Household Solid Fuel Pollution: Recent Health Effects Results from Guatemala

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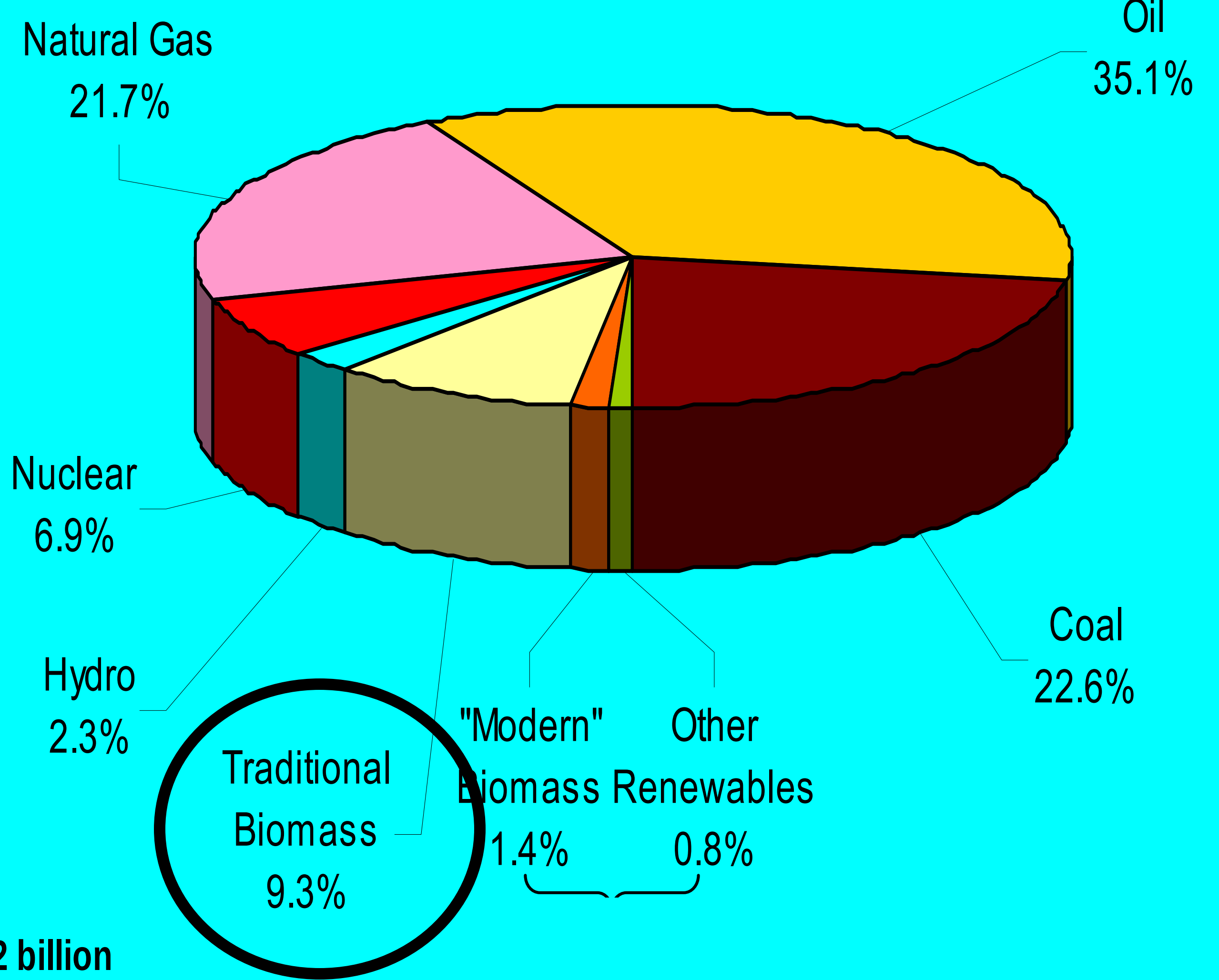
Workshop on Emissions of Toxic Air Contaminants from Biomass Burning for Cooking and Brick Production

CIEco-UNAM, Morelia, Michoacan
September 30, 2008

Household Solid Fuel Burning

- Why solid fuel use might be a hazard
- Summary of current risk estimates for child pneumonia
- Recent results from the first randomized trial – RESPIRE in the Guatemalan Higlands
  - Pneumonia in children <18 mo
  - Blood pressure in women
  - Low birth weight

World Energy – 2001

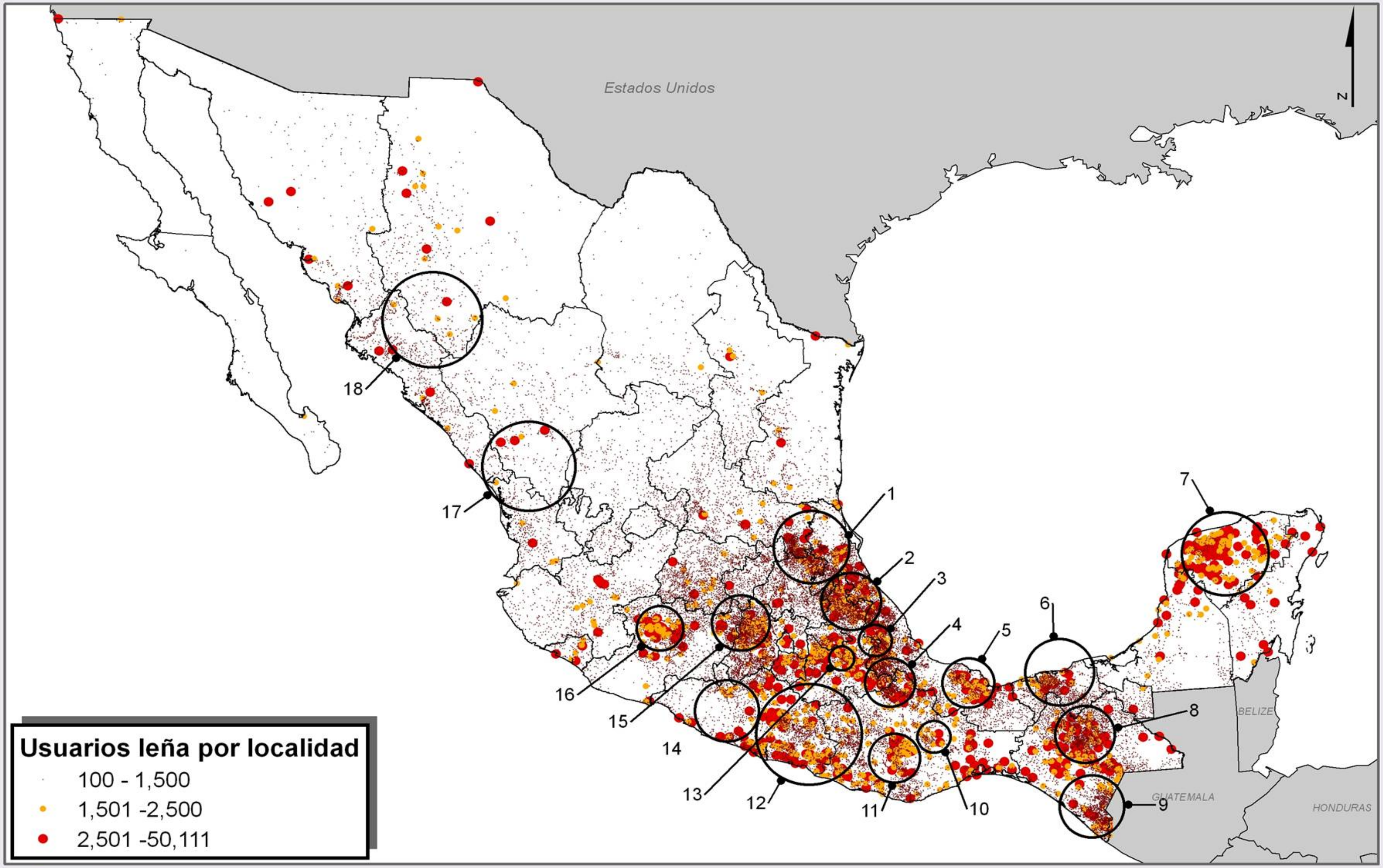


Population: 6.102 billion

Total energy use: 10.2 Gtoe

Per capita energy consumption: 1.67 toe

World Energy Assessment, 2004



Usuarios de leña por localidad, áreas prioritarias - 2000

Determinación de 18 áreas prioritarias de acuerdo al Indice de Prioridad por uso de Leña (IPL).

1:12,500,000

Fuente: Censo de población y Vivienda 2000.
Creado en ArcGIS 9.2 utilizando ArcMap.
Elaboró: Ghilardi A. 2008.

Albers Equal Area Conic Projection
North American Datum 1927
Ver detalles en el Anexo III

Woodsmoke is natural – how can it hurt you?

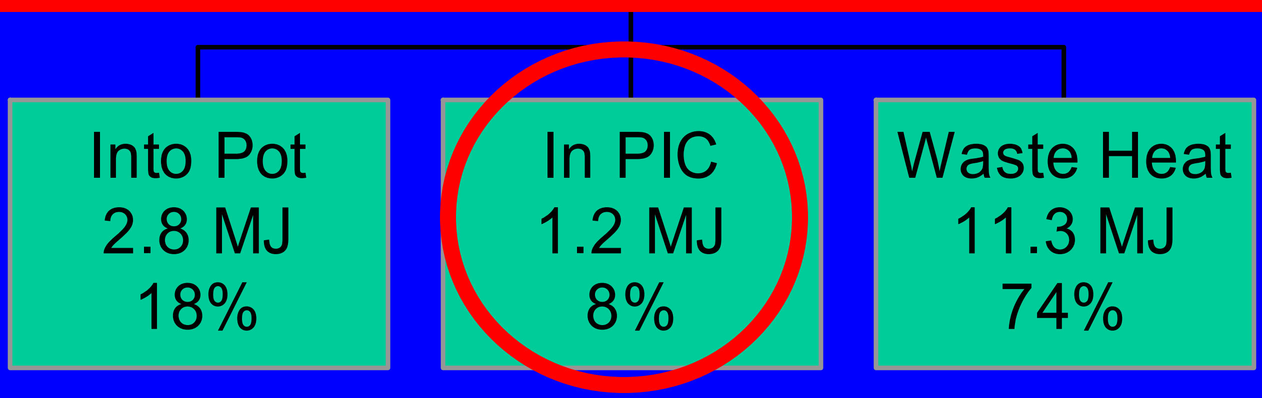
Or, since wood is mainly just carbon, hydrogen, and oxygen, doesn't it just change to CO_2 and H_2O when it is combined with oxygen (burned)?

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



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

Source: Smith, et al., 2000

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

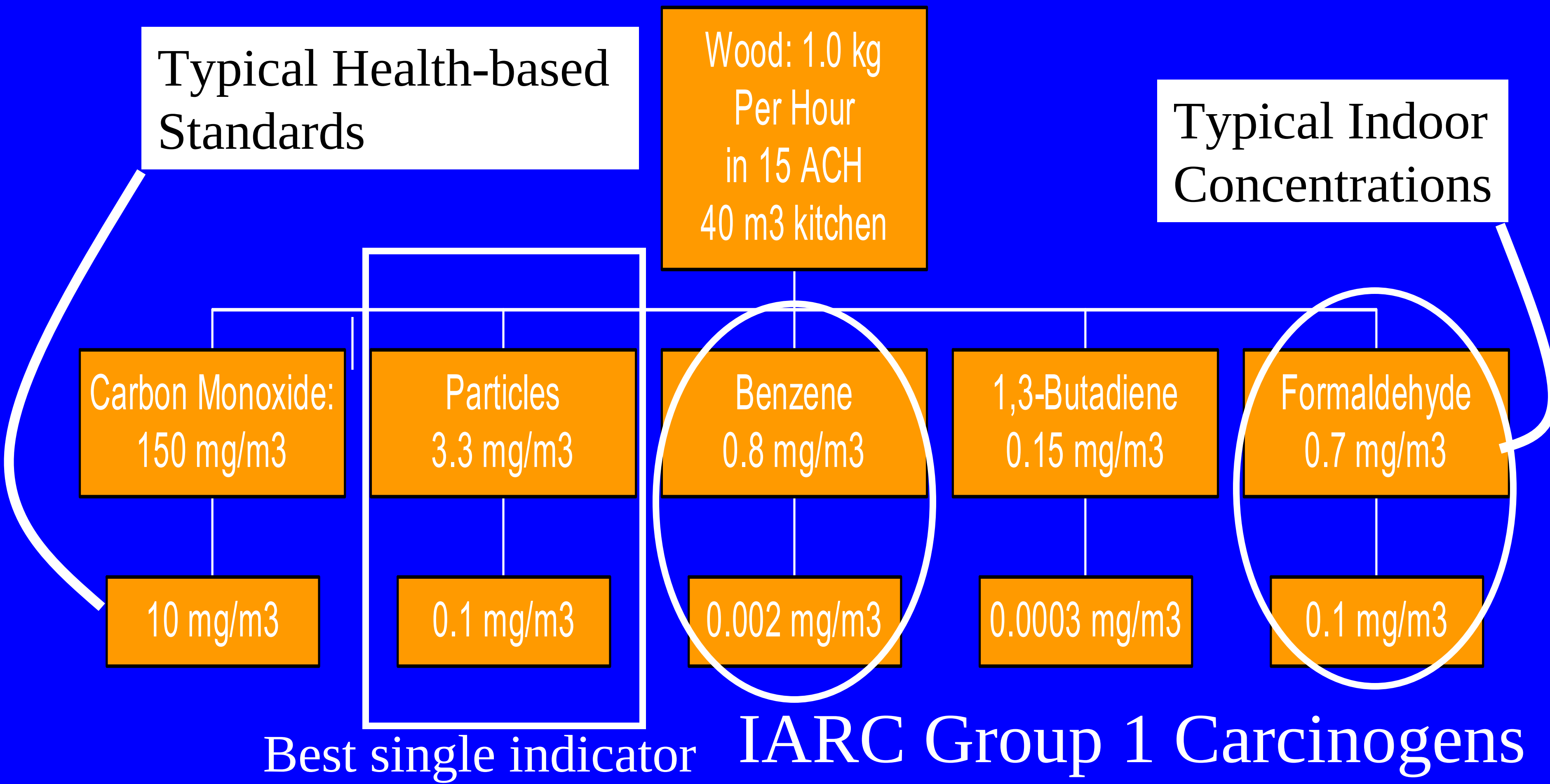
- Small particles, CO, NO_2
- Hydrocarbons
  - 25+ saturated hydrocarbons such as *n-hexane*

In US regulatory terminology, there are significant emissions of
3 Criteria Air Pollutants and
at least 28 Hazardous Air Pollutants (HAPs)

- 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*

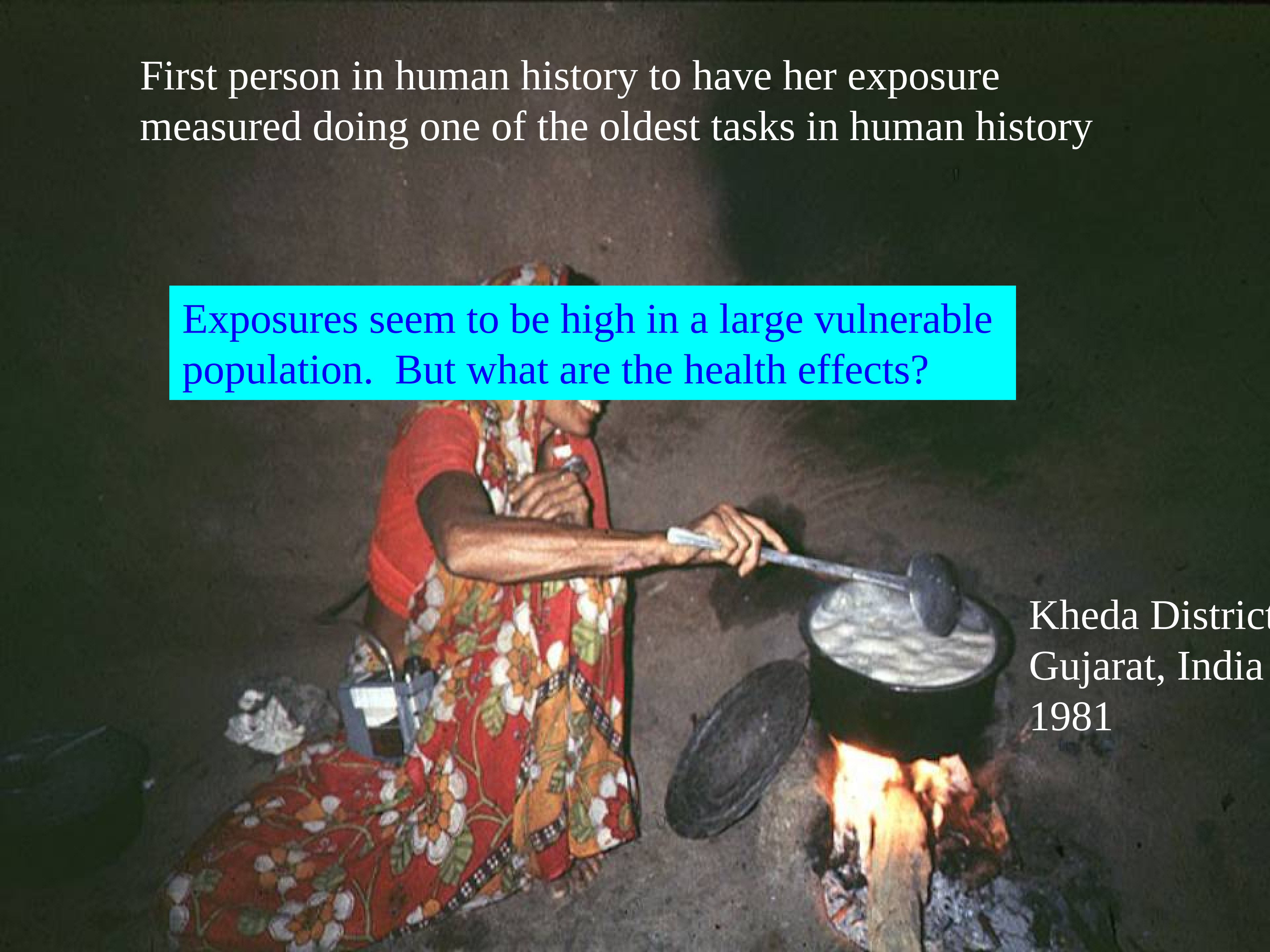
Source: Naeher et al,
J Inhal Tox, 2007

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



First person in human history to have her exposure measured doing one of the oldest tasks in human history

Exposures seem to be high in a large vulnerable population. But what are the health effects?



Kheda District
Gujarat, India
1981

How Much Global Ill-Health can be Attributed to Household Indoor Air Pollution?

- What do we mean by “ill-health?”
- What do we mean by “attributed?”
- What do we mean by “indoor air pollution”

What do we mean by ill-health?

- Lost life-years, which accounts for age of premature death and duration of illness
- DALYs = Disability adjusted life years lost

What do we mean by "indoor air pollution"

- Too few measurements worldwide to determine exposures by measurements
- Can use solid fuel use as a proxy as widespread surveys available
- Makes physical sense because of larger pollutant emissions
- There is a growing epidemiologic literature showing health effects

The Energy Ladder: Relative Pollutant Emissions Per Meal

	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

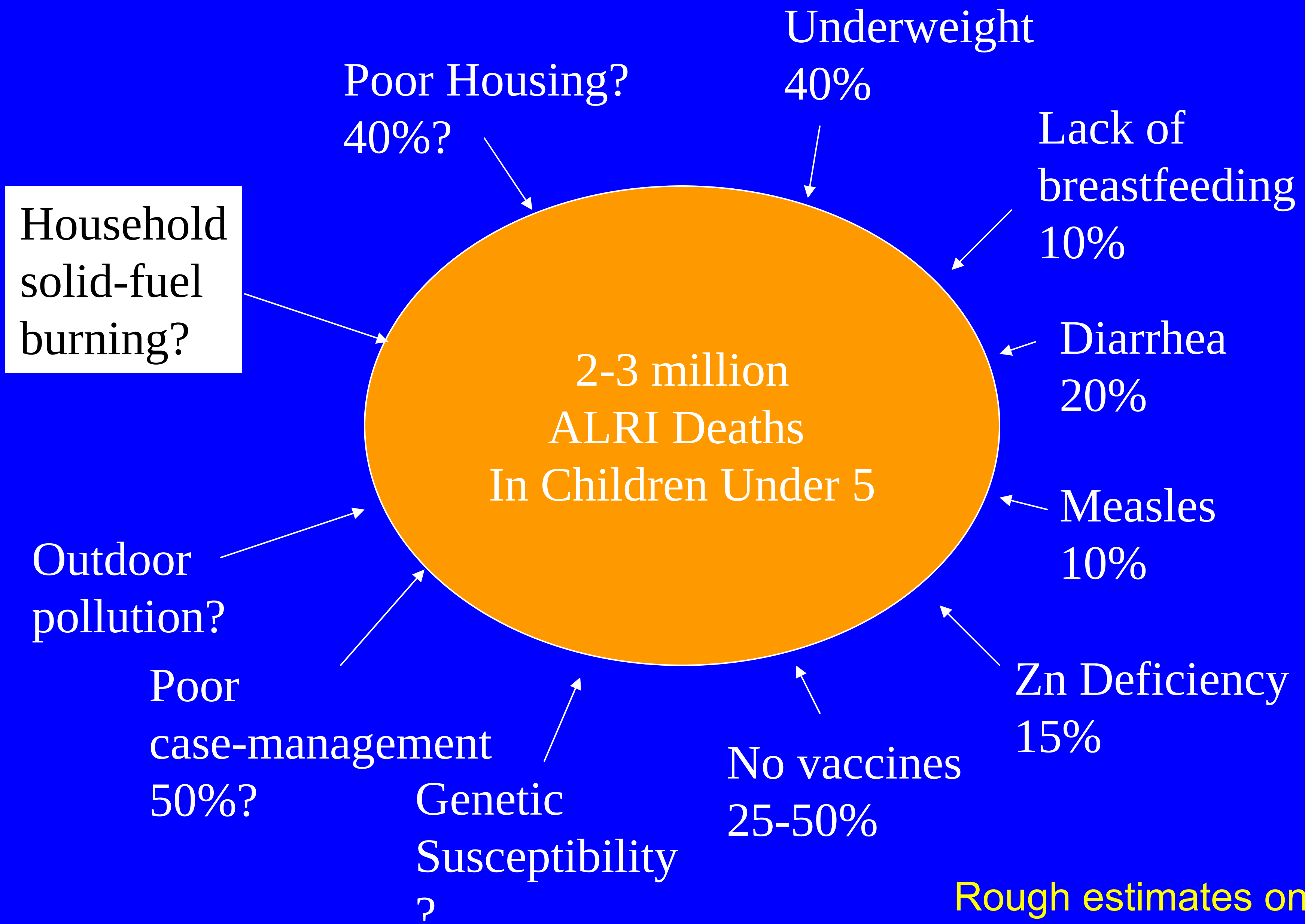
Smith, et al., 2005

CO *Hydrocarbons* *PM*

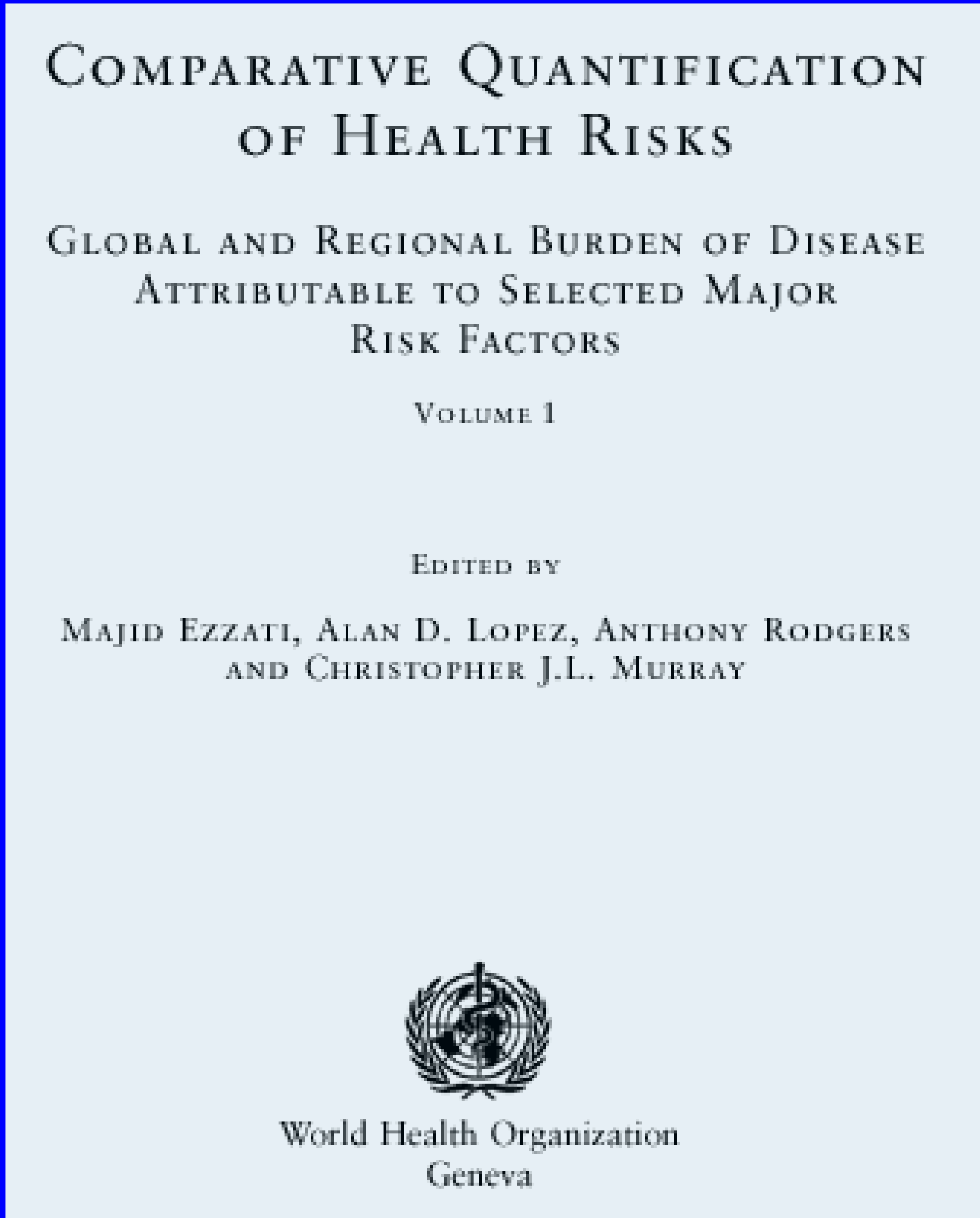
Attributable Risk?

- The amount of ill-health that would not exist today if the exposure to the risk factor had not occurred in the past.
- Assumes all other risk factors remain constant
- Need to compare to some feasible alternative such as clean fuels (no cooking is not feasible)
- Calculated as if all other risk factors remain the same and thus addition of attributable risks must be done with care

Attributable Fractions do not add to 100%



Rough estimates only


COMPARATIVE QUANTIFICATION OF HEALTH RISKS

GLOBAL AND REGIONAL BURDEN OF DISEASE ATTRIBUTABLE TO SELECTED MAJOR RISK FACTORS

VOLUME 1

EDITED BY

MAJID EZZATI, ALAN D. LOPEZ, ANTHONY RODGERS AND CHRISTOPHER J.L. MURRAY

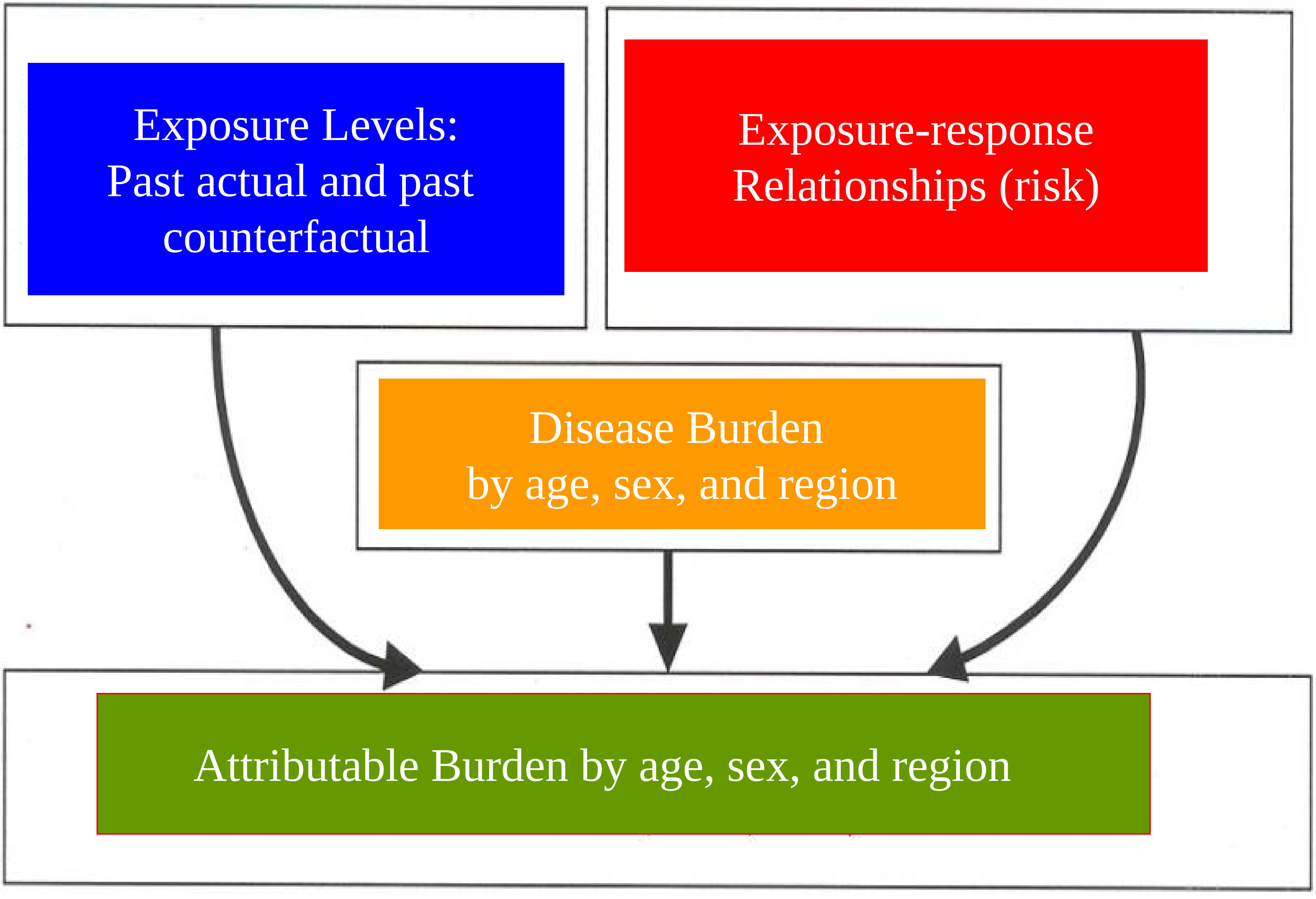
World Health Organization
Geneva

Published in late 2004, 2 vols, ~2500 pp

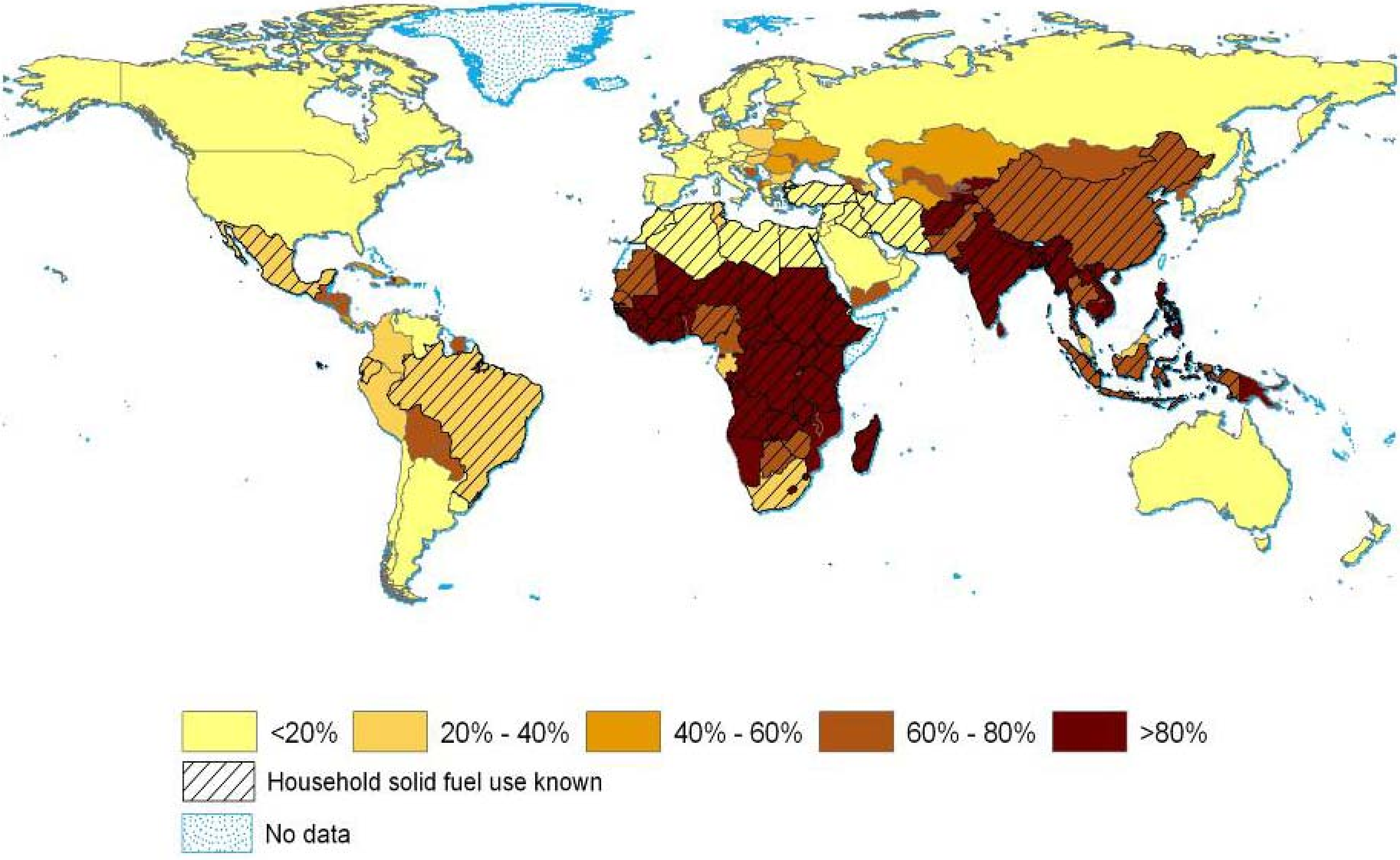
Available on World Health Organization website

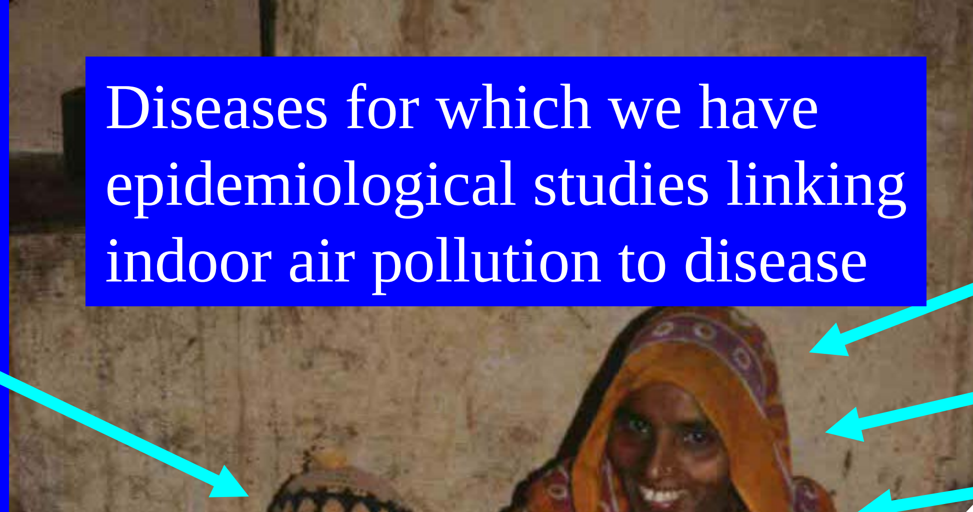
http://www.who.int/publications/cra/en/

Comparative Risk Assessment Method



National Household Solid Fuel Use, 2000





Diseases for which we have epidemiological studies linking indoor air pollution to disease

ALRI/ Pneumonia (meningitis)

Chronic obstructive lung disease

Only two qualified with sufficient evidence to be included in the WHO CRA

Acute lower respiratory infections (ALRI)

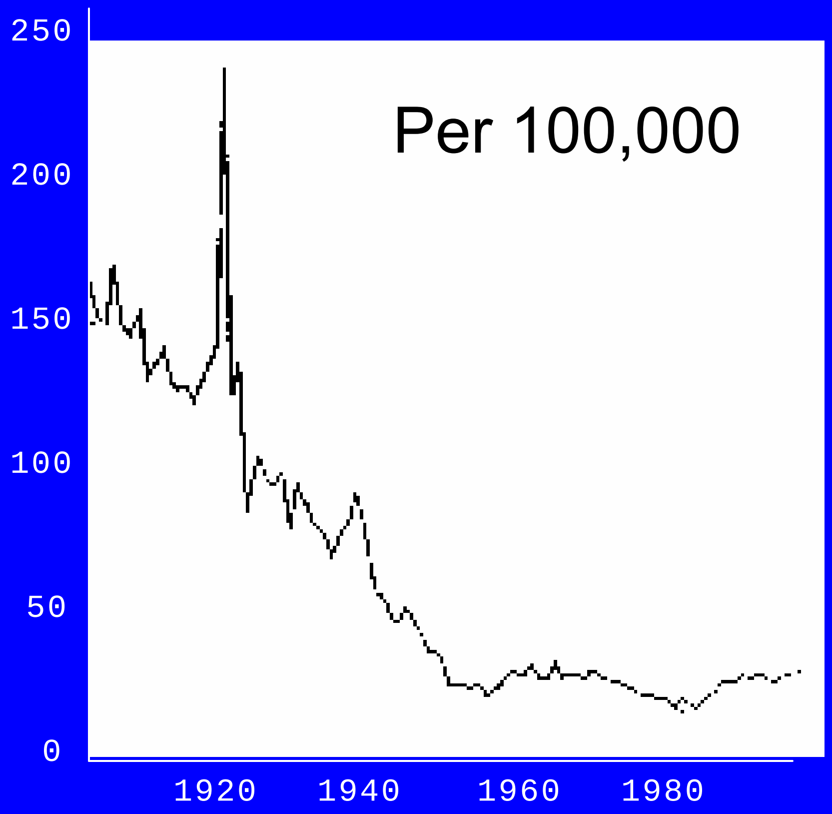
Chief cause of death among the world's children (>2 million per year). Thus, it is the chief global cause of lost healthy life years.

Child mortality occurs almost entirely in developing countries, and as pneumonia.

Well-accepted risk factors (malnutrition, micro-nutrient deficiencies, other diseases, crowding, chilling) do not account for its scale.

Pneumonia Deaths in the United States

Not so long ago Pneumonia was chief cause of death in developed countries



SOURCE: National Center for Health Statistics, 2004. No age adjustment

ALRI associated with use of solid fuels: analysis of ~10 observational studies

Subgroup analyses	Odds ratio (95% CI)
All studies	2.3 (1.9-2.7)
Use of solid fuel	2.0 (1.4-2.8)
Duration of time child spent near the cooking fire	2.3 (1.8-2.9)
Studies adjusting for nutritional status	3.1 (1.8-5.3)
Studies not adjusting for nutritonal status	2.2 (2.0-3.0)
Children aged <2 years old	2.5 (2.0-3.0)
Children aged <5 years old	1.8 (1.3-2.5)

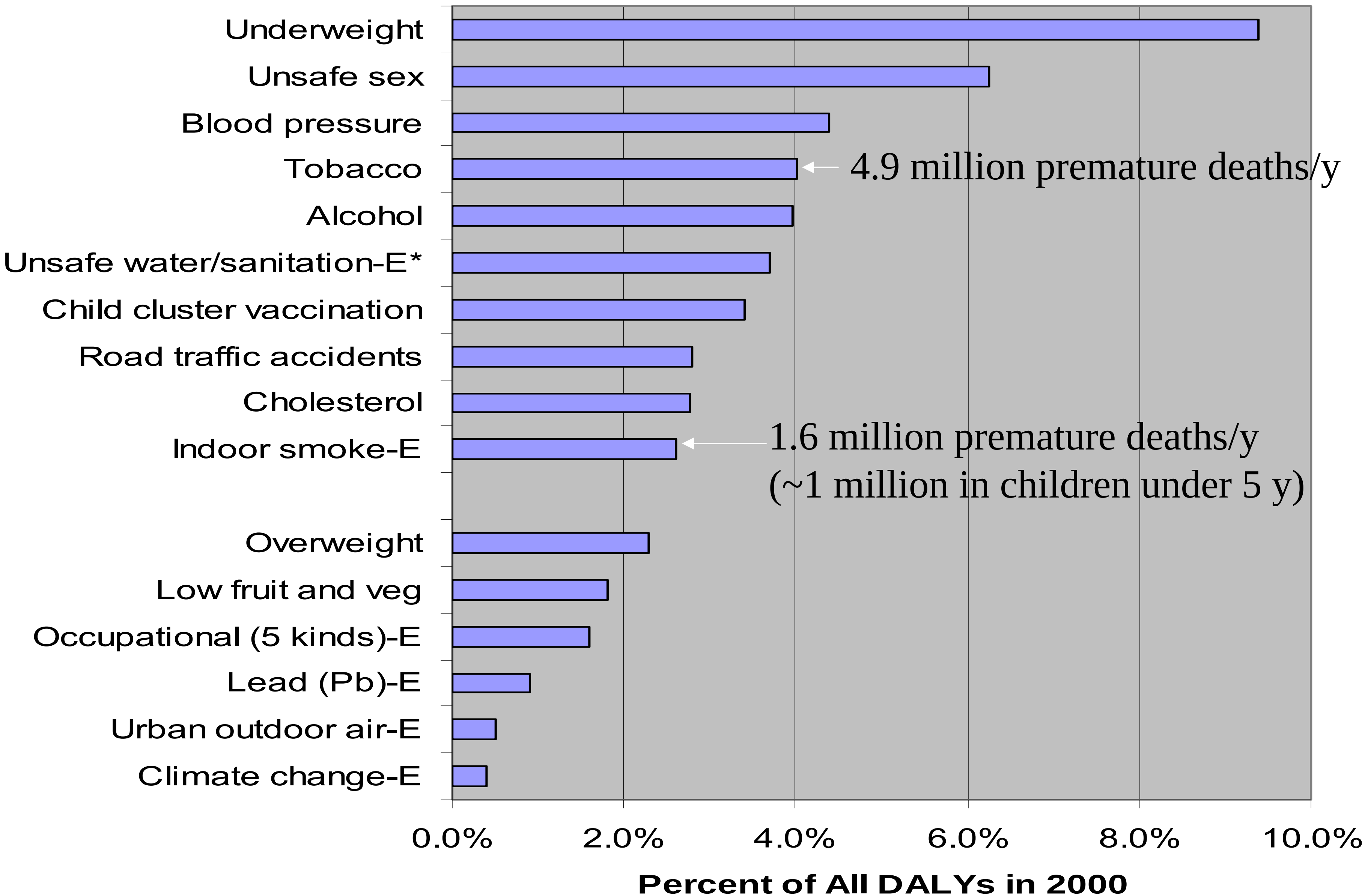
Smith et al in WHO, Comparative quantification of health risks, 2004

Consistent with

- Controlled animal and human exposures showing effects on respiratory immune system
- Dozens of studies of the effect of environmental tobacco smoke exposures in children
- A few studies of outdoor air pollution

Global Burden of Disease from Top 10 Risk Factors

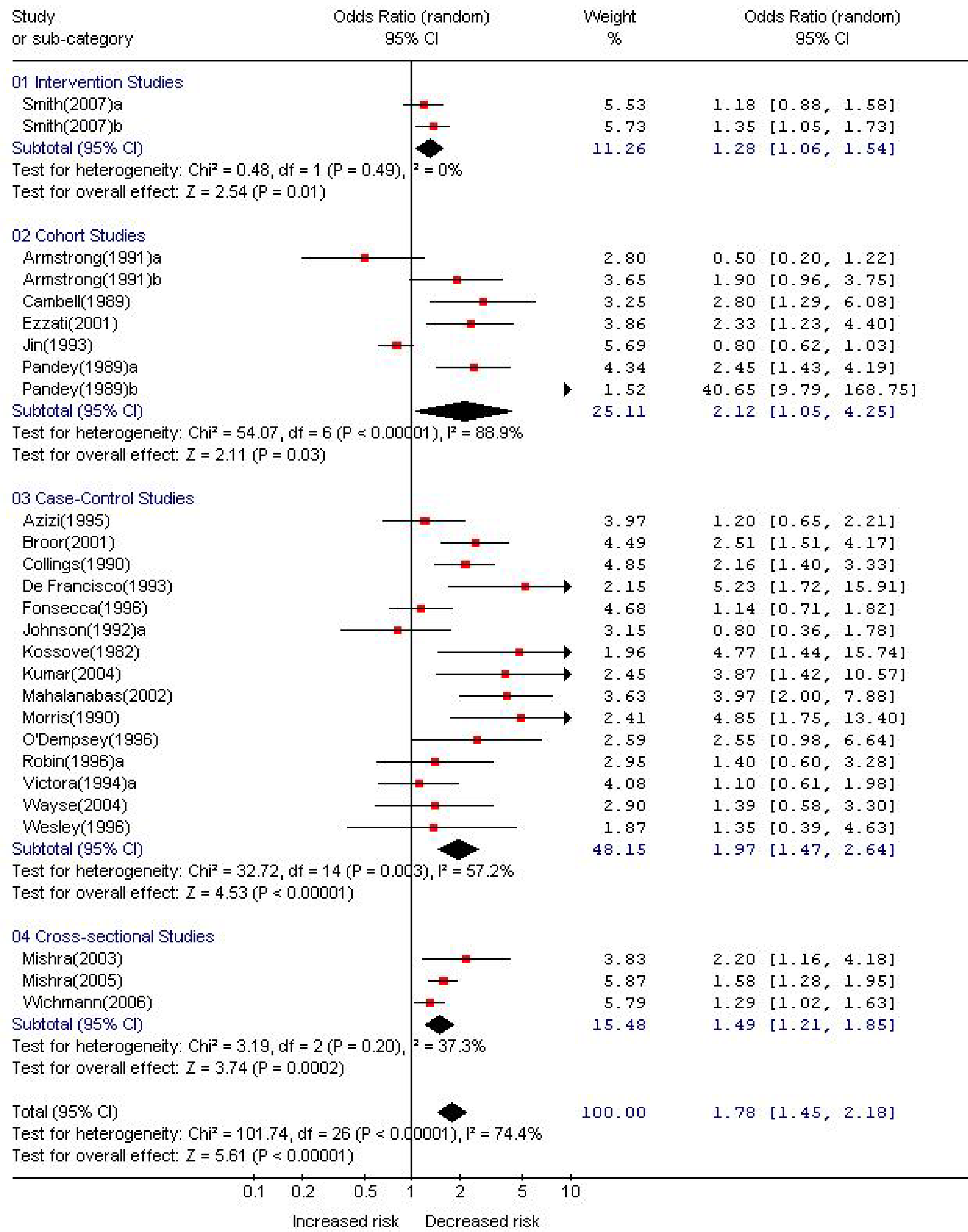
plus selected other risk factors



New ALRI-IAP Systematic Review and Meta-Analysis

Dherani et al. Bull WHO, 2008

Study design	N *	OR	95% CI
Intervention	2	1.28	1.06, 1.54
Cross-sectional	3	1.49	1.21, 1.85
All	26	1.78	1.45, 2.18



Problems with all Previous ALRI and IAP Studies

- Studies were all observational and there may have been residual confounding, i.e., the effect may be due to poverty-related issues not air pollution itself.
- Little or no exposure assessment.
- Given distribution of upper and lower respiratory infections, disease measures used were sensitive (not too many false negatives) but not specific enough, i.e., there were too many false positives.

Acute Respiratory Infections in the World – 2002 In Children 0-5 years

Acute Lower Respiratory Infections (ALRI) + Acute Upper Respiratory Infections (AURI)

Incidence/100,000	ALRI	AURI	ALRI/AURI
World	41,000	536,000	0.08
OECD	3,000	450,000	0.01
India	45,000	700,000	0.06
Ratio Poor/Rich	15	1.6	

In India, if an ALRI assessment method is 82% sensitive and 88% specific,* then only 31% of the ALRI found by the method is actually ALRI The rest is probably AURI or nothing!

WHO, Global Burden of Disease Database

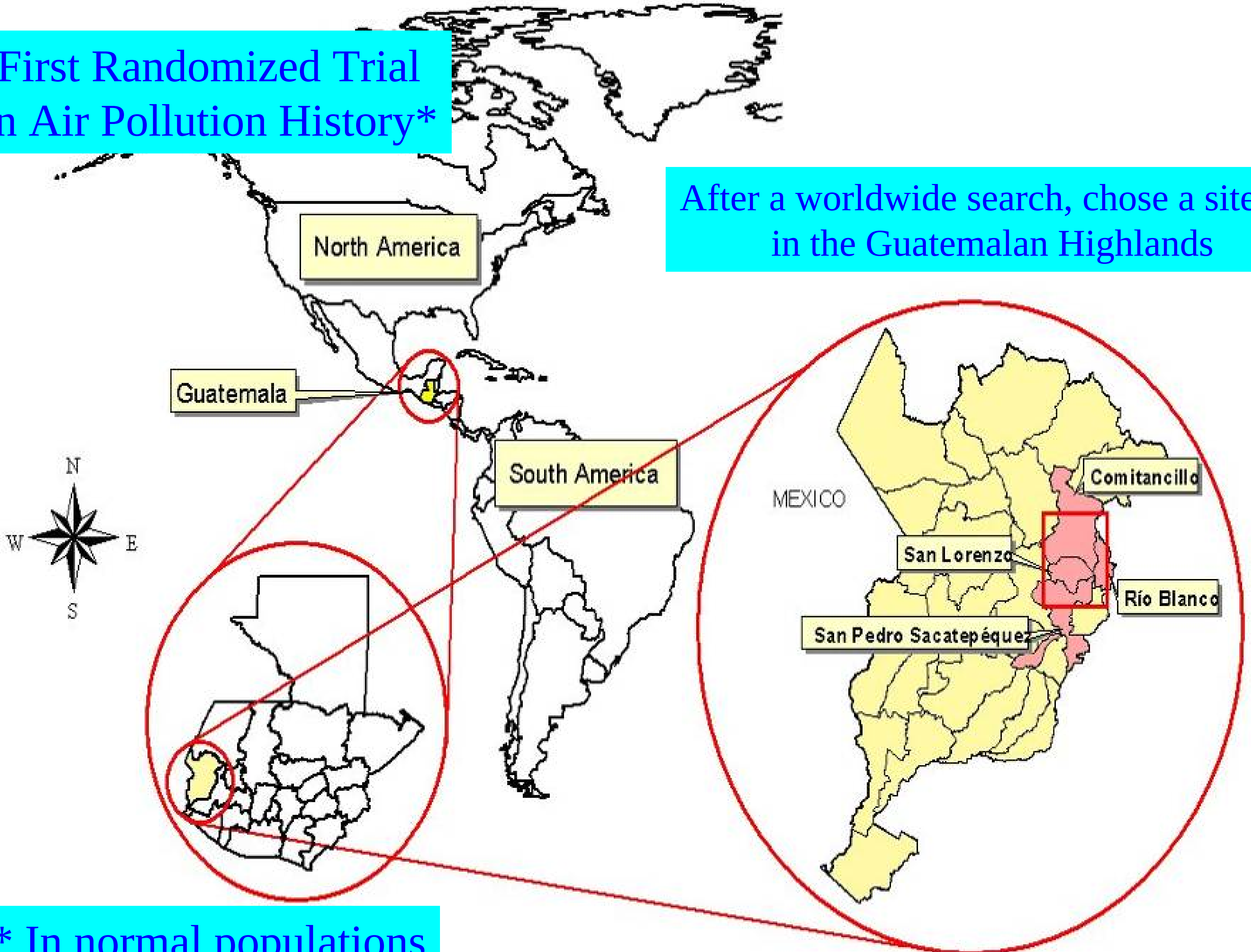
*Average of three best studies

History of a RCT

- ~1980: Early studies of health effects in Nepal and elsewhere
- 1981: First measurements of pollution levels in India
- 1984: International meeting to decide on needed research
  - Chose randomized control trial (RCT) of ALRI
- 1986-89: Unfunded proposals to do RCT in Nepal
- 1990: WHO establishes committee to find best sites
- 1990-1992: Criteria established and site visits made
- 1992: Highland Guatemala chosen
- 1991-1999: Pilot studies to establish data needed for proposal
- 1996-1999: Unfunded proposals
- 2001: NIEHS funding secured
- 2002-2005: Fieldwork completed
- 2007: First results published
- 23+ years from deciding to conduct RCT to results!

First Randomized Trial In Air Pollution History*

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

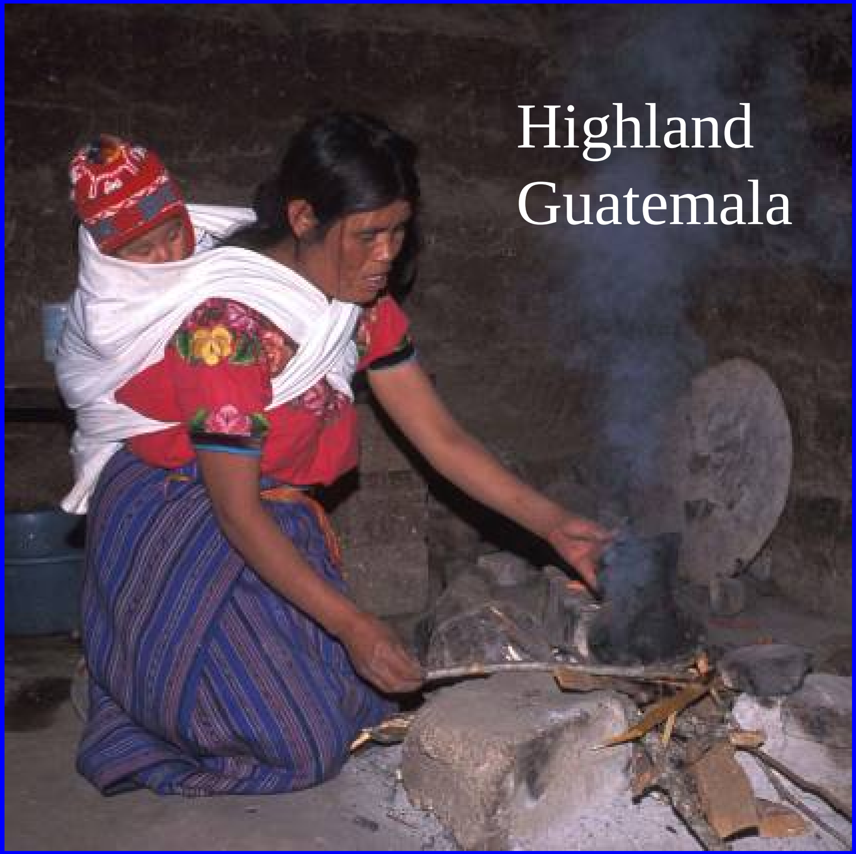


* In normal populations

Setting

- Rural highlands of San Marcos, western Guatemala
- Population nearly all indigenous Mayan Indians
- Nearly all depend on wood for cooking and heating
- Traditional stove is the 3-stone fire – no venting to outside
- Very poor, high IMR, pneumonia, diarrhea and stunting common
- Poor health service uptake - culture, language, transport, time
- Intervention is a stove with chimney that is well-accepted by community

RESPIRE: (Randomized Exposure Study of Pollution Indoors and Respiratory Effects)



Traditional 3-stone open fire

Plancha chimney wood stove

RESPIRE Teams

- 25-35 fulltime field staff
  - 17-25 locally hired bilingual (Mam-Spanish) fieldworkers
  - Field manager
  - 2 field supervisors
  - Data manager
  - 2-3 physicians
  - Environment engineer for air pollution monitoring
  - 4-6 office/data entry staff
  - All Guatemalan
- Investigators and students in Berkeley, Guatemala, Liverpool, Boston, Geneva, and Bergen
- International **Data Safety Management Board** for ongoing protection of human subjects
- NIH and several other funders

Overview of RESPIRE study design

- 530 eligible households: open fire, woman pregnant or child less than 4 months
- Baseline survey and exposure assessment

Year 1

5500 Households total

Randomize

Keep open fire

Plancha

<u>Follow up till aged 18 months</u>

- Surveillance for ALRI, diarrhoea, &c
- Detailed exposure monitoring

Years 1-3

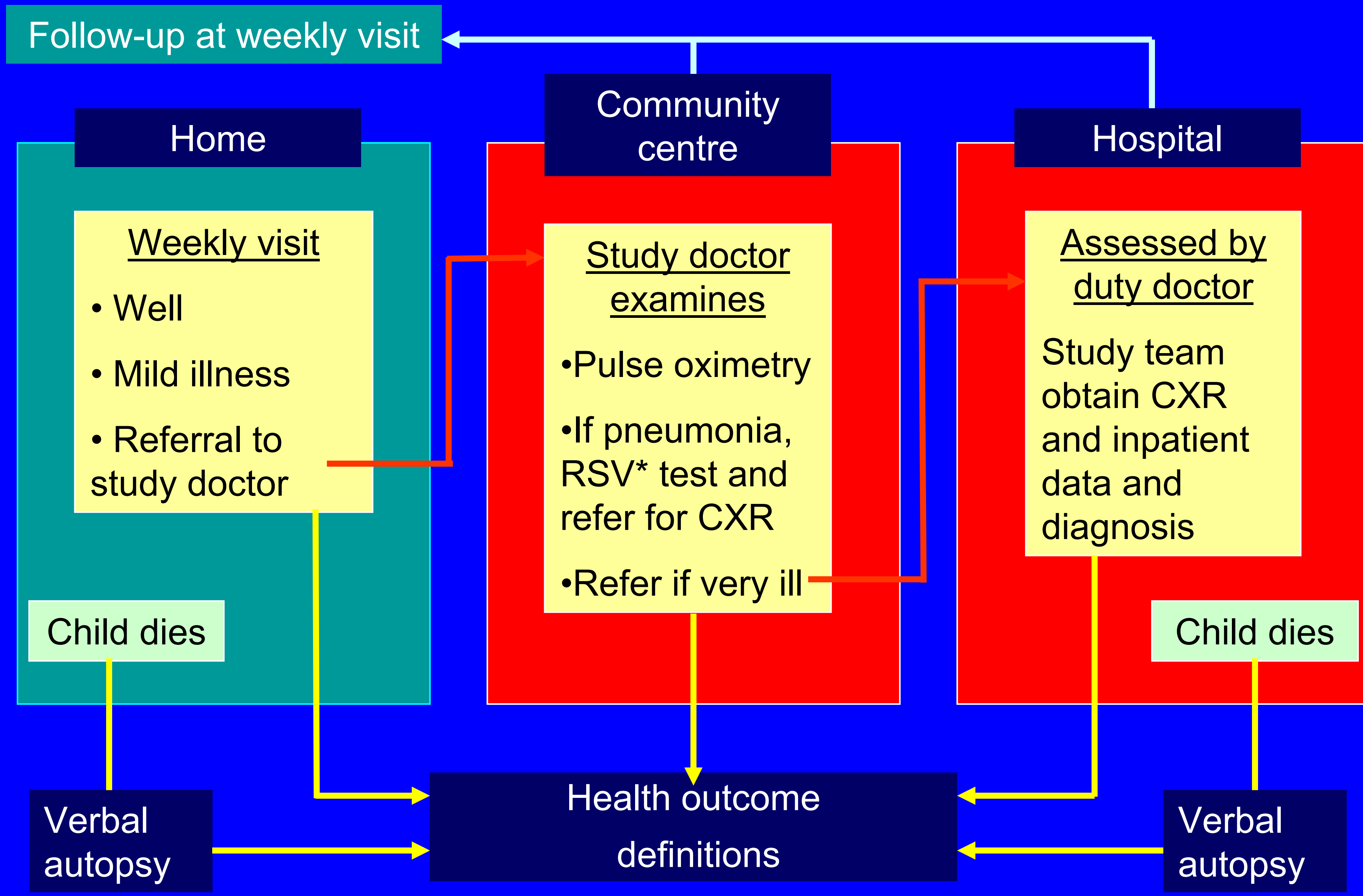
Compare incidence and exposure in 2 groups
Plancha offered to ‘controls’

Years 3-4

Randomisation: balance of groups at baseline

Variable	Control	Intervention
Socio-demographic factors		
Mother's Age (years)	27.0	26.4
Pregnant at recruitment (%)	48.3	51.3
Own home (%)	92.8	94.1
Migrates part of year (%)	17.7	17.1
House structure		
Separate enclosed cooking area (%)	76.2	74.3
Completely open eaves (%)	42.7	40.6
Walls – adobe (mud) (%)	88.7	90.7
Roof – metal (%)	77.4	74.3
Floor – earth (%)	92.5	88.8
Leaks in roof (water) (%)	24.5	33.3
Electricity (%)	70.8	69.3
Other sources of smoke		
Other fire near house (%)	14.6	14.4
Smoking (tobacco) indoors (%)	26.8	20.4
Use traditional sauna bath (%)	84.5	87.8
Geographic		
Mean altitude (metres)	2613	2601

Overview of child health outcomes assessment



* Respiratory syncitial virus

Overview of weekly visits

		Plancha	Control
Number of children		265	253
Weekly visits	Total possible in follow up period	16,446	15,664
	Completed	14,756	14,369
% of possible weekly visits completed		89.7%	91.7%*
Mean (SD, range) visits per child		55.7 (17.8; 1 to 80)	56.8 (17.3; 2 to 81)
Number (%) children - no missed visit		17 (6.4%)	19 (7.5%)
Withdrawals		19 (7.2%)	14 (5.5%)

* $P < 0.001$

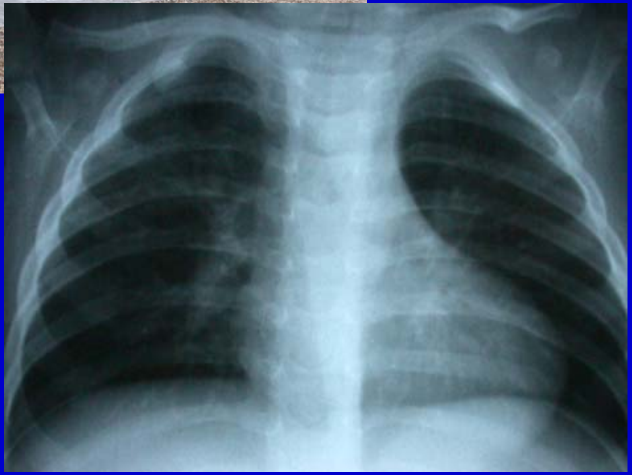
PHYSICIAN ASSESSMENT

- Clinical assessment is the key outcome
- Needed to standardise
- Six employed (four assessed 96.4% referrals)
- Use of agreed terms and signs
- Initial 'calibration' and ongoing ($\pm$ monthly) clinical sessions

PULSE OXIMETRY

- Non-invasive and well-accepted (99%)
- Measure of severity (of respiratory illness):
  - mortality up to x5 in hypoxaemic
- Well children (n=55)
  - Mean (SD) 93.2% (3.0)
  - Hypoxaemic defined as mean – 2SD = 87%
- Bogota (5d – 24mo) altitude 2640m, mean (SD) 93.3% (2.1)

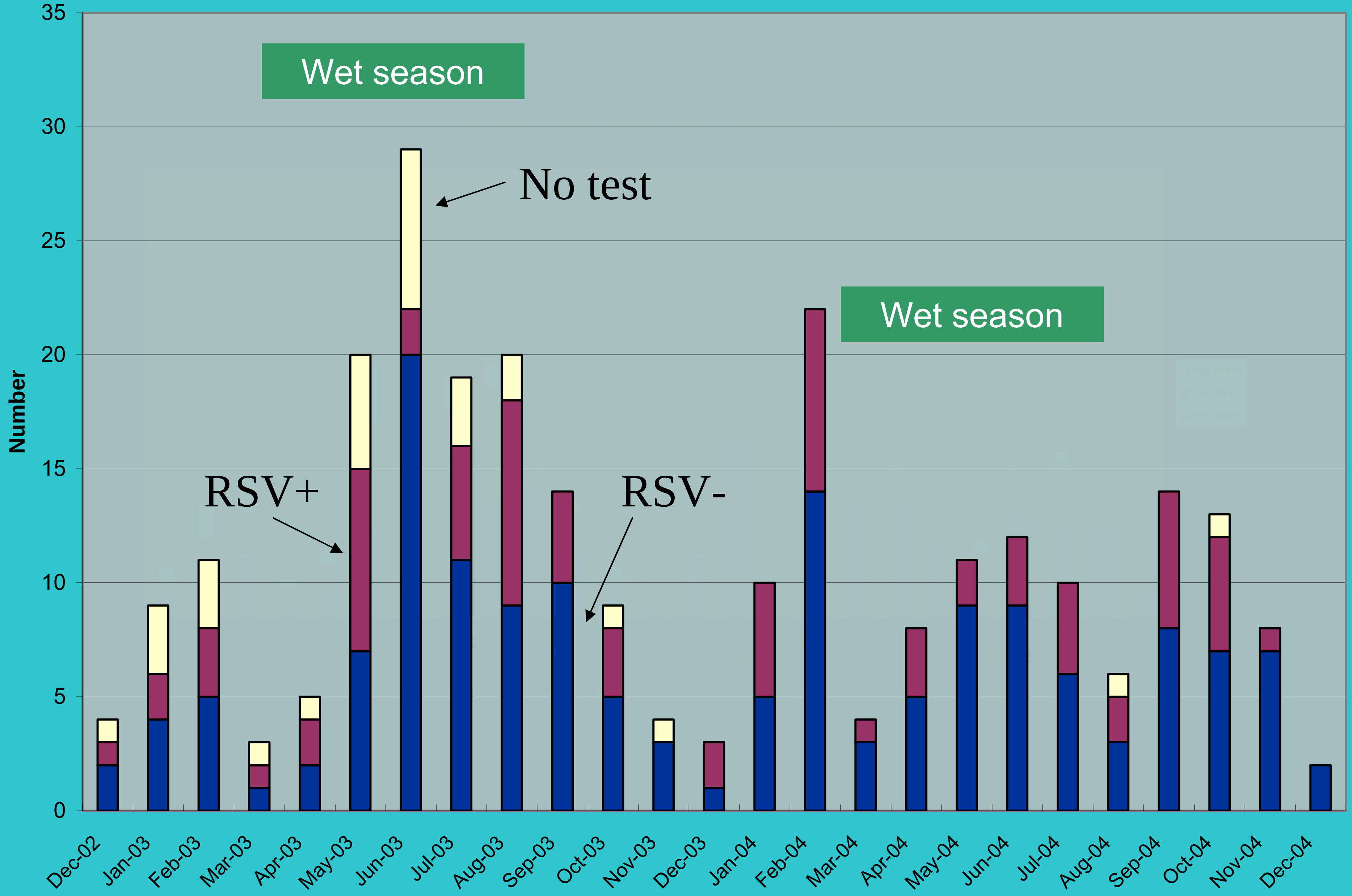
Chest X-rays



- Eligible: all pneumonia cases
- 207 (79 %) of cases attended for CXR
  - Plancha: 82.3%
  - Control: 76.3%
- Reading - WHO protocol*
  - Training
  - Test films: 75% agreement
  - Study films read independently, & blind
  - Agreement assessed
  - WHO readers (TC, HO) assisted re disagreements

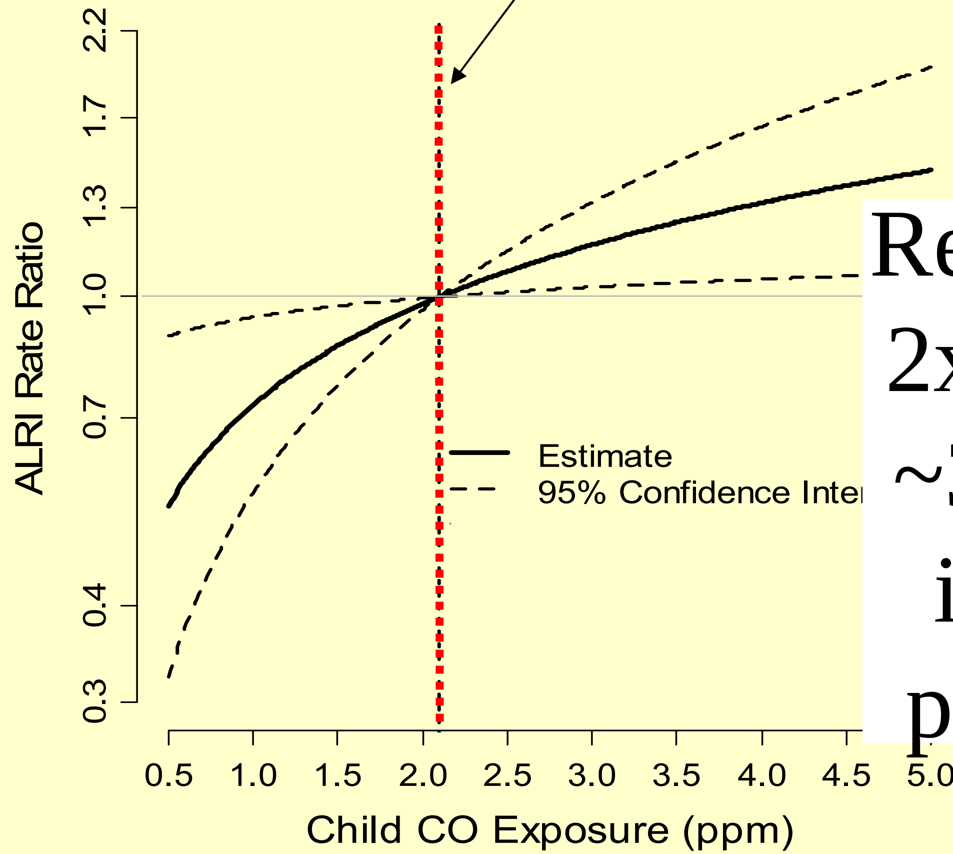
*Standardised method for pneumonia interpretation

Pneumonia by month and RSV status



Exposure-response relationship
(Preliminary Results from Guatemala RCT)

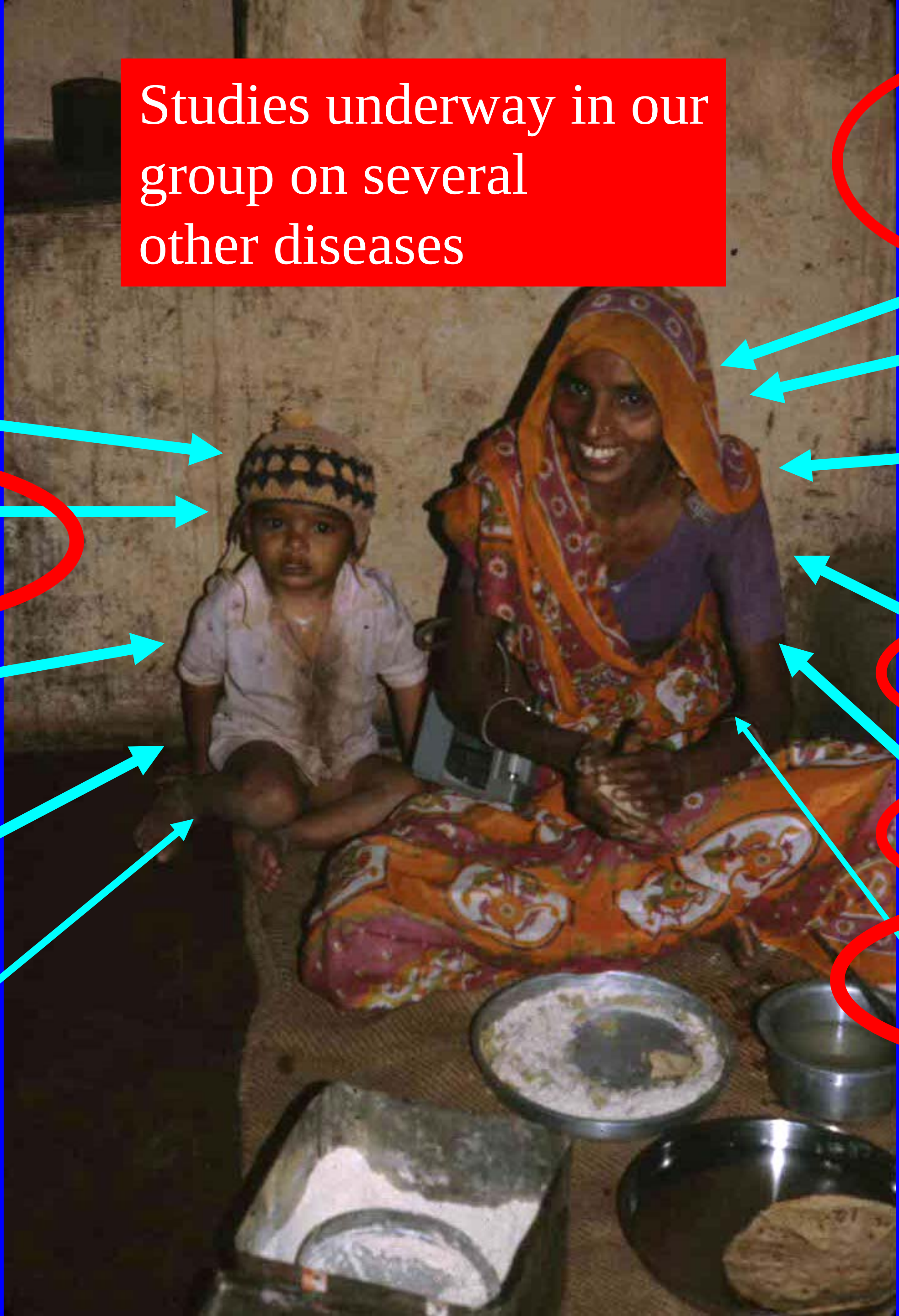
Reference point (RR=1) is mean CO in controls



Reduction of 2x exposure ~30% drop in serious pneumonia

Log linear function provided the best fit

Studies underway in our group on several other diseases



ALRI/ Pneumonia (meningitis)

Low birth weight

Asthma

Early infant death

Cognitive Impairment?

Chronic obstructive lung disease

Interstitial lung disease

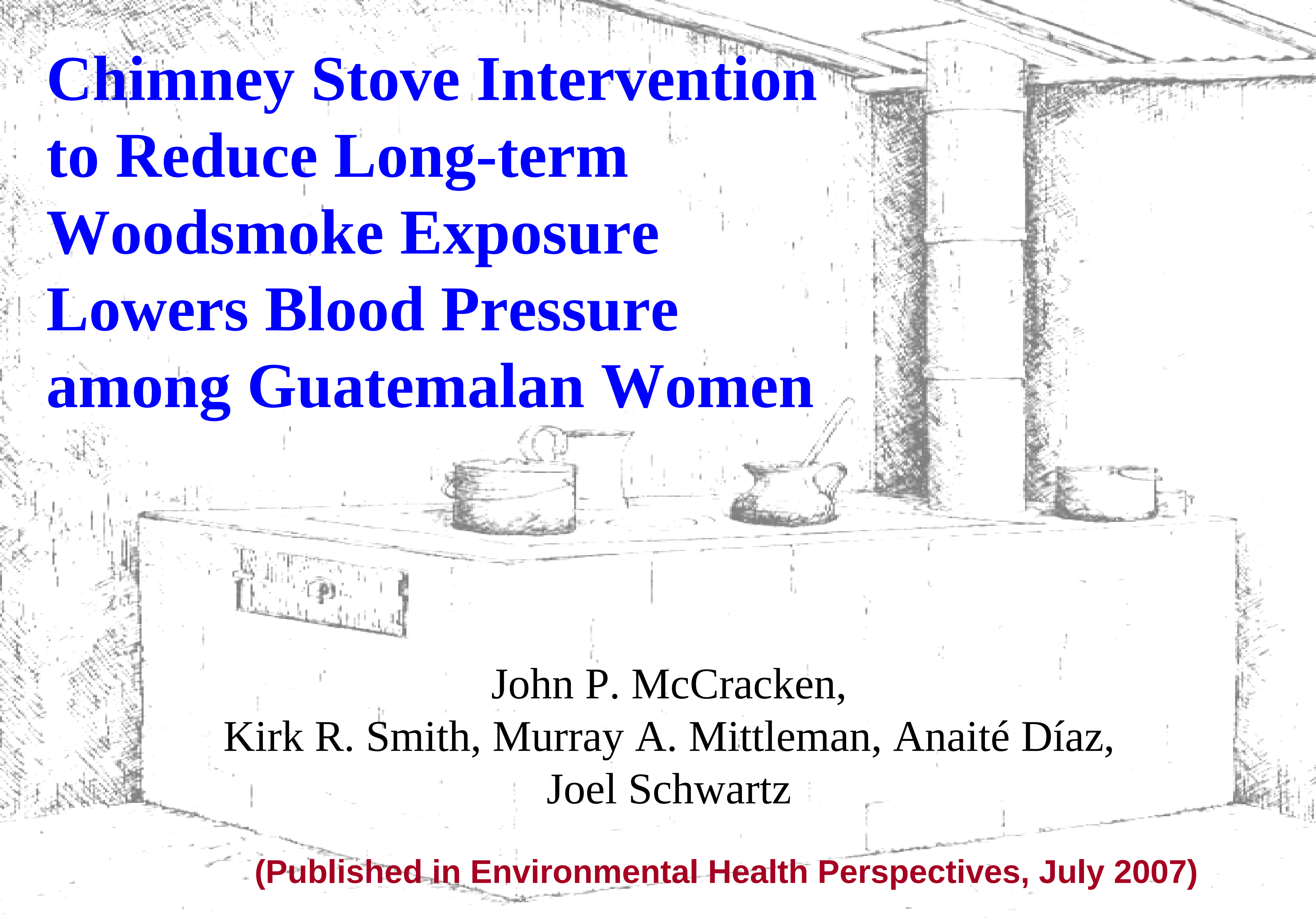
Cancer (lung, NP, cervical, aero-digestive)

Blindness (cataracts, trachoma)

Tuberculosis

Heart disease

Chimney Stove Intervention to Reduce Long-term Woodsmoke Exposure Lowers Blood Pressure among Guatemalan Women



John P. McCracken,
Kirk R. Smith, Murray A. Mittleman, Anaité Díaz,
Joel Schwartz

(Published in Environmental Health Perspectives, July 2007)

Objectives

Goal: To evaluate the effect of long-term reductions in woodsmoke exposure on systolic (SBP) and diastolic blood pressure (DBP).

Specific hypotheses:

1. Personal fine particle ($PM_{2.5}$) exposures will be lower among women using chimney stoves to cook.
2. Chimney stove intervention will be associated with lower SBP and DBP.

Study Design

- Study population
  - Eligible: Women ≥ 38 years, cooking daily
  - Excluded: pregnant, breastfeeding
- Two follow-up periods
  - Trial period (7/03-12/04)
  - Echo-intervention period (3/04-3/05)

Personal $PM_{2.5}$

SBP and DBP

Measures by Group and Period

Subjects (Measures)

	Trial Period	Echo-Intervention Period
Intervention Group	49 (115)	
Control Group	71 (111)	55 (65)

Between-Groups Results

	Number of subjects (measures)		Adjusted mean difference*		
	Control group	Intervention group	Estimate	95% CI	p-value
SBP	71 (111)	49 (115)	-3.7	-8.1, 0.6	0.10
DBP	71 (111)	49 (115)	-3.0	-5.7, -0.4	0.02

* Adjusted for age, body mass index, daily temperature, season, day of the week, time of day, use of wood-fired sauna, household electricity, an asset index, ever smoking, and secondhand tobacco smoke exposure

Before-and-After Results

	Number of subjects (measures)		Adjusted mean difference*		
	Trial period	Echo-intervention	Estimate	95% CI	p-value
SBP	55 (88)	55 (65)	-3.1	-5.3, -0.8	0.01
DBP	55 (88)	55 (65)	-1.9	-3.5, -0.4	0.01

* Adjusted for age, body mass index, daily temperature, season, day of the week, time of day, use of wood-fired sauna, household electricity, an asset index, ever smoking, and secondhand tobacco smoke exposure

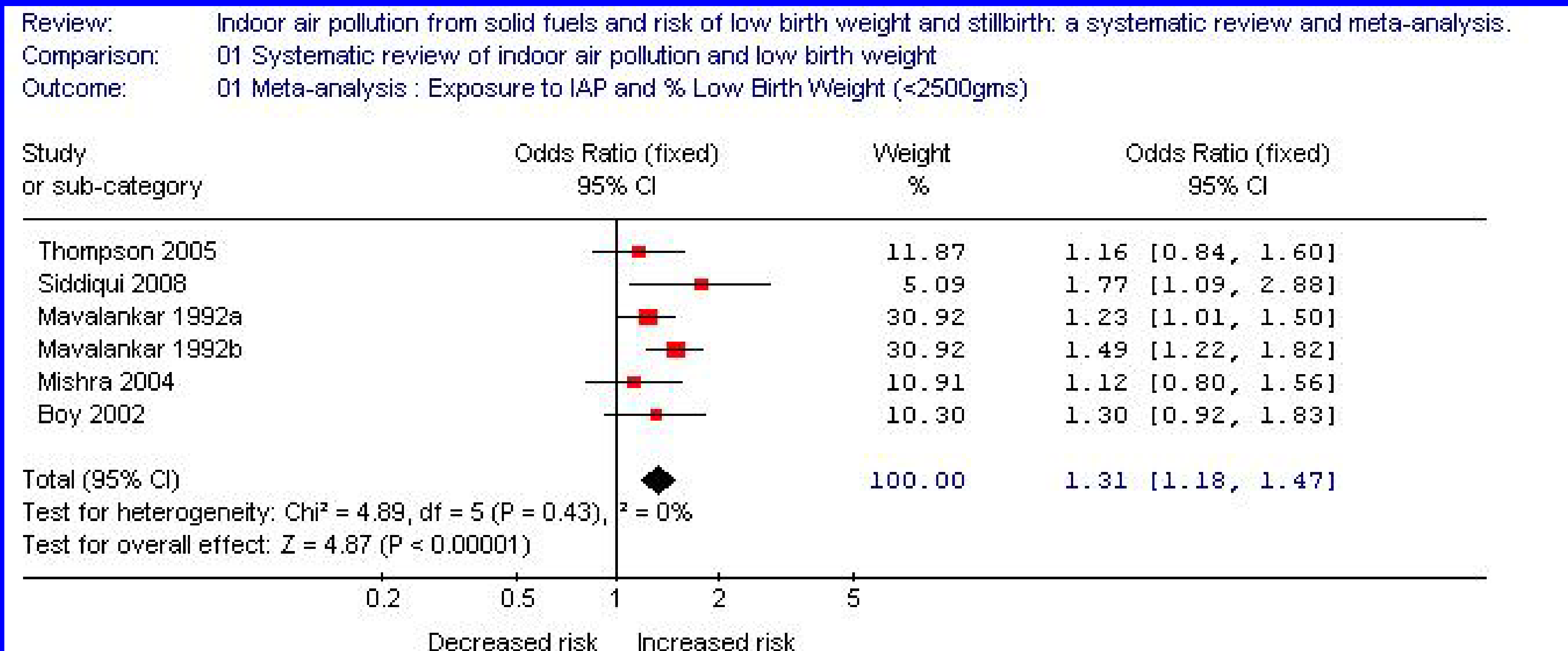
Low birth weight (associated with IAP)

- Large direct impact on child mortality
- Of which perhaps 25% is ALRI
- LBW now linked to chronic disease over life time

Low Birth Weight

- Small number of studies conducted appearing to show results for IAP consistent with evidence from ETS and ambient air pollution.
- Pregnant women in countries with high rates of (a) solid fuel use, and (b) adverse pregnancy outcomes rarely able to avoid activities that expose them and their unborn children to IAP
- Hence, even modest increase in risk for these conditions can be expected to translate into a substantial population attributable risk.
- Systematic review carried out in order to:
  - summarise the extent and quality of the evidence for the relationship between IAP from solid fuel use and adverse pregnancy outcomes
  - quantify these associations by meta-analysis.

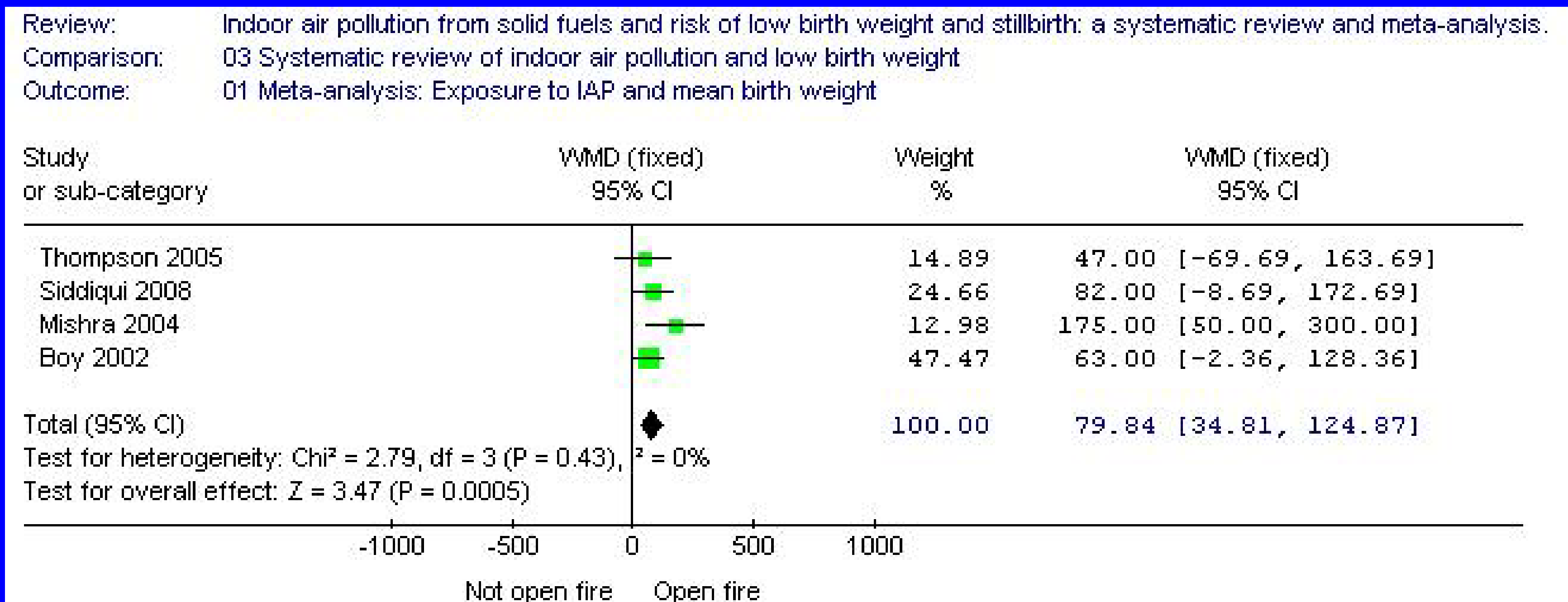
Results: IAP and LBW (<2500gms)



Heterogeneity - (I^2 = 0%; Chi^2 (df=5) = 4.89, p=0.43)

Funnel plot asymmetry - Begg's test (p = 0.566) Egger's test (p=0.989)

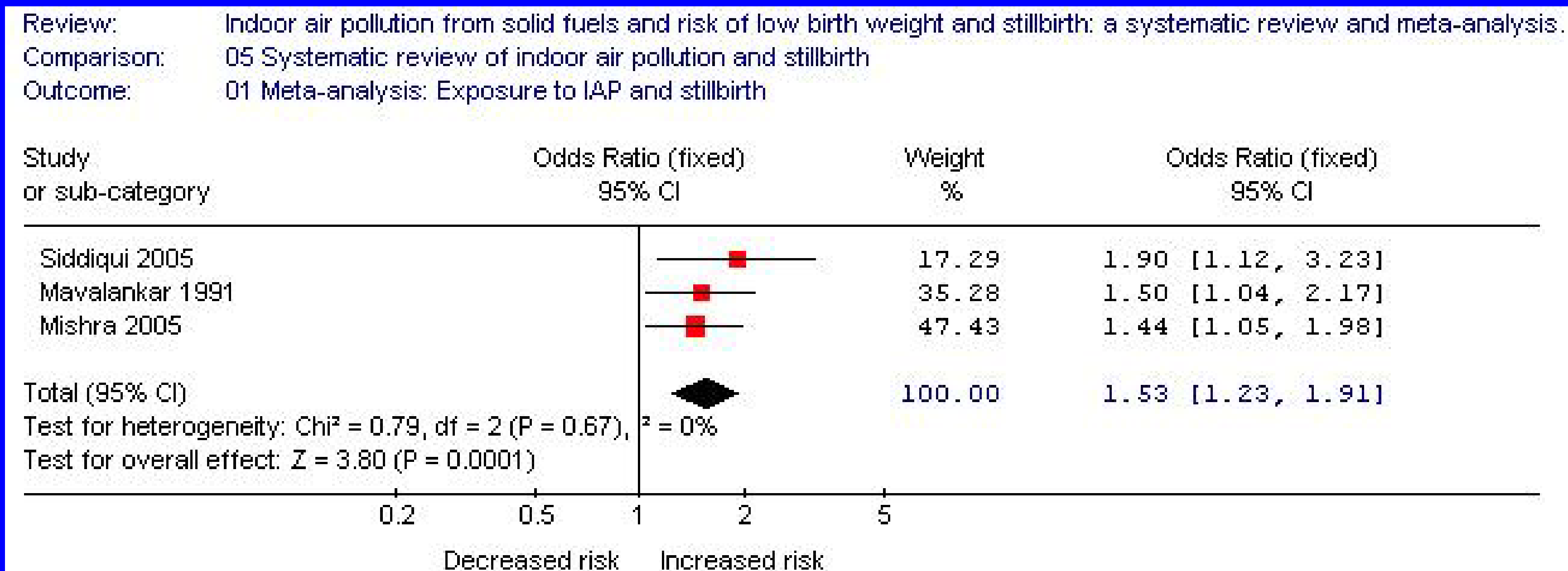
Results: IAP and birth weight



Heterogeneity - (I^2 = 0%; Chi^2 (df=3) = 2.79, p=0.43)

Funnel plot asymmetry - Begg's test (p = 0.308) Egger's test (p=0.479)

Results: IAP and still birth



Heterogeneity - (I^2 = 0%; Chi^2 (df=2) = 0.79, p=0.67)

Funnel plot asymmetry - Begg's test (p = 0.296) Egger's test (p=0.083)

Attributable Fractions do not add to 100%

Underweight 40%

Poor Housing? 40%?

Lack of breastfeeding

Lack of clean

Househ
solid-fu
burnin

In the updated Comparative Risk Assessment being conducted now, depending on the exposure modeling, the estimate will probably be around 750k child ALRI deaths due to household solid fuel smoke globally, but LBW will add others

ea

chimne
20%?

Measles 10%

Outdoor air pollution?

Poor case-management 50%?

Genetic Susceptibility ?

No vaccines 25-50%

Zn Deficiency 15%

Rough estimates only

Thanks to funders for RESPIRE

NIEHS
WHO
Norwegian Government
Guatemala Ministry of Health
AC Griffin Trust
Kresge Foundation

And to all our participants and fieldworkers

Publications available at
http://ehs.sph.berkeley.edu/krsmith/