Carcinogenicity of household solid fuel combustion and of high-temperature frying

Kurt Straif, Robert Baan, Yann Grosse, Béatrice Secretan, Fatiha El Ghissassi, Vincent Cogliano, on behalf of the WHO International Agency for Research on Cancer Monograph Working Group

In October, 2006, 19 scientists from eight countries met at the International Agency for Research on Cancer (IARC) in Lyon, France, to assess the carcinogenicity of household solid fuel combustion (coal and biomass) and of high-temperature frying. These assessments will be published as volume 95 of the IARC Monographs.[1]

About half of the world's population, mostly in low-resource and medium-resource countries, use solid fuels for cooking or heating, often in poorly ventilated spaces.[2] WHO identified indoor smoke from combustion of solid fuels as one of the top ten risks for worldwide burden of disease.[3] Products of incomplete combustion contain respirable (coarse, fine, and ultrafine) particles and many volatile and non-volatile organic compounds, including carcinogens such as benzo[*a*]pyrene, formaldehyde, and benzene. Average indoor concentrations of particulate matter (<10 μm) can be as high as several milligrams per cubic metre, with peak concentrations an order of magnitude higher.[4] Women and young children who are at home for most of the day are most highly exposed.

Although occupational exposure to the combustion products of coal by inhalation is known to cause lung cancer,[5] many studies, mostly from China, now show similar effects from household use of coal. The problem was first noted in the county of Xuan Wei, China,[6] where the type of coal used produces especially smoky emissions. Two case–control studies from Xuan Wei reported a positive exposure–response relationship between the amount of coal used and the risk of lung cancer. Subsequently, a cohort intervention study[7] showed transition to the use of a stove with a chimney from one without reduced this risk. A large study[8] in Shenyang, China, noted positive exposure–response associations for different measures of exposure to coal smoke—including a cumulative index of indoor exposure—after adjusting for smoking and education. Furthermore, a study[9] of non-smoking women in Harbin, China, reported a strong exposure–response relationship between years of use of a coal stove and lung cancer. Case–control studies from Taiwan[10] and the USA[11] have also reported a twofold-increased risk for lung cancer as a result of coal-smoke inhalation after adjusting for potential confounders.

In experiments with animals, inhalation of emissions from coal, burned under conditions similar to those in Xuan Wei, increased the incidence of various types of malignant lung tumours in male and female Kunming mice and of squamous-cell carcinomas in male and female Wistar rats.[12] In another study,[13] the incidence of adenocarcinoma of the lung was increased in male and female Kunming mice exposed to combustion emissions of coal obtained from Harbin.

On the basis of sufficient evidence in both humans and experimental animals, the Working Group concluded that indoor emissions from household combustion of coal are "carcinogenic to humans (Group 1)".[14] Mechanistic data from studies of humans and animals are consistent with this conclusion.[15]

Biomass fuel is much more widely used than coal but the adverse health effects have been studied less. In Taiwan, women who burned wood for cooking had a threefold increase in the risk of lung cancer after adjusting for potential confounders.[9] Additionally, a large multicentre European case–control study[16] recorded an adjusted 20–30% increased risk of lung cancer in people who burned wood but not coal, compared with people who never used coal or wood for cooking or heating. Studies in Japan[17] and Mexico[18] also found an increased risk of lung cancer in non-smoking women, which was related to their exposure to smoke from wood or straw. These studies suggest that exposure to smoke from wood combustion is associated with an increased risk of lung cancer; however, the results on exposure duration and intensity are difficult to interpret.

In animal experiments, exposure to emissions from wood, burned under conditions similar to those in Xuan Wei, increased the incidence of lung adenocarcinomas in male and female Kunming mice, but not in Wistar rats.[12] Extracts from wood smoke, applied to the skin or given subcutaneously, produced cancer in mice and rats.

Combustion emissions from wood are mutagenic because of the presence of compounds from various chemical classes, including polycyclic aromatic hydrocarbons and acidic or polar substances.[19,20] Molecular data, which include changes in expression and phosphorylation of P53 in patients with lung cancer who were exposed to wood smoke,[21] and systemic genotoxicity in charcoal workers[22] and in women who burn cow dung or wood,[23] supports evidence of carcinogenicity of emissions from burning wood.

On the basis of limited evidence of carcinogenicity of biomass combustion emissions (mainly from wood) in humans and experimental animals; sufficient evidence of carcinogenicity of wood-smoke extracts in experimental animals; and strong evidence of mutagenicity,

Upcoming meetings

Feb 6–13, 2007
Alcoholic beverage consumption, acetaldehyde, and urethane

June 5–12, 2007
1,3-butadiene, ethylene oxide and vinyl halides (vinyl fluoride, vinyl chloride and vinyl bromide)

http://monographs.iarc.fr/

the Working Group concluded that indoor emissions from household combustion of biomass fuel (mainly wood) are "probably carcinogenic to humans (Group 2A)".[14]

Stir-frying, deep-frying, and pan-frying, which involve heating oil to high temperatures, are practiced worldwide, especially in China. A study from Hong Kong[24] estimated the total number of dishes prepared by these frying methods and showed a significant increase in the risk of lung cancer associated with moderate or high frequency of frying. In two other studies from Shanghai,[25,26] the risk of lung cancer was increased by stir-frying, deep-frying, or pan-frying. In a study in Gansu,[27] although the risk of lung cancer increased significantly with increasing frequency of stir-frying, it did not increase with deep-frying. However, potentially confounding factors, such as combustion of solid cooking fuels, can not be ruled out in the latter three studies. No consistent differences in risk patterns emerged with regard to the effects of the different types of frying or the use of a specific type of cooking oil.

Two experiments with animals investigated the carcinogenicity of emissions from rapeseed oil heated to high temperatures (>260°C), and showed the incidence of lung carcinoma (mainly adenocarcinoma) increased in mice[28] and rats.[29] The exposure–response relationship was significant in male and female mice, in female rats, but not in male rats.

Positive results for mutagenicity of emissions from various cooking oils heated to high temperatures (>240°C) were recorded in almost every category of an in-vivo-rodent assay.[30] Mechanistic data show the probable involvement of peroxidation products of polyunsaturated fatty acids;[31,32] however, the involvement of polycyclic aromatic hydrocarbons, which have also been detected in cooking oil emissions, cannot be discounted.

On the basis of limited evidence in humans and sufficient evidence in experimental animals, the Working Group concluded that emissions from high-temperature frying are "probably carcinogenic to humans (Group 2A)".[14]

The IARC authors declare no conflicts of interest.

Monograph Working Group
Members
K Smith – *Chair* (USA); G Chen, P White (Canada); Y-T Gao, IT Yu (China); J Sinton (France); K Balakrishnan (India); I Romieu (Mexico); RS Chapman (Thailand, unable to attend); N Bruce (UK); D Barnes, J Bond, D DeMarini, Q Lan, J Lewtas, MD Reed, L Wallace, A Wu, J Zhang (USA)

Conflicts of interest
Before 2005, K Smith received research support from the World Liquid Petroleum Gas Association, which promotes the use of liquid petroleum gas. Before 2005, MD Reed's employer received funding from the Hearth, Patio and Barbecue Association, which promotes the interests of the hearth products industry in North America. All other members of the Working Group declare no conflicts of interest.

Invited Specialist
M Sen (USA)

Conflicts of interest
M Sen declares no conflicts of interest

Representatives of health agencies
O Hänninen (WHO European Centre for Environment and Health, Germany); E Rehfuess (WHO, Sustainable Development and Healthy Environments, Switzerland)

Observers
None

1 IARC. IARC monographs on the evaluation of carcinogenic risks to humans. Volume 95. Household use of solid fuels and high-temperature frying. Lyon: International Agency for Research on Cancer (in press).
2 Rehfuess E, Mehta S, Prüss-Üstün A. Assessing household solid fuel use: multiple implications for the Millenium Development Goals. *Environ Health Perspect* 2006; **114:** 373–78.
3 Ezzati M, Rodgers A, Lopez AD, et al. Mortality and burden of disease attributable to individual risk factors. In: Ezzati M, Lopez AD, Rodgers A, Murray CJL, eds. Comparative quantification of health risks. Global and regional burden of disease attributable to selected major risk factors. Volume 2. Geneva: World Health Organisation, 2004: 2141–66.
4 Smith KR. Indoor air pollution and exposure database: household measurements in developing countries. http://ehs.sph.berkeley.edu/hem/page.asp?id=33 (accessed Nov 8, 2006).
5 IARC. IARC monographs on the evaluation of carcinogenic risks to humans. Supplement 7. Overall evaluations of carcinogenicity: an updating of IARC monographs volumes 1 to 42. Lyon: International Agency for Research on Cancer, 1987.
6 Mumford JL, He XZ, Chapman RS, et al. Lung cancer and indoor air pollution in Xuan Wei, China. Science 1987; **235:** 217–20.
7 Lan Q, Chapman RS, Schreinemachers DM, et al. Household stove improvement and risk of lung cancer in Xuanwei, China. *J Natl Cancer Inst* 2002; **94:** 826–35.
8 Xu ZY, Blot WJ, Xiao HP, et al. Smoking, air pollution, and the high rates of lung cancer in Shenyang, China. *J Natl Cancer Inst* 1989; **81:** 1800–06.
9 Dai XD, Lin CY, Sun XW, et al. The etiology of lung cancer in nonsmoking females in Harbin, China. *Lung Cancer* 1996; **14** (suppl 1)**:** S85–91.
10 Lee CH, Ko YC, Cheng LS-C, et al. The heterogeneity in risk factors of lung cancer and the difference of histologic distribution between genders in Taiwan. *Cancer Causes Control* 2001; **12:** 289–300.
11 Wu AH, Hendersosn BE, Pike MC, et al. Smoking and other risk factors for lung cancer in women. *J Natl Cancer Inst* 1985; **74:** 747–51.
12 Liang CK, Quan NY, Cao SR, et al. Natural inhalation exposure to coal smoke and wood smoke induces lung cancer in mice and rats. *Biomed Environ Sci* 1988; **1:** 42–50.
13 Lin C, Dai X, Sun X, et al. [Expression of oncogene and anti-oncogene in mouse lung cancer induced by coal burning smoke.] *Zhonghua Zhong Liu Za Zhi* 1995; **17:** 432–33. (in Chinese)
14 IARC. IARC monographs on the evaluation of carcinogenic risks to humans. Preamble. Lyon, France: International Agency for Research on Cancer, 2006.
15 DeMarini DM, Landi S, Tian D, et al. Lung tumor *KRAS* and *TP53* mutations in nonsmokers reflect exposure to PAH-rich coal combustion emissions. *Cancer Res* 2001; **61:** 6679–81.
16 Lissowska J, Bardin-Mikolajczak A, Fletcher T, et al. Lung cancer and indoor pollution from heating and cooking with solid fuels: the IARC international multicentre case-control study in Eastern/Central Europe and the United Kingdom. *Am J Epidemiol* 2005; **162:** 326–33.
17 Sobue T, Suzuki T, Nakayama N, et al. [Association of indoor air pollution and passive smoking with lung cancer in Osaka Japan.] *Gan No Rinsho* 1990; **Spec No:** 329–33. (in Japanese)
18 Hernández-Garduño E, Brauer M, Pérez-Neria J, et al. Wood smoke exposure and lung adenocarcinoma in non-smoking Mexican women. *Int J Tuberc Lung Dis* 2004; **8:** 377–83.
19 Kamens R, Bell D, Dietrich A, et al. Mutagenic transformations of dilute wood smoke systems in the presence of ozone and nitrogen dioxide. Analysis of selected high-pressure liquid chromatography fractions from wood smoke particle extracts. *Environ Sci Technol* 1985; **19:** 63–69.
20 Bell DA, Karam H, Kamens RM. Nonaqueous ion-exchange separation technique for use in bioassay-directed fractionation of complex mixtures: application to wood smoke particle extracts. *Environ Sci Technol* 1990; **24:** 1261–64.
21 Delgado J, Martinez LM, Sanchez TT, et al. Lung cancer pathogenesis associated with wood smoke exposure. *Chest* 2005; **128:** 124–31.
22 Kato M, Loomis D, Brooks LM, et al. Urinary biomarkers in charcoal workers exposed to wood smoke in Bahia state, Brazil. *Cancer Epidemiol Biomarkers Prev* 2004; **13:** 1005–12.
23 Musthapa MS, Lohani M, Tiwari S, et al. Cytogenetic biomonitoring of Indian women cooking with biofuels: micronucleus and chromosomal aberration tests in peripheral blood lymphocytes. *Environ Mol Mutagen* 2004; **43:** 243–49.
24 Yu IT, Chiu YL, Au JS, et al. Dose–response relationship between cooking fumes exposures and lung cancer among Chinese nonsmoking women. *Cancer Res* 2006; **66:** 4961–67
25 Gao YT, Blot WJ, Zheng W, et al. Lung cancer among Chinese women. *Int J Cancer* 1987; **40:** 604–09.
26 Zhong L, Goldberg MS, Gao YT, et al. A case–control study of lung cancer and environmental tobacco smoke among nonsmoking women living in Shanghai, China. *Cancer Causes Control* 1999; **10:** 607–16.
27 Metayer C, Wang Z, Kleinerman RA, et al. Cooking oil fumes and risk of lung cancer in women in rural Gansu, China. *Lung Cancer* 2002; **35:** 111–17.
28 Zhang ZH, Chen F, Tan YM, *et al.* [Pulmonary carcinoma pathological change caused by COF in Balb/c mouse.] *Chin J Public Health* 2003; **19:** 1455–57. (in Chinese)
29 Long LL, Chen F, He XP, et al. [Experimental study on lung cancer induced by cooking oil fumes in SD rats.] *J Environ Health* 2005; **22:** 114–16. (in Chinese)
30 Chen H, Yang M, Ye S. A study on genotoxicity of cooking fumes from rapeseed oil. *Biomed Environ Sci* 1992; **5:** 229–35.
31 Chang LW, Lo WS, Lin P. *Trans,Trans*-2,4-Decadienal, a product found in cooking oil fumes, induces cell proliferation and cytokine production due to reactive oxygen species in human bronchial epithelial cells. *Toxicol Sci* 2005; **87:** 337–43.
32 Dung CH, Wu SC, Yen GC. Genotoxicity and oxidative stress of the mutagenic compounds formed in fumes of heated soybean oil, sunflower oil and lard. *Toxicol In Vitro* 2006; **20:** 439–47.