Recent Health Effects Results from Guatemala: Implications for the Stove Community

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University of California, Berkeley

PCIA Forum, Kampala
March 28, 2009
Household Solid Fuel Burning

• Why solid fuel use can be a hazard
• Summary of current risk estimates for child pneumonia
• Results from the first randomized trial – RESPIRE in the Guatemalan Highlands
• M&E updates
• Implications for stove technology and dissemination
World Energy – 2001

- Natural Gas: 21.7%
- Nuclear: 6.9%
- Hydro: 2.3%
- Traditional Biomass: 9.3%
- "Modern" Biomass Renewables: 1.4%
- Other Biomass Renewables: 0.8%
- Coal: 22.6%
- Oil: 35.1%

Population: 6.102 billion
Total energy use: 10.2 Gtoe
Per capita energy consumption: 1.67 toe

World Energy Assessment, 2004
More than 75% of households

50-74% of households

2000 Census
Woodsmoke is natural – how can it hurt you?

Or, since wood is mainly just carbon, hydrogen, and oxygen, doesn’t it just change to CO₂ and H₂O 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, NO₂
- Hydrocarbons
  - 25+ saturated hydrocarbons such as \textit{n-hexane}
  - 40+ unsaturated hydrocarbons such as \textit{1,3 butadiene}
  - 28+ mono-aromatics such as \textit{benzene} \& \textit{styrene}
  - 20+ polycyclic aromatics such as \textit{benzo(\alpha)pyrene}
- Oxygenated organics
  - 20+ aldehydes including \textit{formaldehyde} \& \textit{acrolein}
  - 25+ alcohols and acids such as \textit{methanol}
  - 33+ phenols such as \textit{catechol} \& \textit{cresol}
  - Many quinones such as \textit{hydroquinone}
  - Semi-quinone-type and other radicals
- Chlorinated organics such as \textit{methylene chloride} and \textit{dioxin}

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

Typical Health-based Standards

- Carbon Monoxide: 150 mg/m³
  - 10 mg/m³

- Particles: 3.3 mg/m³
  - 0.1 mg/m³

Wood: 1.0 kg Per Hour in 15 ACH 40 m³ kitchen

Typical Indoor Concentrations

- Benzene: 0.8 mg/m³
  - 0.002 mg/m³

- 1,3-Butadiene: 0.15 mg/m³
  - 0.0003 mg/m³

- Formaldehyde: 0.7 mg/m³
  - 0.1 mg/m³

Best single indicator

IARC Group 1 Carcinogens

IARC Group 1 Carcinogens
<table>
<thead>
<tr>
<th>Location</th>
<th>Region</th>
<th>Number of households</th>
<th>Range (24 hour average of PM 10)</th>
<th>Mean (µg/m³) (24 hr average of Kitchen &amp; Living Concentrations of PM10)</th>
<th>Other Determinants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tamil Nadu</td>
<td>South</td>
<td>4</td>
<td>110-410</td>
<td>223</td>
<td>Fuel/Kitchen/Stove</td>
</tr>
<tr>
<td>Andhra Pradesh</td>
<td>South</td>
<td>3</td>
<td>115-980</td>
<td>485</td>
<td>Fuel/Kitchen</td>
</tr>
<tr>
<td>Karnataka</td>
<td>South</td>
<td>3</td>
<td>608-1443</td>
<td>898</td>
<td>Fuel/Stove</td>
</tr>
<tr>
<td>Madhya Pradesh</td>
<td>West/Central</td>
<td>7</td>
<td>280-3300</td>
<td>690</td>
<td>Fuel/Kitchen</td>
</tr>
<tr>
<td>Gujarat</td>
<td>West</td>
<td>6</td>
<td>489-1530</td>
<td>780</td>
<td>Fuel/Kitchen</td>
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<tr>
<td>Goa</td>
<td>West</td>
<td>1</td>
<td>450-978</td>
<td>635</td>
<td>Fuel/Kitchen</td>
</tr>
<tr>
<td>West Bengal</td>
<td>East/North East</td>
<td>9</td>
<td>270-2240</td>
<td>795</td>
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<tr>
<td>Haryana</td>
<td>North</td>
<td>1</td>
<td></td>
<td>850</td>
<td>Fuel/Kitchen</td>
</tr>
<tr>
<td>Uttarakhand</td>
<td>North/Mountain</td>
<td>76</td>
<td>270-2240</td>
<td>620</td>
<td>Fuel/Kitchen</td>
</tr>
</tbody>
</table>

WHO Global Air Quality Guideline for Indoor/Outdoor particle Levels

20 µg/m³

Absolutely no population even in the poorest countries should be exposed to more than

70 µg/3
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

### India Data

<table>
<thead>
<tr>
<th>Source</th>
<th>CO</th>
<th>Hydrocarbons</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biogas</td>
<td>0.1</td>
<td>0.3</td>
<td>2.5</td>
</tr>
<tr>
<td>LPG</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Kerosene</td>
<td>3.0</td>
<td>4.2</td>
<td>1.3</td>
</tr>
<tr>
<td>Wood</td>
<td>19</td>
<td>17</td>
<td>26</td>
</tr>
<tr>
<td>Roots</td>
<td>22</td>
<td>18</td>
<td>30</td>
</tr>
<tr>
<td>Crop Residues</td>
<td>60</td>
<td>32</td>
<td>124</td>
</tr>
<tr>
<td>Dung</td>
<td>64</td>
<td>115</td>
<td>63</td>
</tr>
</tbody>
</table>

Smith, et al., 2005

### Clean vs. Dirty

- **CO**: 0.1, 1.0, 3.0, 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

*Note: The chart visualizes the relative emissions of CO, Hydrocarbons, and PM for different energy sources*
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.
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

- Exposure Levels: Past actual and past counterfactual
- Exposure-response Relationships (risk)
- Disease Burden by age, sex, and region
- Attributable Burden by age, sex, and region
National Household Solid Fuel Use, 2000

Being updated – now more than 300 nationally representative household surveys available
Diseases for which we have studies showing links to household solid fuel use:

- ALRI/Pneumonia (meningitis)
- Chronic obstructive lung disease
- Interstitial lung disease
- Cancer (lung, NP, cervical, aero-digestive)
- Blindness (cataracts, trachoma)
- Tuberculosis
- Heart disease?

Other health issues:

- Low birth weight & stillbirth
- Asthma?
- Early infant Death?
- Cognitive Effects (lower IQ)?
- Birth defects?; cleft
- Fire-related deaths and burns
ALRI/ Pneumonia (meningitis)  

Diseases for which we have studies showing links to household solid fuel use  

Chronic obstructive lung disease  

Only two qualified with sufficient evidence to be included in the original WHO Comparative Risk Assessment – 2004  

More to be added in the update, slated for 2010
Fire-related deaths in India in 2001: a retrospective analysis of data

Prachi Sanghavi, Kavi Bhalla, Veena Das

Summary
Background Hospital-based studies have suggested that fire-related deaths might be a neglected public-health issue in India. However, no national estimates of these deaths exist and the only numbers reported in published literature come from the Indian police. We combined multiple health datasets to assess the extent of the problem.

Methods We computed age–sex-specific fire-related mortality fractions nationally using a death registration system based on medically certified causes of death in urban areas and a verbal autopsy based sample survey for rural populations. We combined these data with all-cause mortality estimates based on the sample registration system and the population census. We adjusted for ill-defined injury categories that might contain misclassified fire-related deaths, and estimated the proportion of suicides due to self-immolation when deaths were reported by external causes.

Findings We estimated over 163,000 fire-related deaths in 2001 in India, which is about 3% of all deaths. This number was six times that reported by police. About 106,000 of these deaths occurred in women, mostly between 15 and 34 years of age. This age–sex pattern was consistent across multiple local studies, and the average ratio of fire-related deaths of young women to young men was 3:1.

Interpretation The high frequency of fire-related deaths in young women suggests that these deaths share common causes, including kitchen accidents, self-immolation, and different forms of domestic violence. Identification of populations at risk and description of structural determinants from existing data sources are urgently needed so that interventions can be rapidly implemented.

Funding None.
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

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

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

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

- Underweight
- Unsafe sex
- Blood pressure
- Tobacco
- Alcohol
- Unsafe water/sanitation-E*
- Child cluster vaccination
- Road traffic accidents
- Cholesterol
- Indoor smoke-E
- Overweight
- Low fruit and veg
- Occupational (5 kinds)-E
- Lead (Pb)-E
- Urban outdoor air-E
- Climate change-E

Percent of All DALYs in 2000

- 4.9 million premature deaths/y
- 1.6 million premature deaths/y
  (~1 million in children under 5 y)
Burden of Disease in Sub-Saharan Africa from Top 10 Risk Factors and Selected Other Risk Factors

- Unsafe sex
- Underweight
- Lack of Malaria control*
- Unsafe water/sanitation
- Childhood cluster*
- Vitamin A deficiency
- Zinc deficiency
- Indoor smoke from solid fuels
- Iron deficiency
- Alcohol
- Road traffic accidents*
- Blood pressure
- Tobacco
- Climate change
- Occupational hazards (5 types)
- Lead (Pb) pollution
- Urban outdoor air pollution

In Smith et al., 2005. Derived from WHO data
Problems with all Previous ALRI and IAP Studies

• Studies were all observational and thus not able to be sure the effect was not due just to poverty and not air pollution.
• Too much confusion with upper respiratory infections
• Little or no exposure assessment.
• Solution is a
  – Randomized control trial (RCT) in which half households receive improved stove on a random basis at the start, other keep open fires until end
  – Much better diagnosis of disease
  – Full exposure assessment
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 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)

Highland Guatemala

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

Randomize

Keep open fire

Plancha

Follow up till aged 18 months
- Surveillance for ALRI, diarrhoea, &c
- Detailed exposure monitoring

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

Year 1
5500 Households total

Years
1-3

Years
3-4
### Randomisation: balance of groups at baseline

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

Follow-up at weekly visit

Home

Weekly visit
- Well
- Mild illness
- Referral to study doctor

Child dies

Verbal autopsy

Community centre

Study doctor examines
- Pulse oximetry
- If pneumonia, RSV* test and refer for CXR
- Refer if very ill

Health outcome definitions

Hospital

Assessed by duty doctor
Study team obtain CXR and inpatient data and diagnosis

Child dies

Verbal autopsy

* Respiratory syncitial virus
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 (+ 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)
Pneumonia by month and RSV status
Unpublished results from RESPIRE have been removed.

Watch the website below where they will be posted as soon as they are published.

http://ehs.sph.berkeley.edu/krsmith

Regrets/KR Smith
What a Well-Operating Chimney Does

McCracken, et al., 2009
Effect of Plancha on PM2.5

- Open fire: ~90% Reduction, sig.
- Plancha: ~20% reduction, ns

Log Scale

48-h ug/m³

Kitchen
Reasons that child personal exposures did not lower as much as kitchen levels:

--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

--Other burning around house not different
Neighborhood Pollution

Highland Guatemala
Friday, Feb 20, 2004
~6:15 AM
Neighborhood Pollution in an Indian Village

Smith, 1987
Large areas of rural India and China have high ambient air pollution – much from household fuel.
### China National Stove Contest - 2007

#### Efficiency

<table>
<thead>
<tr>
<th></th>
<th>CO/CO₂</th>
<th>PM g/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal#</td>
<td>0.12</td>
<td>1.6</td>
</tr>
<tr>
<td>Traditional Biomass</td>
<td>0.13</td>
<td>4.0</td>
</tr>
<tr>
<td>Biomass Stove Contest Winners</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daxu</td>
<td>0.020</td>
<td>0.28</td>
</tr>
<tr>
<td>Jinqilin</td>
<td>0.014*</td>
<td>0.20</td>
</tr>
<tr>
<td>Xintai</td>
<td>0.025</td>
<td>0.36</td>
</tr>
<tr>
<td>Zhenghong</td>
<td>0.019</td>
<td>0.24</td>
</tr>
</tbody>
</table>

Compared to traditional biomass stove:

28.7 g to 1.2 g small particles/meal >20x less

# Zhang, et al., 2000

*Not including water heating function
Why M&E?
You don’t get what you expect, but what you inspect

Abandoned improved stove, Guatemala

Misplaced self-polluting chimney, Guatemala
Standard Methods are too slow, too imprecise, too labor intensive, and too expensive for use with millions of stoves.

**Fuel savings** estimation through KPT (kitchen performance test) and sales records

**Tracking drop out rates** through surveys, visits and phone interviews

**Monitoring reductions in indoor air pollution and black carbon emissions**
What can be done?

Where can we monitor what we do?

Smith, 1983

Small, Smart, Fast, and Cheap monitors
Available or under testing

Smith, 1983

Figure 1.8. Categorization and flowchart of separate topics involved in investigating the extent and impact of air pollution exposures from combustion of biofuels in developing countries. Modified from Smith et al. (1983).
UCB-SUMS: The Stove Use Monitoring System

**Fuel savings quantification using the SUMS system**

**Monitoring drop out rates and patterns of use with the SUMS system**
Objective Monitoring with the UCB-SUMS System

Ruiz et al., 2008

Continuous Information of Stove Use:
Sensor-data provide a complete record of how this improved stove was only used during the first 2 days of monitoring.
Measuring Adoption Dynamics with the UCB-SUMS

Population Level Information:
Each point is the average hours for a population of 40 households that a stove is used each day.

Data from the CRECER Guatemala Study

Ruiz et al., 2008
Transition from open fire to a new Plancha stove

Ruiz et al., 2008
Measure of fuel use
IN MEMORIAM
119 Nancy Tait, Henri Pezerat

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143 Reducing the Incidence of Acute Pesticide Poisoning by Educating Farmers on Integrated Pest Management in South India
152 Components of Particulate Air Pollution and Mortality in Chile
166 Mesothelioma Risk and Environmental Exposure to Asbestos: Past and Future Trends in Japan
173 Hospital Staff Responses to Workplace Violence in a Psychiatric Hospital in Taiwan
Measuring Personal Exposure to PM2.5 from Woodsmoke with the UCB-Particle Monitor and the UCB-Personal Locator

[Graph showing PM2.5 concentrations over time with markers for kitchen and mother's presence.]

Locator – tells who is in kitchen
SSFC Monitors

• Available from Berkeley Air
  – UCB-PATS: particles and temperature
  – UCB-SUMS: stove use – (May, 2009)

• Active field testing
  – UCB-TAMS: time-activity
  – UCB-FUMS: fuel-use

• Under development
  – UC-BEMS: black-carbon emissions
  – UCB-PEMS: particle emissions
Bottom lines

• Health effects information is growing – more diseases and age groups

• RESPIRE provides first serious exposure-response data for one major endpoint – child pneumonia (ALRI)
  – Consistent with outdoor air pollution studies
  – Non-linear at higher levels

• Chimneys alone do not seem to reduce exposures down to levels sufficient to fully protect health

• Need to move to low-emission stoves ASAP

• M&E is vital, but new methods needed for interventions measured in 10s of millions of households
Worldwide population of households using primarily coal and/or biomass stoves: ~500 million (half world population)
On behalf of all my colleagues and students

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/