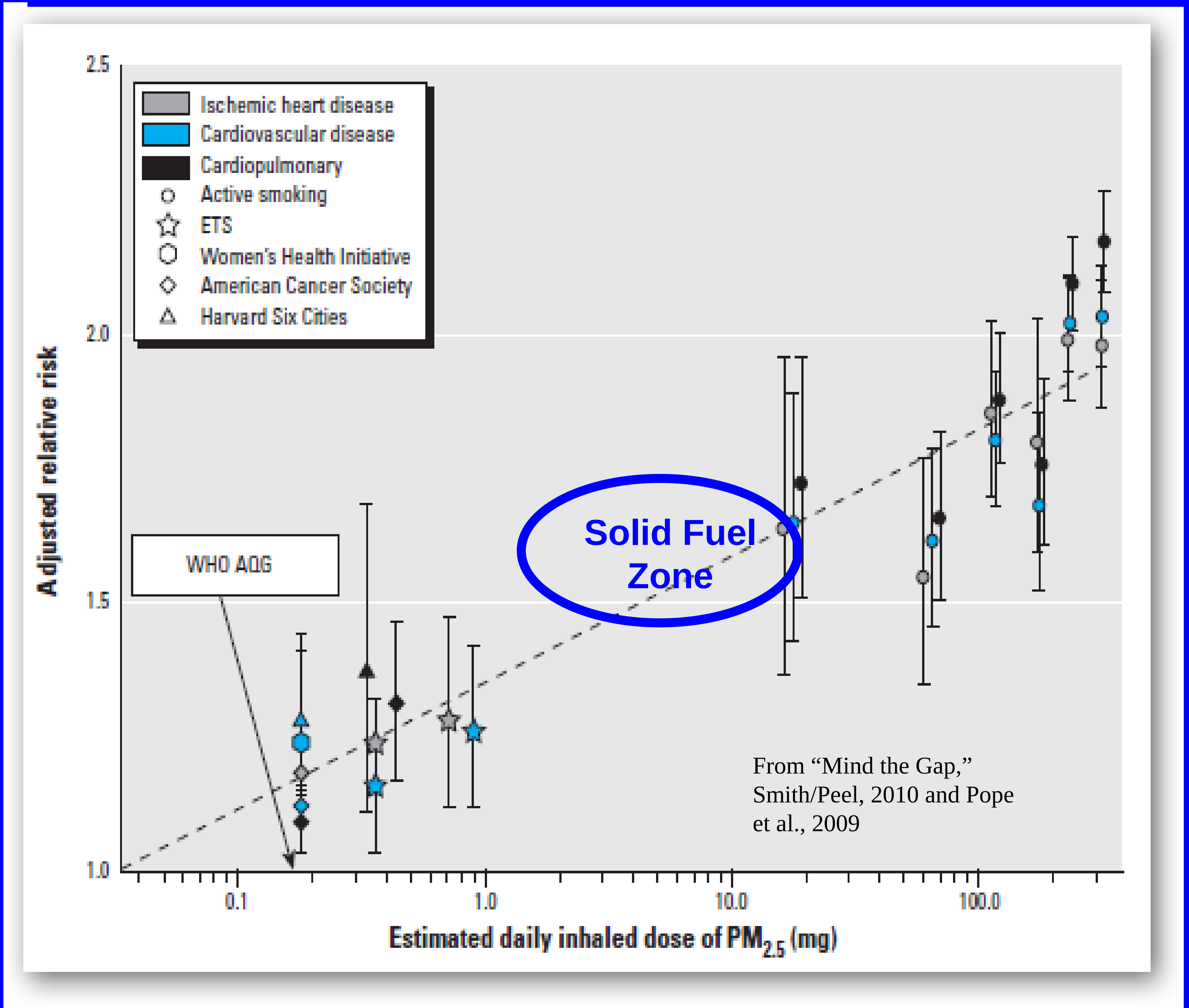
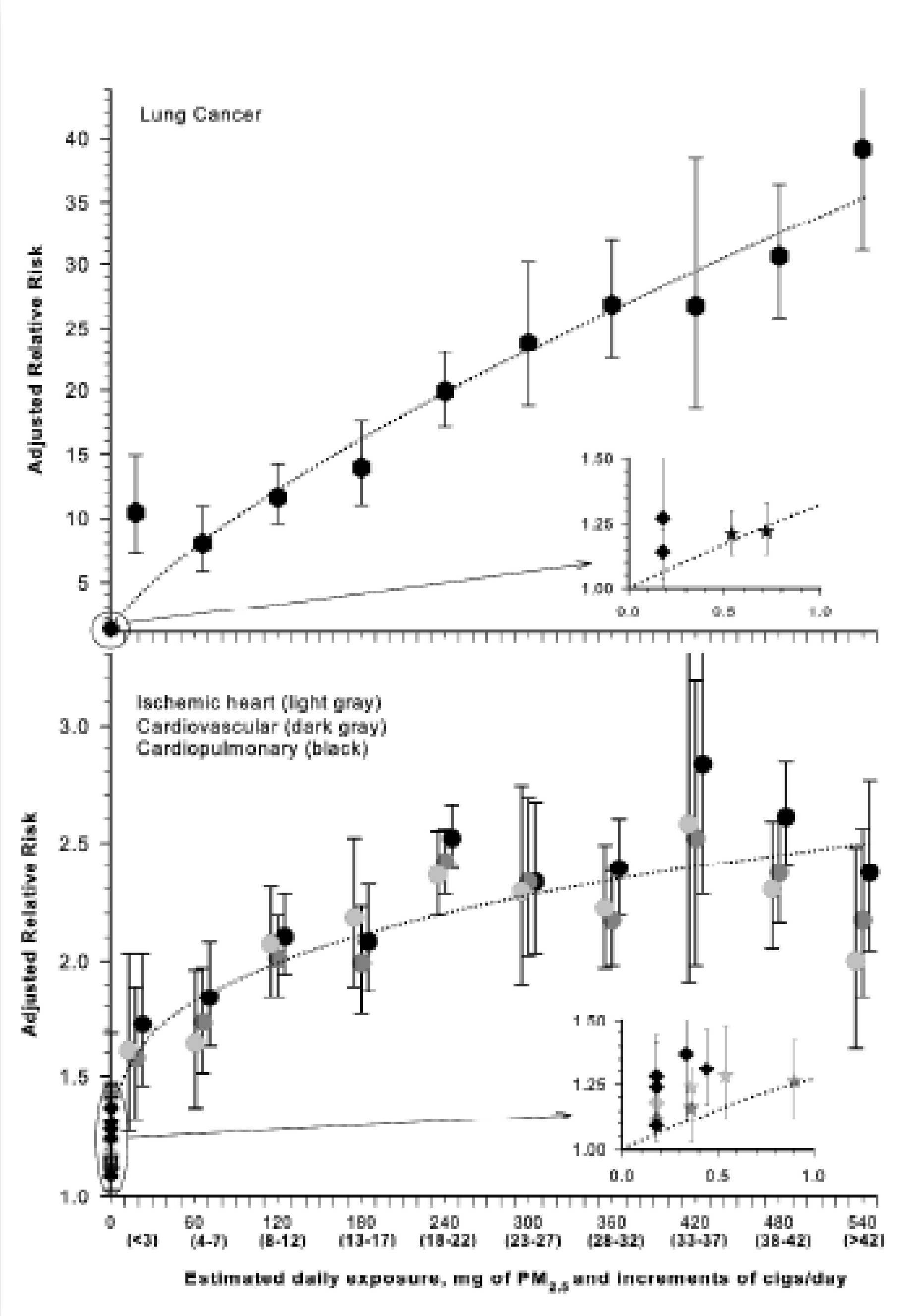


Table 2. Adjusted relative risk estimates[a] for various increments of exposure from cigarette smoking (versus never smokers), second hand cigarette smoke, and ambient air pollution from the present analysis and selected comparison studies.

Source of risk estimate	Increments of Exposure	Adjusted RR (95% CI)				Estimated Daily Dose $PM_{2.5}$ (mg)[b]
		Lung Cancer	IHD	CVD	CPD	
ACS- present analysis	≤3 (1.5) cigs/day	10.44 (7.30-14.94)	1.61 (1.27-2.03)	1.58 (1.32-1.89)	1.72 (1.46-2.03)	18
ACS- present analysis	4-7 (5.5) cigs/day	8.03 (5.89-10.96)	1.64 (1.37-1.96)	1.73 (1.51-1.97)	1.84 (1.63-2.08)	66
ACS- present analysis	8-12 (10) cigs/day	11.63 (9.51-14.24)	2.07 (1.84-2.31)	2.01 (1.84-2.19)	2.10 (1.94-2.28)	120
ACS- present analysis	13-17 (15) cigs/day	13.93 (11.04-17.58)	2.18 (1.89-2.52)	1.99 (1.77-2.23)	2.08 (1.87-2.32)	180
ACS- present analysis	18-22 (20) cigs/day	19.88 (17.14-23.06)	2.36 (2.19-2.55)	2.42 (2.28-2.56)	2.52 (2.39-2.66)	240
ACS- present analysis	23-27 (25) cigs/day	23.82 (18.80-30.18)	2.29 (1.91-2.75)	2.33 (2.02-2.69)	2.33 (2.03-2.67)	300
ACS- present analysis	28-32 (30) cigs/day	26.82 (22.54-31.91)	2.22 (1.97-2.49)	2.17 (1.98-2.38)	2.39 (2.19-2.60)	360
ACS- present analysis	33-37 (35) cigs/day	26.72 (18.58-38.44)	2.58 (1.91-3.47)	2.52 (1.98-3.19)	2.83 (2.28-3.52)	420
ACS- present analysis	38-42 (40) cigs/day	30.63 (25.79-36.38)	2.30 (2.05-2.59)	2.37 (2.16-2.59)	2.61 (2.40-2.84)	480
ACS- present analysis	43+ (45) cigs/day	39.16 (31.13-49.26)	2.00 (1.62-2.48)	2.17 (1.84-2.56)	2.37 (2.04-2.76)	540
ACS-air pol. original	24.5 $\mu g/m^3$ ambient $PM_{2.5}$	-----	-----	-----	1.31(1.17-1.46)	0.44
ACS-air pol. extend.	10 $\mu g/m^3$ ambient $PM_{2.5}$	1.14(1.04-1.23)	1.18(1.14-1.23)	1.12(1.08-1.15)	1.09(1.03-1.16)	0.18
HSC-air pol. original	18.6 $\mu g/m^3$ ambient $PM_{2.5}$	-----	-----	-----	1.37(1.11-1.68)	0.33
HSC-air pol. extend.	10 $\mu g/m^3$ ambient $PM_{2.5}$	1.21(0.92-1.69)	-----	1.28(1.13-1.44)	-----	0.18
WHI-air pol.	10 $\mu g/m^3$ ambient $PM_{2.5}$	-----	-----	1.24(1.09-1.41)[c]	-----	0.18
SGR-SHS	Low- moderate SHS exp.	-----	-----	1.16(1.03-1.32)	-----	0.36
SGR-SHS	Moderate-high SHS exp	-----	-----	1.26(1.12-1.42)	-----	0.90
SGR-SHS	Live with smoking spouse	1.21(1.13-1.30)	-----	-----	-----	0.54
SGR-SHS	Work with SHS exposure	1.22(1.13-1.33)	-----	-----	-----	0.72
INTERHEART	1-7 hrs/wk SHS exp.	-----	1.24(1.17-1.32)[d]	-----	-----	0.36
INTERHEART	Live with smoking spouse	-----	1.28(1.12-1.47)[d]	-----	-----	0.54

Pope et al.
Environmental Health Perspectives
2011, in press

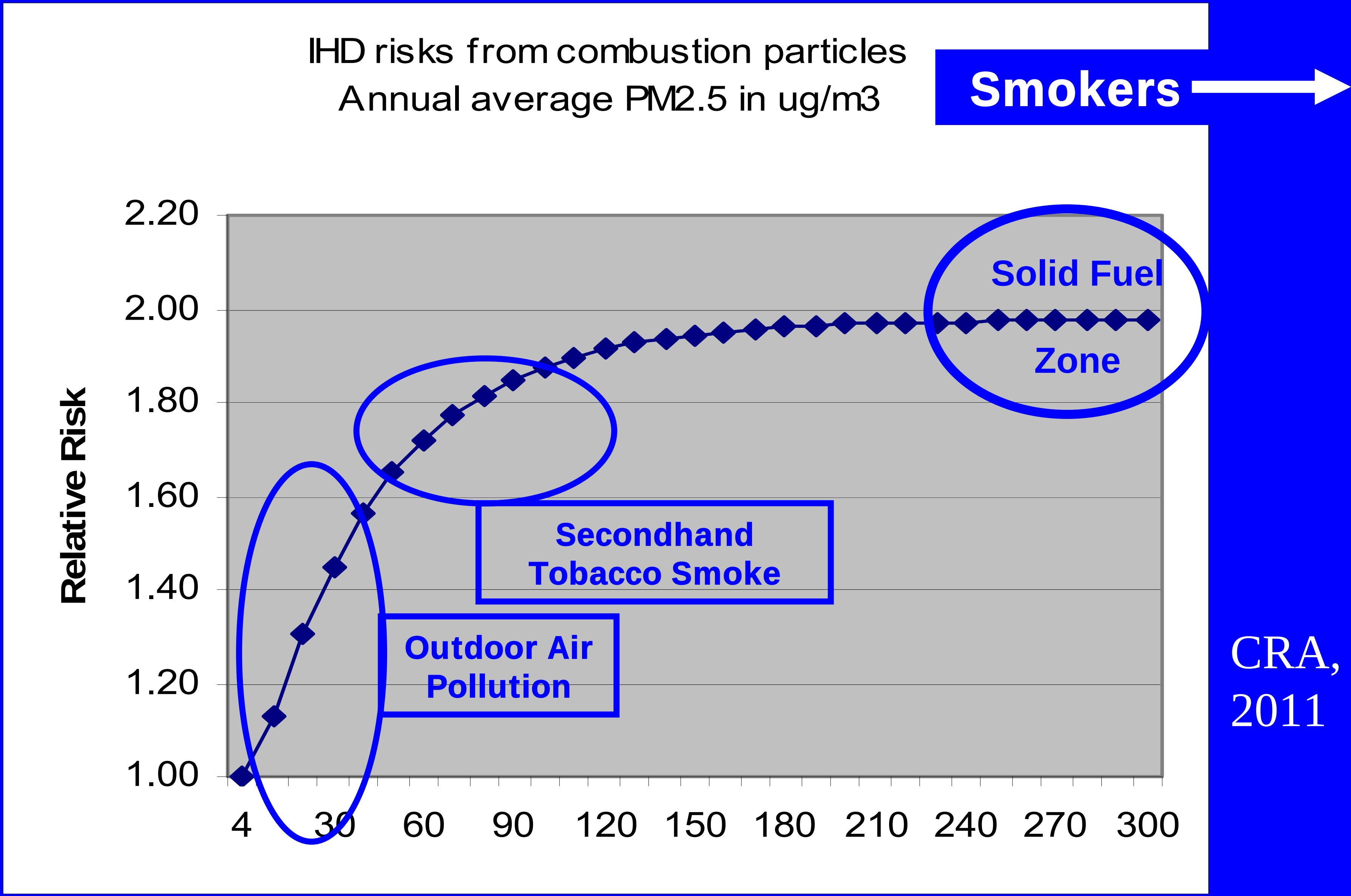


Lung Cancer

Heart Disease

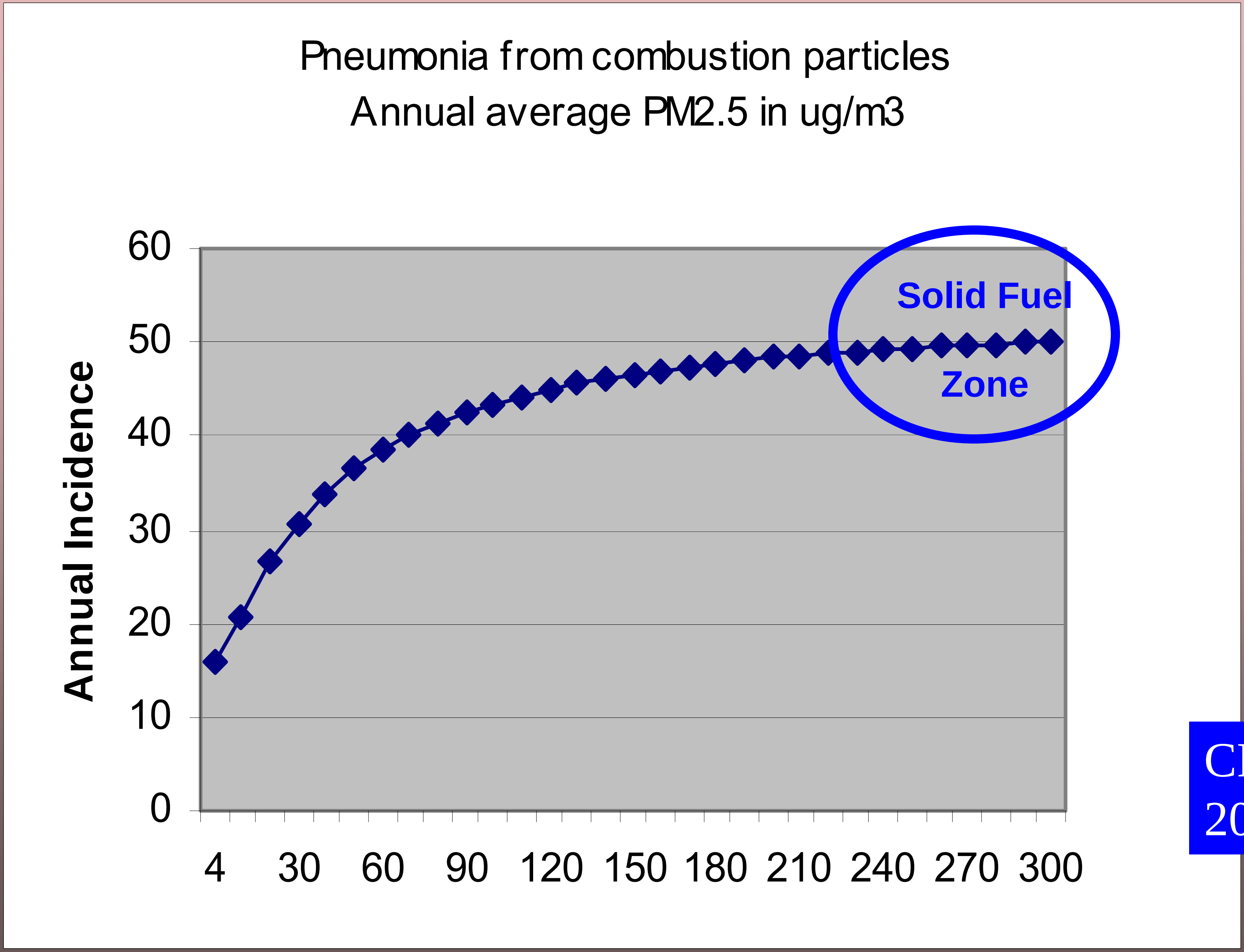
Pope et al. Environmental Health Perspectives 2011

Generalized Exposure-Response: Outdoor Air, SHS, and Smoking



CRA, 2011

Generalized Exposure-Response: Outdoor Air, SHS, and HAP



CRA, 2011

What we can expect based on ATS epidemiological evidence?

- “Traditional” ATS cancers: lung, oral cavity, pharynx, larynx, oesophagus, pancreas, urinary bladder and renal pelvis
- “New” ATS cancers: nasal, sinus, nasopharynx, stomach, liver, kidney, uterine cervix, oesophagus, and leukaemia

Review of Epi Evidence: Lung Cancer, 2004

ETS/SHS and Cancer?

- Causes lung cancer in nonsmoking adults. …living with a smoker increases a nonsmoker’s chances of developing lung cancer by 20 to 30 percent.
- Some research suggests that SHS/ETS may increase the risk of breast cancer, nasal sinus cavity cancer, and nasopharyngeal cancer in adults and the risk of leukemia, lymphoma, and brain tumors in children.

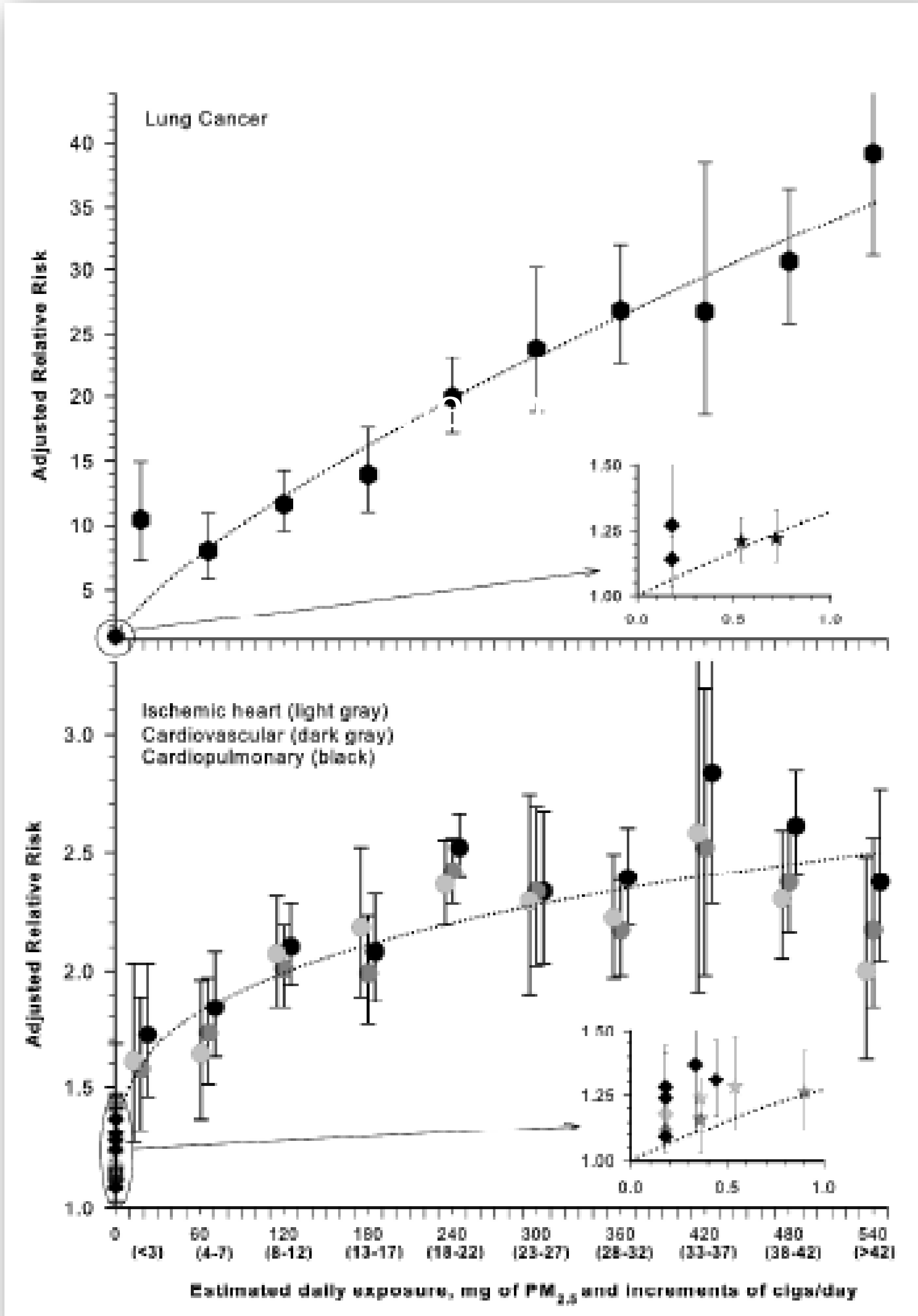
NCI Factsheet, 2012

The cancer research challenge

- **Hypothesis #1**: Most if not all the same cancers found for ATS can also be found for ETS/SHS and HAP, albeit at appropriately lower risks
- **Hypothesis #2**: They have not yet all been confirmed for ETS/SHS because lower exposures and resultant risk levels make detection difficult compared to ATS studies.
- Living with substantially higher exposures than SHS/ETS, even if lower than ATS, HAP-exposed populations offer excellent opportunities for pinning down a range of cancer risks and associated mutagenicity and genetic associations
- Considering that the HAP-population is larger and younger than those for ATS or ETS/SHS, the total cancer global burden of cancer is likely to be substantial.

Two policy dilemmas

- How to think about protection when some major impacts are linear, e.g. lung cancer, and others highly non-linear, e.g., heart disease?
- How to think about protection when the major reductions in risk occur only at relatively low levels, or put differently, there is relatively little benefit by changing from high to moderate levels of exposure?



Lung Cancer

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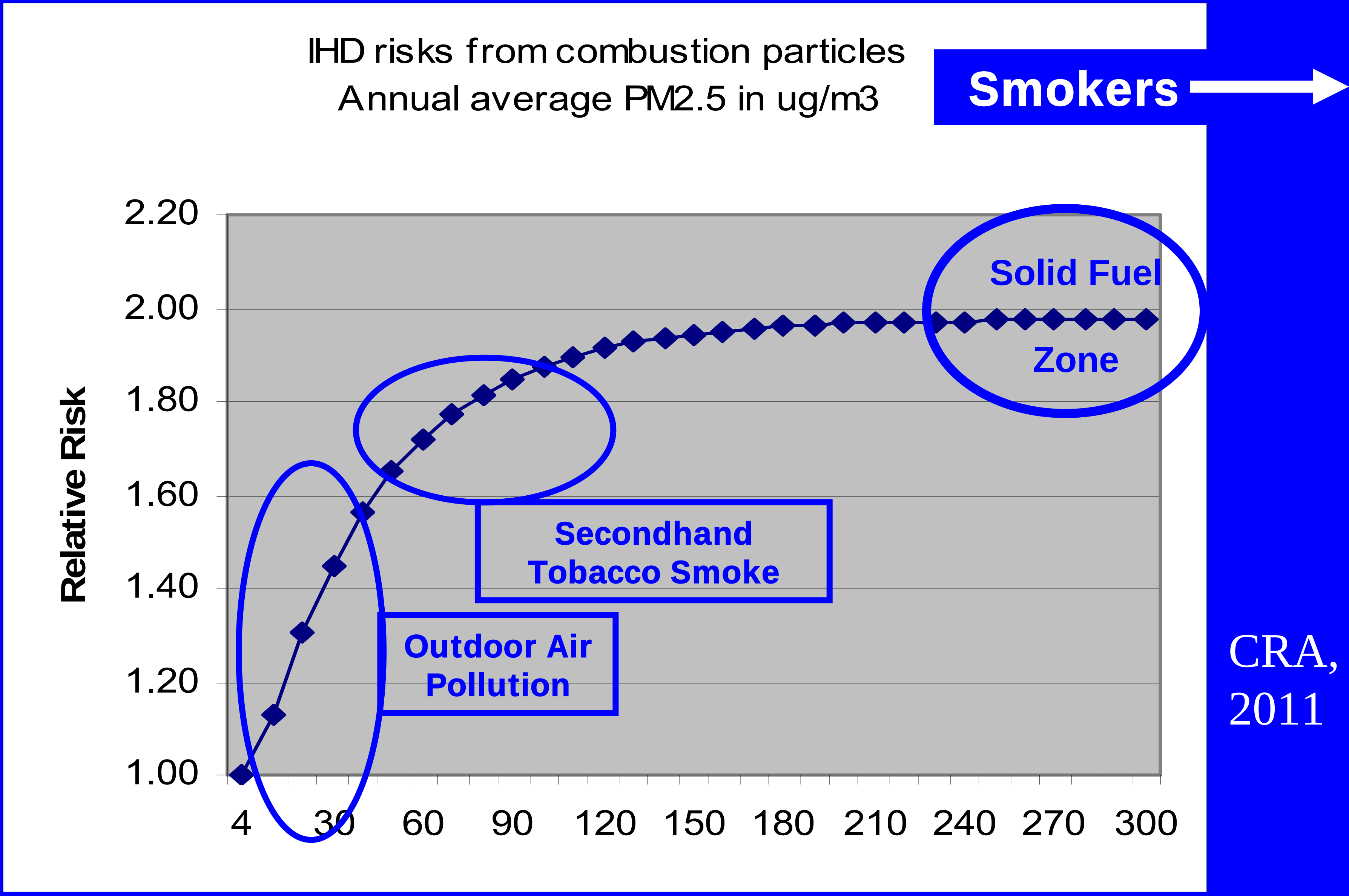
Pope et al. Environmental Health Perspectives 2011, in press

Generalized Exposure-Response: Outdoor Air, SHS, and Smoking



CRA, 2011

Many thanks

Publications and presentations on website – easiest to just "google" Kirk R. Smith