Presentation to

CONSULTATIVE MEETING ON GLOBAL ACTION PLAN FOR PREVENTION AND CONTROL OF PNEUMONIA (GAPP)

UNICEF/WHO

March 5-7, 2007

Gex/La Mainaz, France
Exposure to indoor air pollution from solid fuels and risk of childhood pneumonia:

Background and review of evidence

Kirk R. Smith and Nigel Bruce
Overview

- Sources of IAP
- Pollutants and known health risks
- Geographic and socio-economic patterns of solid fuel use and burden of exposure
- Levels of pollution and exposure
- Systematic review and meta-analysis of risk for childhood ALRI
- Other recent studies
- Burden of disease estimates (ALRI)
- Discussion and conclusions
- Rationale for doing Randomized Control Trial
6.1 billion people

World Energy - 2001

- Oil: 35.1%
- Coal: 22.6%
- Natural Gas: 21.7%
- Nuclear: 6.9%
- Hydro: 2.3%
- Traditional Biomass: 9.3%
- "Modern" Other Renewables: 1.4%
- Other Renewables: 0.8%
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$_2$O 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: 2.8 MJ, 18%
- In PIC: 1.2 MJ, 8%
- Waste Heat: 11.3 MJ, 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 $benzo(\alpha)$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 Inhhal Tox, 2007
Indoor Air Pollution from Cooking and Heating with Solid Fuels

• Solid fuels: dung, wood, agricultural residues, charcoal, coal
• Largest traditional source of indoor air pollution (over half the world)

Solid fuels + poor ventilation / inefficient stoves
→ high concentrations of a complex mix of health damaging pollutants, including PM, CO, R-CH, NO\textsubscript{X}
• Women and young children, who spend most time indoors at home, experience largest exposure burdens
First person in human history to have her exposure measured doing one of the oldest tasks in human history

Kheda District, Gujarat, India
1981
Exposure Pyramid: Example of Indoor Air Pollution from Solid Fuel Use

1. Regional/National Fuel use
2. Sub-national household fuel use
3. Household fuel use, Housing characteristics
4. Household Air concentrations, without Time activity patterns
5. Household Air concentrations, Time activity patterns
6. Personal monitoring
7. Biomarkers of Exposure

Surveys
Measurements

National
Community
Households
Individuals
Internal Metabolism

Cost and accuracy
Scale
Health Effects of Indoor Air Pollution From Solid Fuel Use

• Relative risk estimates based on crude exposure classifications of exposure (whether solid fuels used for cooking or heating)

• Strong evidence: ALRI, COPD (women), lung cancer (coal)

• Moderate evidence: lung cancer (biomass), COPD (men), asthma, blindness (cataract), tuberculosis

• Limited evidence: adverse pregnancy outcomes, cardiovascular disease, trachoma
The Energy Ladder: Relative Pollutant Emissions Per Meal

Smith, et al., 2005

<table>
<thead>
<tr>
<th></th>
<th>Biogas</th>
<th>LPG</th>
<th>Kerosene</th>
<th>Wood</th>
<th>Roots</th>
<th>Crop Residues</th>
<th>Dung</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO</strong></td>
<td>0.1</td>
<td>1.0</td>
<td>3</td>
<td>19</td>
<td>22</td>
<td>60</td>
<td>64</td>
</tr>
<tr>
<td><strong>Hydrocarbons</strong></td>
<td>0.3</td>
<td>1.0</td>
<td>4.2</td>
<td>17</td>
<td>18</td>
<td>32</td>
<td>115</td>
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<tr>
<td><strong>PM</strong></td>
<td>2.5</td>
<td>1.0</td>
<td>1.3</td>
<td>26</td>
<td>30</td>
<td>124</td>
<td>63</td>
</tr>
</tbody>
</table>
Households Using Biomass Fuels ~80% in India

*Source: Census of India*
Final Fuel Prediction Model

- Parameters:

<table>
<thead>
<tr>
<th>Standardized Coefficients</th>
<th>95% Confidence Interval for B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beta</td>
<td>t</td>
</tr>
<tr>
<td>(Constant)</td>
<td>3.1926</td>
</tr>
<tr>
<td>RURAL</td>
<td>0.3527</td>
</tr>
<tr>
<td>EMR</td>
<td>-0.2838</td>
</tr>
<tr>
<td>LNGNP</td>
<td>-0.2646</td>
</tr>
<tr>
<td>per capita Petroleum Use</td>
<td>-0.2244</td>
</tr>
</tbody>
</table>

- Model Summary:
  - R: 0.8637
  - R²: 0.7460
  - Adjusted R²: 0.7244
  - Standard Error of the Estimate: 0.1891

- Model meets assumptions of normalcy, constant variance.
- Collinearity and Tolerance also assessed.
### Sample Model Results: Solid Fuel Use by WHO Region

<table>
<thead>
<tr>
<th>Region</th>
<th>Population</th>
<th>Solid Fuel Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa – Poor</td>
<td>300 million</td>
<td>73%</td>
</tr>
<tr>
<td>Africa – V Poor</td>
<td>338</td>
<td>84</td>
</tr>
<tr>
<td>Americas - Rich</td>
<td>321</td>
<td>1.5</td>
</tr>
<tr>
<td>Americas - Mid</td>
<td>431</td>
<td>25</td>
</tr>
<tr>
<td>Americas - Poor</td>
<td>71</td>
<td>53</td>
</tr>
<tr>
<td>Near East - Mid</td>
<td>140</td>
<td>6.1</td>
</tr>
<tr>
<td>Near East - Poor</td>
<td>357</td>
<td>54</td>
</tr>
</tbody>
</table>
Indoor Air Pollution and ALRI

- We cannot determine the risk associated with specific pollutants or concentrations of pollutants
  - Binary exposure categories → no exposure-response curve
  - Misclassification of exposure is differential
    (misclassification of unexposed) → bias towards the null

- Practical application of the result: used to quantify the risk-factor disease relationship in CRA for indoor air pollution
Identification of Studies

- Systematic literature search: review articles, MEDLINE, bibliographies of retrieved articles, personal communication
- Eligibility criteria:
  - Primary studies, not re-analyses or reviews
  - Examine either ARI, ALRI, or death due to ARI or ALRI in children under five years of age as outcome
  - Examine some proxy for exposure to indoor smoke from the use of solid fuels for cooking and/or heating purposes
  - Report an odds ratio and its variance or sufficient data to estimate them
  - Written or abstracted in English.
Identification of Studies

Results of search: 567 references
• 143 were considered
• 15 studies met initial criteria for inclusion
• 8 studies included in the analysis

Some characteristics of excluded studies
• Extremely low prevalence of exposure (6% in one study)
• Inappropriate exposure classification (households with ineffective improved stoves classified as unexposed)
• One study classified exposures to cooking fuels, but did not address exposures to charcoal heating in the population
• Cause-specific deaths not reported for pneumonias
IAP and Childhood ALRI: Studies included in Meta-Analysis

• **9 Case-control**: South Africa, Zimbabwe, *Nigeria, Tanzania, Gambia, *Brazil, *India, Argentina
  6 adjusted for confounders; $n = 4311$; Odds Ratios = 2.2-9.9

• **3 Cohort**: Nepal, Gambia
  2 adjusted for confounders; $n = 910$; Odds Ratios = 2.2-6.0

• **1 Case-fatality**: Nigeria
  Hospitalized patients; $n = 103$; Odds Ratio = 8.2

• **2 US Case-control**: $n = 206$ Adjusted for confounders. Odds Ratios = 4.8
Included Studies

- 2 cohort, 6 case-control
- 6 from developing countries (Gambia, Zimbabwe, Nigeria, Nepal)
- 2 from Native American populations
  - Concern: these studies most likely to differ in their socio-economic characteristics
  - Overall odds ratio did not change substantially when these studies excluded
    - Including studies: OR= 2.0 (95% CI: 1.7, 2.4)
    - Excluding studies OR= 2.0 (95% CI: 1.7, 2.3)
  - Subsequent analysis performed including these studies
## Systematic review: studies (1):

<table>
<thead>
<tr>
<th>Country, yr, author</th>
<th>Design</th>
<th>Number and population</th>
<th>Exposure</th>
<th>Outcome</th>
<th>Adj</th>
<th>OR (95%CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Argentina 90 (Cerquiero)</td>
<td>Case-control</td>
<td>616, 669 Children &lt;5yr</td>
<td>Questions on fuel type</td>
<td>ALRI last 12 days, clinic</td>
<td>No</td>
<td>9.9 (1.8, 31.4)</td>
</tr>
<tr>
<td>Brazil 94 (Victora)</td>
<td>Case-control</td>
<td>510, 510 Children &lt;2yr</td>
<td>Question on indoor smoke</td>
<td>Hospital ALRI, clinical, CXR</td>
<td>Yes</td>
<td>1.1 (0.6, 2.0)</td>
</tr>
<tr>
<td>Gambia 91 (Armstrong)</td>
<td>Cohort</td>
<td>500 Children &lt;5yr</td>
<td>Child on back while cooking</td>
<td>ALRI at weekly home visits</td>
<td>Yes</td>
<td>M: 0.5 (0.2, 1.2) F: 1.9 (1.0, 3.9)</td>
</tr>
<tr>
<td>Gambia 89 (Campbell)</td>
<td>Cohort</td>
<td>271 Children &lt;1yr</td>
<td>Child on back while cooking</td>
<td>ALRI at weekly home visits</td>
<td>Yes</td>
<td>2.8 (1.3, 6.1)</td>
</tr>
<tr>
<td>Gambia 93 (de Francisco)</td>
<td>Case-control</td>
<td>129, 270 Children &lt;2yr</td>
<td>Child on back while cooking</td>
<td>Death from ALRI by VA</td>
<td>Yes</td>
<td>5.2 (1.7, 15.9)</td>
</tr>
<tr>
<td>Gambia 96 (O’ Dempsey)</td>
<td>Case-control</td>
<td>80, 159 Children &lt;5yr</td>
<td>Child on back while cooking</td>
<td>Hospital ALRI, clinical, CXR, laboratory</td>
<td>Yes</td>
<td>2.5 (1.0, 6.6)</td>
</tr>
<tr>
<td>India 94 (Shah)</td>
<td>Case-control</td>
<td>400 Children ≤5yr</td>
<td>Stove produces smoke</td>
<td>Severe ARI hospital cases</td>
<td>Yes</td>
<td>1.2 (0.7, 2.3)</td>
</tr>
</tbody>
</table>

= included in meta-analysis
<table>
<thead>
<tr>
<th>Country</th>
<th>Design</th>
<th>Number and population</th>
<th>Exposure</th>
<th>Outcome</th>
<th>Adj</th>
<th>OR (95%CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya 01</td>
<td>Cohort</td>
<td>93 Children &lt;5yr</td>
<td>Daily PM$_{10}$ exposure</td>
<td>Weeks with ALRI criteria</td>
<td>Yes</td>
<td>2.93 (1.34, 6.39)</td>
</tr>
<tr>
<td>(Ezzati)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Nepal 89</td>
<td>Cohort</td>
<td>280 Children &lt;2yr</td>
<td>Time near fireplace</td>
<td>ARI by bi-weekly home visits</td>
<td>No</td>
<td>2.3 (1.8, 2.9)</td>
</tr>
<tr>
<td>(Pandey)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Nigeria 92</td>
<td>Case-control</td>
<td>103, 103 Children &lt;5yr</td>
<td>Type of fuel used</td>
<td>Hospital ALRI, clinical, CXR, lab</td>
<td>No</td>
<td>0.8 (0.4, 1.7)</td>
</tr>
<tr>
<td>(Johnson)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>S Africa 82</td>
<td>Case-control</td>
<td>132, 18 Children ≤1yr</td>
<td>Child stays in smoke</td>
<td>Hospital ALRI, clinical, CXR</td>
<td>No</td>
<td>4.8 (1.7, 13.6)</td>
</tr>
<tr>
<td>(Kossove)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Tanzania 92,</td>
<td>Case-control</td>
<td>456, 1160 Children &lt;5yr</td>
<td>Child sleeps in cooking room</td>
<td>Death all causes by VA and MD</td>
<td>Yes</td>
<td>2.8 (1.8, 4.3)</td>
</tr>
<tr>
<td>(Mtango)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA 90</td>
<td>Case-control</td>
<td>58, 58 Children &lt;2yr</td>
<td>Main source: heating, cook</td>
<td>Hospital ALRI, clinical, CXR</td>
<td>Yes</td>
<td>4.9 (1.7, 12.9)</td>
</tr>
<tr>
<td>(Morris)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA 96</td>
<td>Case-control</td>
<td>45, 45 Children &lt;2yr</td>
<td>Use wood for cooking</td>
<td>Hospital ALRI</td>
<td>Yes</td>
<td>5.0 (0.6, 42.8)</td>
</tr>
<tr>
<td>(Robin)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zimbabwe 90</td>
<td>Case-control</td>
<td>244, 500 Children &lt;3yr</td>
<td>Open wood fire to cook</td>
<td>Hospital ALRI, clinical, CXR</td>
<td>Yes</td>
<td>2.2 (1.4, 3.3)</td>
</tr>
<tr>
<td>(Collings)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
Meta-analyses

• Followed general principles of Greenland
• Heterogeneous exposure measurements and diverse analytical strategies used by investigators (especially control of confounding)

→ A single statistical analysis not appropriate
  - Several meta-analyses conducted for different sub-groupings of studies
  - Results remarkably consistent, with pooled relative risk estimates increasing with increased precision of exposure
Sub-analysis: Exposure assessment

1. Carrying child on the back during cooking (more specific)
2. Use of solid fuels for cooking or heating

<table>
<thead>
<tr>
<th></th>
<th>OR (f)</th>
<th>95% CI</th>
<th>OR (r)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrying the child on the back</td>
<td>3.1</td>
<td>1.8, 5.3</td>
<td>3.1</td>
<td>1.8, 5.3</td>
</tr>
<tr>
<td>Use of solid fuels for cooking or</td>
<td>2.0</td>
<td>1.4, 2.8</td>
<td>2.1</td>
<td>1.0, 4.7</td>
</tr>
<tr>
<td>heating</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

OR (f): Odds ratio from fixed effects model
OR (r): Odds ratio from random effects model
Sub-analysis: Age

- Almost all studies adjusted for age
- Results of sub-analysis suggest a stronger effect in younger children

<table>
<thead>
<tr>
<th>Age</th>
<th>OR (f)</th>
<th>95% CI</th>
<th>OR (r)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age &lt; 24 months</td>
<td>2.5</td>
<td>2.0, 3.0</td>
<td>2.6</td>
<td>2.0, 3.5</td>
</tr>
<tr>
<td>Age 0-59 months</td>
<td>1.8</td>
<td>1.3, 2.5</td>
<td>1.7</td>
<td>0.8, 3.2</td>
</tr>
</tbody>
</table>

OR (f): Odds ratio from fixed effects model
OR (r): Odds ratio from random effects model
Sub-analysis: Nutritional Status

• Malnutrition is a major risk factor for ARI
• Three studies adjusted for nutritional status
• Studies that did not adjust for nutritional status may overestimate the association between indoor air pollution and ARI.
• Studies that adjusted for nutritional status had the most precise exposure measure (carriage on the mother’s back)

<table>
<thead>
<tr>
<th></th>
<th>OR (f)</th>
<th>95% CI</th>
<th>OR (r)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted for nutritional status</td>
<td>3.1</td>
<td>1.8, 5.3</td>
<td>3.1</td>
<td>1.8, 5.3</td>
</tr>
<tr>
<td>Not adjusted for nutritional status</td>
<td>2.2</td>
<td>1.8, 2.6</td>
<td>2.1</td>
<td>1.4, 3.2</td>
</tr>
</tbody>
</table>

OR (f): Odds ratio from fixed effects model
OR (r): Odds ratio from random effects model
### Summary of Sub-analyses

<table>
<thead>
<tr>
<th></th>
<th>OR (f)</th>
<th>95% CI</th>
<th>OR (r)</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>All studies</td>
<td>2.3</td>
<td>1.9, 2.7</td>
<td>2.3</td>
<td>1.7, 3.2</td>
</tr>
<tr>
<td>Carrying the child on the back</td>
<td>3.1</td>
<td>1.8, 5.3</td>
<td>3.1</td>
<td>1.8, 5.3</td>
</tr>
<tr>
<td>Use of solid fuels for cooking or</td>
<td>2.0</td>
<td>1.4, 2.8</td>
<td>2.1</td>
<td>1.0, 4.7</td>
</tr>
<tr>
<td>heating</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted for nutritional status</td>
<td>3.1</td>
<td>1.8, 5.3</td>
<td>3.1</td>
<td>1.8, 5.3</td>
</tr>
<tr>
<td>Not adjusted for nutritional status</td>
<td>2.2</td>
<td>1.8, 2.6</td>
<td>2.1</td>
<td>1.4, 3.2</td>
</tr>
<tr>
<td>Age &lt; 24 months</td>
<td>2.5</td>
<td>2.0, 3.0</td>
<td>2.6</td>
<td>2.0, 3.5</td>
</tr>
<tr>
<td>Age 0-59 months</td>
<td>1.8</td>
<td>1.3, 2.5</td>
<td>1.7</td>
<td>0.8, 3.2</td>
</tr>
</tbody>
</table>

**OR (f):** Odds ratio from fixed effects model  
**OR (r):** Odds ratio from random effects model
Practical Application to CRA

- As we could not separate better exposure measures from adjustment for nutritional status, we used the combined odds ratios from all eight studies in the CRA.
- This is consistent with:
  - Difference between exposure measures (less vs. more precise)
  - Differences between age groups (GBD does not differentiate within the 0-5 age group). Note that around 2/3 of ARI in the final model occurs in <24 month age group, similar to age distribution of ARI in many areas.
## Burden of disease from biomass fuel (ALRI)

<table>
<thead>
<tr>
<th>Subregion</th>
<th>Deaths (000s)</th>
<th>DALYs (000s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AFR - D</td>
<td>153</td>
<td>5221</td>
</tr>
<tr>
<td>AFR - E</td>
<td>198</td>
<td>6746</td>
</tr>
<tr>
<td>AMR - A</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>AMR - D</td>
<td>6</td>
<td>291</td>
</tr>
<tr>
<td>AMR - D</td>
<td>9</td>
<td>314</td>
</tr>
<tr>
<td>EMR – B</td>
<td>2</td>
<td>59</td>
</tr>
<tr>
<td>EMR – D</td>
<td>94</td>
<td>3306</td>
</tr>
<tr>
<td>EUR – A</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>EUR - B</td>
<td>12</td>
<td>417</td>
</tr>
<tr>
<td>EUR – C</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>SEAR – B</td>
<td>19</td>
<td>761</td>
</tr>
<tr>
<td>SEAR – D</td>
<td>355</td>
<td>12506</td>
</tr>
<tr>
<td>WPR – A</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>WPR - B</td>
<td>62</td>
<td>2275</td>
</tr>
<tr>
<td>World</td>
<td>910</td>
<td>31919</td>
</tr>
</tbody>
</table>
## Global Burden from Indoor Air Pollution

<table>
<thead>
<tr>
<th>Disease</th>
<th>AF (%)</th>
<th>Deaths (thousands)</th>
<th>YLLs /death</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALRI (&lt;5 y)</td>
<td>36</td>
<td>1020</td>
<td>30.0</td>
</tr>
<tr>
<td>COPD</td>
<td>22</td>
<td>588</td>
<td>6.5</td>
</tr>
<tr>
<td>Lung Cancer</td>
<td>1</td>
<td>12</td>
<td>8.8</td>
</tr>
<tr>
<td><strong>Total-indoor</strong></td>
<td>--</td>
<td>1620</td>
<td>21.6</td>
</tr>
<tr>
<td><strong>Total-outdoor</strong></td>
<td>--</td>
<td>804</td>
<td>8.0</td>
</tr>
</tbody>
</table>
Other recent studies

• Not included in meta-analysis, hence did not contribute to risk estimates for CRA
  – India: Broor et al. 2001
  – Kenya: Ezzati et al. 2001
  – Zimbabwe: Mishra 2003
  – India: Mahalanabis et al. 2003
  – India: Mishra et al. 2005
  – Other?

• All showed significant effects, with no large differences from MA results.
Kenya (cohort study)
Unadjusted exposure-response (ages 0-4 years)

Ezzati M and Kammen D (2001)

N = 93 children
Zimbabwe – DHS

- Demographic and Health Survey
- Zimbabwe (1999)
- Analysis of 3559 children aged 0-59 months
- ALRI: respondent recall of cough with short, rapid breathing in prior 2 weeks
- Exposure: type of fuel (biomass vs. clean fuel)
- Multivariate logistic regression: OR = 2.20 (95% CI: 1.16, 4.19)
- Potential limitations of study design and ALRI definition (2-week prevalence of 15.8% is high for true ALRI)

Mishra 2003
How Does This Compare to the Largest Modern Source of IAP?

Environmental tobacco smoke (ETS)

Similarities between the sources:

- Both are result of incomplete combustion of biomass in inadequately ventilated households
- Similar chemical and physical characteristics and potential intervention approaches
- Both address exposure to “smoke” rather than a specific agent → studies included in the meta-analyses rely on proxies for exposure
- In most cases, subjects are classified as exposed or unexposed based on binary categories of exposure
## Solid Fuel Use vs. ETS

<table>
<thead>
<tr>
<th>Exposure Intensity</th>
<th>Solid Fuel Use</th>
<th></th>
<th>Environmental Tobacco Smoke</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exposure Proxy</td>
<td>OR (95% CI)</td>
<td>Exposure Proxy</td>
<td>OR (95% CI)</td>
</tr>
<tr>
<td>Low</td>
<td>Use of solid fuels for cooking or heating (4 studies)</td>
<td>2.0 (1.4, 2.8)</td>
<td>Paternal smoking (4 studies)</td>
<td>1.3 (1.2, 1.5)</td>
</tr>
<tr>
<td>Intermediate</td>
<td>Child remains indoors during cooking (studies with this proxy excluded for methodological reasons)</td>
<td>Not applicable</td>
<td>Parental smoking (11 studies)</td>
<td>1.5 (1.4, 1.6)</td>
</tr>
<tr>
<td>High</td>
<td>Carriage on mother’s back during cooking (3 studies)</td>
<td>3.1 (1.8, 5.3)</td>
<td>Maternal smoking (7 studies)</td>
<td>1.6 (1.4, 1.7)</td>
</tr>
</tbody>
</table>

ETS: Strachan and Cook, 1997
Outdoor Air Pollution
Number of daily emergency visits for child pneumonia, Santiago, Chile

Adjusted for time (time)$^2$, (time)$^3$, (time)$^4$, week-day/weekend, minimum temperature, (mintemp)$^2$, relative humidity, months, epidemic

Ilabaca et al., JAWMA, 1999
Percentage change in non-accidental deaths, in children, per 10 μg/m³ increase in outdoor PM$_{10}$

![Graph showing percentage change in mean daily number deaths per 10 μg/m³ increase in concentration of PM$_{10}$](image)

- Sao Paulo (Loomis et al. 1999)
- Sao Paulo (Pereira et al. 1998)
- Sao Paulo (Saldiva et al. 1994)
- Sao Paulo (Gouveia and Fletcher 2000)
- Bangkok (Ostro et al. 1999a)

Cohen et al in WHO, Comparative quantification of health risks, 2004
Biological model for infant health

- Respiratory disease
- Diminish ingestion
- Hypoxia
- Antecedents: Small height of the parents
- Weight at birth
- Gender
- Smoking
- Diminish ingestion
- Diarrheas
- Other diseases
- Infant Health: Respiratory Development & Growth
- Pollution: CO, SO2, NO2, PM
- Energetic diet and micronutrients
- Breast feeding
- Socio-demographic: Living condition
- Occupation
- Parents schooling
- Fuel type: CO - SO2 - NO2 - PM
Rationale for RCT

• Evidence to date observational:
  – Problem of (residual) confounding
  – ‘Competing’ with RCT evidence
• ALRI definition and case-finding:
  – Varies from WHO pneumonia (sensitive) to clinical with CXR (specific)
  – Few (none) used highly specific case definition with community case-finding
• No direct exposure measurement
• No studies have measured the health impact of a feasible intervention
Acute Respiratory Infections in the World – 2002
In Children 0-5 years
Acute Lower Respiratory Infections (ALRI) +
Acute Upper Respiratory Infections (AURI)

<table>
<thead>
<tr>
<th>Incidence/100,000</th>
<th>ALRI</th>
<th>AURI</th>
<th>ALRI/AURI</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td>41,000</td>
<td>536,000</td>
<td>0.08</td>
</tr>
<tr>
<td>OECD</td>
<td>3,000</td>
<td>450,000</td>
<td>0.01</td>
</tr>
<tr>
<td>India</td>
<td>45,000</td>
<td>700,000</td>
<td>0.06</td>
</tr>
<tr>
<td>Ratio Poor/Rich</td>
<td>15</td>
<td>1.6</td>
<td></td>
</tr>
</tbody>
</table>

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 the RCT

- ~1980: early accounts 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
- 1992: Guatemala chosen
- 1991-1999: Pilot studies to establish data needed for proposal
- 1996-1999: unfunded proposals
- 2001: NIH funds first randomized control trial for air pollution in highland Guatemala
- 2002-2006: fieldwork completed
- 2007: first results being published
- 23 years from deciding to conduct RCT to results!
What Can be Done?

- Poverty is the problem, but poverty-alleviation may not be the best answer:
  - It is too slow -- it will take many decades at least
  - It is too inefficient – it is possible to target improvements in improving household ventilation and fuel quality just as it is possible to target improvement in household sanitation and water quality
  - Healthy people needed to propel economic growth as well as end in themselves
What Can be Done?
Improved Stove in Shanxi
Technical Solutions

- Better Ventilation
  - Windows
  - Chimneys
  - Hoods

- Better Stoves
  - Fuel efficiency
  - Combustion efficiency

- Better Fuels
  - Clean solids (?)
  - Gases and liquids

Short Term

Long Term
As an environmental intervention,

- Often not cost-effective in narrow disease context, i.e., for pneumonia, compared to vaccines, etc.
- But has other health benefits
  - Protects entire family
  - Multiple diseases
  - Hygiene, safety, ergonomics
- Important non-health benefits
  - Economic benefits
    - Fuel savings
    - Energy security
  - Social benefits, e.g., time savings (think of clean water)
  - Environmental protection benefits
    - Local biodiversity
    - Climate change
2-3 million ALRI Deaths In Children Under 5

- Poor case-management 50%
- Underweight 40%
- Lack of breastfeeding 10%
- Diarrhea 20%
- Measles 10%
- Zn Deficiency 15%
- No vaccines 25-50%
- Genetic Susceptibility 25-50%
- Outdoor air pollution?
- Poor Housing? 40%
- Household solid-fuel burning? 20%
- Lack of chimneys? 20%

Attributable Fractions do not add to 100%

Rough estimates only
Thank you