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Indoor Air - Assessment

Indoor Concentrations of Environmental Carcinogens

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INDOOR AIR — ASSESSMENT

INDOOR CONCENTRATIONS OF ENVIRONMENTAL CARCINOGENS

Environmental Criteria and Assessment Office
Office of Health and Environmental Assessment
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

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PREFACE

In October 1986, Congress passed the Superfund Amendments and Reauthorization Act (SARA, PL 99-499) that includes Title IV—The Radon Gas and Indoor Air Quality Research Act. The Reauthorization Act directs EPA to undertake a comprehensive indoor air research program.

Research program requirements under Superfund Title IV are specific. They include identifying, characterizing, and monitoring (measuring) the sources and levels of indoor air pollution, developing instruments for indoor air quality data collection, and studying high-risk building types. The statute also requires research directed at identifying effects of indoor air pollution on human health. In the area of mitigation and control, the following are required: development of measures to prevent or abate indoor air pollution, demonstration of methods to reduce or eliminate indoor air pollution, development of methods to assess the potential for contamination of new construction from soil gas, and examination of design measures for preventing indoor air pollution. EPA's indoor air research program is designed to be responsive in every way to the legislation.

In responding to the requirements of Title IV of the Superfund Amendments, EPA-ORD has organized the Indoor Air Research Program around the following five categories of research: (1) sources of indoor air pollution, (2) building diagnosis and measurement methods, (3) health effects, (4) exposure and risk (Health Impact) assessment, and (5) building systems and indoor air quality control options.

EPA is directed to undertake this comprehensive research and development effort not only through in-house work, but also in coordination with other Federal agencies, state and local governments, and private sector organizations having an interest in indoor air pollution.

The ultimate goal of SARA Title IV is the dissemination of information to the public. This activity includes the publication of scientific and technical reports in the areas described above. To support these research activities and other interests as well, EPA publishes its results in the INDOOR AIR report series. This series consists of five subject categories: Sources, Measurement, Health, Assessment, and Control. Each report is printed in a limited quantity. Copies may be ordered while supplies last from:

U.S. Environmental Protection Agency
Center for Environmental Research Information
26 West Martin Luther King Drive
Cincinnati, OH 45268

When EPA supplies are depleted, copies may be ordered from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

ABSTRACT

In this report, indoor concentration data are presented for the following general categories of air pollutants: radon-222, environmental tobacco smoke (ETS), asbestos, gas phase organic compounds, formaldehyde, polycyclic aromatic hydrocarbons (PAH), pesticides, and inorganic compounds. These pollutants are either known or suspect carcinogens (i.e., radon-222 and asbestos) or more complex mixtures or classes of compounds that contain known or suspect carcinogens.

Concentration data for individual carcinogenic compounds in complex mixtures are usually far from complete. The data presented for complex mixtures often include compounds that are not carcinogenic or for which data are insufficient to evaluate carcinogenicity. Their inclusion is justified, however, by the possibility that further work may show them to be carcinogens, cocarcinogens, initiators or promotors, or that they may be employed as markers (e.g., nicotine, acrolein) for the estimation of exposure to complex mixtures.

This report is the fourth in a series of EPA/Environmental Criteria and Assessment Office Monographs. The series includes the following titles:

I. DEVELOPMENT OF A RISK CHARACTERIZATION FRAMEWORK

II. A REVIEW OF INDOOR AIR QUALITY RISK CHARACTERIZATION STUDIES

III. USE OF BENZENE MEASUREMENT DATA IN RISK CHARACTERIZATION ESTIMATES: A PRELIMINARY APPROACH

IV. INDOOR CONCENTRATIONS OF ENVIRONMENTAL CARCINOGENS

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INTRODUCTION

In this report, indoor concentration data are presented for the following general categories of air pollutants: radon-222, environmental tobacco smoke (ETS), asbestos, gas phase organic compounds, formaldehyde, polycyclic aromatic hydrocarbons (PAH), pesticides, and inorganic compounds. These pollutants are either known or suspect carcinogens (i.e., radon-222 and asbestos) or more complex mixtures or classes of compounds that contain known or suspect carcinogens.

Concentration data for individual carcinogenic compounds in complex mixtures are usually far from complete. The data presented for complex mixtures often include compounds that are not carcinogenic or for which data are insufficient to evaluate carcinogenicity. Their inclusion is justified, however, by the possibility that further work may show them to be carcinogens, cocarcinogens, initiators or promoters, or that they may be employed as markers (e.g., nicotine, acrolein) for the estimation of exposure to complex mixtures.

RADON

Average outdoor ground-level radon-222 concentrations have been estimated to be in the order of 5 to 10 Bq/m^3 (about 0.15 to 0.30 pCi/L), with concentrations over uranium ore-grade soil typically between 20 to 40 Bq/m^3 (Eichholz, 1987; Nazaroff and Nero, 1988). For the general population, the radiation dose to the lung from inhaled radon-222 daughters comprises about half the total dose equivalent to that received from natural radioactivity. The most important source of this exposure is the residential dwelling.

Over the past decade, major research efforts have been undertaken in several European countries, Canada, and the United States to assess the sources, levels, and risks of indoor radon-222 exposures and to develop appropriate control measures. The indoor measurement studies have focused primarily on residential dwellings and have generated a substantial data base of indoor radon-222 concentrations from which exposure estimates and risk assessments can be developed. These studies have often differed greatly in design, scope, measurement methods employed, and objectives. However, two significant findings have been recurrent: (1) radon-222 concentrations inside residences are routinely much higher than outdoor levels, and (2) indoor concentrations in individual homes are sometimes an order of magnitude or more above the average, with radon-222 concentrations in the range of 200 to 2000 Bq/m^3 occurring with surprising frequency (Nazaroff and Nero, 1988).

Figure 1 shows the frequency distributions of indoor (residential) radon-222 concentrations based on large surveys conducted in Canada (Letourneau et al., 1984; McGregor at al., 1980), the Federal Republic of Germany (Federal Republic of Germany Ministry of the Interior, 1986; Schmier and Wicke, 1985), Italy (Sciocchetti et al., 1985), the Netherlands (Put et al., 1985), Scandinavia (Finland, Norway, Sweden) (Castren et al., 1984, 1985; Stranden, 1986; Swedjemark and Mjones, 1984a), the United Kingdom (Green et al., 1985; Wrixon and O'Riordan, 1985; Wrixon et al., 1984), and the United States (Nero et al., 1986). In all cases, the measured frequency distribution of indoor radon-222 concentrations approximates a log-normal distribution. Except for the Scandinavian countries, these frequency distributions indicate mean and median indoor radon-222 concentrations of 30-60 Bq/m^3 and 15-50 Bq/m^3, respectively. (The combined frequency

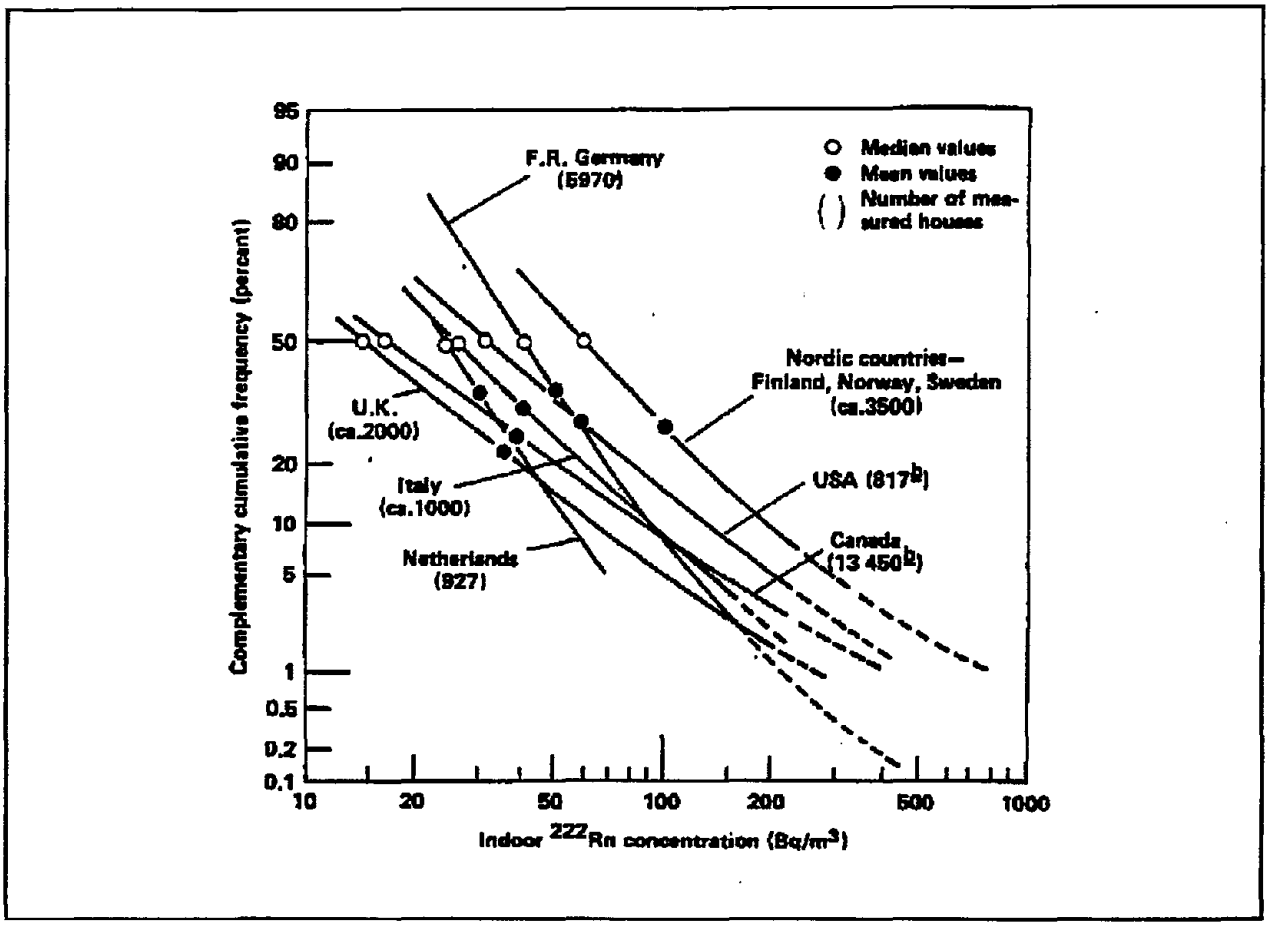

Figure 1. Complementary cumulative frequency distribution of the ^{222}Rn concentration in dwellings.[a]

[a]Source: International Commission on Radiological Protection (1987)
[b]Single family houses only

distribution for Finland, Norway, and Sweden yields mean and median indoor radon-222 concentrations of 100 Bq/m^3 and 60 Bq/m^3, respectively.) Based on a mean equilibrium factor in which F = 0.45 for radon-222 daughters in indoor air, the mean concentration of radon-222 daughters has been estimated to be in the range 9-30 Bq/m^3 (International Commission on Radiological Protection, 1987). Table 1 provides a more complete summary of several radon-222 surveys conducted in various countries.

Many countries have been found to have geographical areas or housing types in which indoor radon-222 concentrations are much higher than the average. In Sweden elevated levels have been associated with the use of alum shale concrete building materials in houses

TABLE 1. SUMMARY OF RADON-222 AND DAUGHTER (RnD) CONCENTRATIONS IN VARIOUS COUNTRIES[a]

Country	No. of homes monitored	Type	Concentration (Bq/m³) GM	Concentration (Bq/m³) AM	GSD or % of tail	Notes	Reference
U.S.	817	Single-family	33	55	2.8	Aggregated 22 data sets adjusting to annual average	Nero et al. (1986)
	453		38	54	2.36	Non-representative sampling: 100 geographical locations	Cohen (1986)
Canada	13,436	Single-family	17		2.7	Median values from 19 city surveys; mostly basement values; EEDC converted assuming equil. factor = 0.5	McGregor et al. (1980)
Sweden[b,c]	500	Detached (315)	69	122	10% > 266 Bq/m³ 2% > 800 Bq/m³	Built before 1975; representative sampling	Swedjemark and Mjones (1984a)
		Apartments (191)	53	85	10% > 187 Bq/m³ 0.5% > 800 Bq/m³		
	96	Detached		59	10% > 140 Bq/m³ (max. 280 Bq/m³)	Built between 1978 and 1980; representative sampling	Swedjemark and Mjones (1984b)
	50,367	Multi- and single-family homes			7% > 70 RnD Bq/m³ 34% > 200 RnD Bq/m³ 10% > 400 RnD Bq/m³ 2% > 800 RnD Bq/m³ 0.5% > 2,000 RnD Bq/m³	Suspect buildings built before 1981; maximum annual average 18,000 RnD Bq/m³	Swedjemark (1987)

TABLE 1 (cont'd). SUMMARY OF RADON-222 AND DAUGHTER (RnD) CONCENTRATIONS IN VARIOUS COUNTRIES[a]

Country	No. of homes monitored	Type	Concentration (Bg/m³) GM	Concentration (Bg/m³) AM	GSD or % of tail	Notes	Reference
Sweden[b,c] (cont'd)	1,165	Multi- and single-family - conventional construction (383)	81 RnD		20% > 70 RnD Bq/m³ 2.6% > 400 RnD Bq/m³	Suspect buildings built after 1981	Swedjemark (1987)
		- Rn-safe construction (782)	30 RnD		6% > 70 RnD Bq/m³ 0.5% > 400 RnD Bq/m³		
Denmark	22	Single-family flats		70 82		Preliminary surveys; average winter and summer means	Sorensen et al. (1985)
Finland	4,500	Small houses	90		1.4% > 800 Bq/m³	Stratified random sampling; strong geographical dependence	Castren et al. (1987)
Norway	1,500	All types, except blocks of flats		160	1% > 800 Bq/m³	Population weighted average of 110 Bq/m³ in heating season	Stranden (1987)
FRG	6,000		40	49	1.8		Keller and Folkerts (1984)
Netherlands	1,000		24		1.6	High levels show excess above lognormal	Put and De Meijer (1985)

TABLE 1 (cont'd). SUMMARY OF RADON-222 AND DAUGHTER (RnD) CONCENTRATIONS IN VARIOUS COUNTRIES[a]

Country	No. of homes monitored	Type	Concentration (Bg/m³) GM	Concentration (Bg/m³) AM	GSD or % of tail	Notes	Reference
Belgium	79		41		1.7	Preliminary national survey	Poffijn et al. (1985)
France	765		44	76	2% > 200 Bq/m³	Incomplete national survey	Rannou et al. (1985)
UK	2,000		15	25	2.6	Living areas; bedrooms had GM of 11 Bq/m³	Green et al. (1985)
Ireland	250		43		10% > 100 Bq/m³	Preliminary survey	McAulay and McLaughlin (1985)
Japan	251		19		2% > 100 Bq/m³	Composite of 4 city surveys	Aoyama et al. (1987)

[a]Adapted from Nazaroff and Nero (1988).
[b]Swedish remedial action level of 400 Bq/m³ EEDC (assuming a typical equilibrium factor of 0.5) = 800 Bq/m³ Rn-222 concentration.
[c]Swedish homes built before 1975, with concrete having elevated radium-226 content; built after 1975, with concrete not having elevated radium-226 content.
AM = Arithmetic mean.
EEDC = Equilibrium-equivalent decay-product concentration.
GM = Geometric mean.
GSD = Geometric standard deviation.

built before 1975 and with high levels of soil gas radon-222 (Swedjemark, 1987; Swedjemark and Mjones, 1984a,b). Areas of Finland (Castren et al., 1987) and the United Kingdom (Green et al., 1985) have been found where average indoor radon-222 concentrations are as high as 350 to 400 Bq/m^3. In one area on the south coast of Finland, 12% of the houses had average indoor radon-222 concentrations greater than 800 Bq/m^3. In Canada elevated indoor radon-222 concentrations have been associated with contamination from uranium and radium refining industry processes and geological areas with elevated uranium content (National Council on Radiation Protection and Measurements, 1984). Extremely high indoor concentrations of radon-222 have also been found in localized areas in the United States, where average winter concentrations range from 500 to 7,500 Bq/m^3 and maximum concentrations can reach as high as 100,000 Bq/m^3 (Nazaroff and Nero, 1988).

More detailed information on recent nationwide radon-222 surveys and other investigations of indoor radon-222 concentrations can be found in the reports of the United Nations Scientific Committee on the Effects of Atomic Radiation (1982, 1989) and other review articles and conference proceedings (Berglund et al., 1984, 1986; Hopke, 1987; Nazaroff and Nero, 1988; Steinhausler, 1985).

ENVIRONMENTAL TOBACCO SMOKE

Environmental tobacco smoke (ETS), which is a combination of diluted sidestream smoke (SS) released into the air from the cigarette's burning end, mainstream smoke (MS) exhaled by the active smoker, and some volatile components (e.g., carbon monoxide) that diffuse through cigarette paper, is a major contributor of particulate and volatile organic matter to indoor air pollution. More than 4,500 compounds have been identified in the vapor and particulate phases of tobacco aerosols: 60 of these are known or suspect carcinogens, including 51 in the particulate phase (Surgeon General of the United States, 1982). Thorough treatments of the physicochemical characteristics of tobacco smoke, including data on relative concentrations of the principal toxic and carcinogenic constituents of ETS, SS, and MS, can be found in the recent literature (Surgeon General of the United States, 1984, 1986; National Research Council, 1981a, 1986; International Agency for Research on Cancer, 1986).

Several ETS components—carbon monoxide, nicotine, nitrogen oxides, aromatic hydrocarbons, acrolein, acetone, nitroso compounds, benzo[*a*]pyrene, and respirable suspended particles (RSP)—have been measured as markers of the contribution of tobacco combustion to indoor air pollution. However, no single compound has been found to represent ETS exposure reliably or to estimate accurately the disease-causing potential of ETS. Nicotine is the best potential marker for ETS because it is unique to tobacco smoke, is present as a major constituent, and can be collected and analysed in both the particulate and vapor phases with high sensitivity (Hammond et al., 1987).

Concentrations of toxic and carcinogenic compounds measured in various indoor environments polluted with ETS are summarized in Table 2. Benzene, N-nitrosoamines, and polynuclear aromatic hydrocarbons (PAH) are of concern because of carcinogenic activity. Levels of N-nitrosoamines and PAH often exceeded maximum levels reported for ambient urban air pollutants by one to three orders of magnitude (Brunnemann and Hoffmann, 1978; International Agency for Research on Cancer, 1986). Additional data on PAH concentrations in homes with and without smokers are provided in the Organic Compounds section (Table 8). Similar data for several ETS markers are presented in Table 3. The possibility of contributions from sources other than ETS cannot be excluded.

TABLE 2. MEASURED CONCENTRATIONS OF VARIOUS TOXIC AGENTS IN ROOMS POLLUTED WITH ETS[a]

Pollutant	Location	Concentration range (mean)	Nonsmoke control concentration range (mean)	References[b]
Benzene	Public places	20-317 $\mu g/m^3$	------	Badre et al. (1978)
	Residences (randomly selected)	<1.0-39 (9.3[b]) $\mu g/m^3$	(6.9[b]) $\mu g/m^3$ (indoors)	Krause et al. (1987)
	Residences (randomly selected)	(10) $\mu g/m^3$	(7) $\mu g/m^3$ (indoors)	Wallace (1987); Pellizzarri et al. (1987a,b)
N-nitrosodimethyl-amine	Restaurant, public places	0.01-0.24 $\mu g/m^3$	0.005 $\mu g/m^3$ (inside)	Brunnemann et al. (1977); Stehlik et al. (1982)
N-nitrosodi-ethylamine	Restaurant, public places	<0.01-0.2 $\mu g/m^3$	------	Stehlik et al. (1982)
Anthanthrene	Coffee houses	0.5-9.4 ng/m^3	2.8-7.0 ng/m^3 (outdoors)	Just et al. (1972); Grimmer et al. (1977)
Benzo[*a*]fluorene	Indoors	39 ng/m^3	------	Grimmer et al. (1977)
Benzo[*ghi*]-perylene	Restaurant, public places	5-25 ng/m^3	------	Grimmer et al. (1977) Just et al. (1972)
Benzo[*a*]pyrene	Restaurant, public places	2.8-760 ng/m^3	4.0-9.3 ng/m^3 (outdoors)	Galuskinova (1964); Just et al. (1972); Perry (1973); Grimmer et al. (1977)

TABLE 2 (cont'd). MEASURED CONCENTRATIONS OF VARIOUS TOXIC AGENTS IN ROOMS POLLUTED WITH ETS[a]

Pollutant	Location	Concentration range (mean)	Nonsmoke control concentration range (mean)	References[b]
Benzo[*e*]pyrene	Coffee houses	3.3-23.4 ng/m^3	3.0-5.1 ng/m^3 (outdoors)	Just et al. (1972) Grimmer et al. (1977)
Coronene	Coffee houses	0.5-1.2 ng/m^3	1.0-2.8 ng/m^3 (outdoors)	Just et al. (1972)
Dibenz[*ai*]anthracene	------	6 ng/m^3	------	Grimmer et al. (1977)
Fluoranthene	Restaurant, public places	50-116 ng/m^3	------	Grimmer et al. (1977)
Perylene	Coffee houses	0.7-1.3 ng/m^3	0.1-1.7 ng/m^3 (outdoors)	Just et al. (1972)
Pyrene	Coffee houses	4.1-9.4 ng/m^3	0.1-1.7 ng/m^3 (outdoors)	Just et al. (1972)
Phenols (volatile)	Coffee houses	7.4-11.5 ng/m^3	------	Just et al. (1972)

[a]Adapted from U.S. National Research Council (1986).
[b]For complete citations of references other than Krause et al. (1987), Wallace (1987), and Pellizzari et al. (1987a,b) refer to the source document for this table.
[c]Median value.

TABLE 3. CONCENTRATIONS OF MAJOR ETS MARKER COMPOUNDS[a]

Compound	Indoor concentration				Outdoor concentration	
	Smoking		Non-smoking			
	Range (n)[b]	Range of means (n)	Range (n)	Range of means (n)	Range (n)	Range of means (n)
Acetone	0.36-5.88 $\mu g/m^3$ (2)	0.32-1.20 $\mu g/m^3$ (4)				
Acrolein	0.2-0.12 $\mu g/m^3$ (2)	0.004-0.185 $\mu g/m^3$ (8)				
Carbon Monoxide	0-42 ppm (25)	1.0-50 ppm (31)	0.4-15.0 ppm (6)	1-11.5 ppm (8)	3.0-3.5 ppm (1)	0.4-9.2 ppm (7)
Nicotine	0.7-52 $\mu g/m^3$ (6)	0.9-1,010 $\mu g/m^3$ (14)				
Nitrogen Oxides						
NO_2	1-151 ppb (5)	21-76 ppb (5)		27 ppb (1)		48-63 ppb (3)
NO	2-414 ppb (5)	9-195 ppb (5)		5 ppb (1)		11-115 ppb (3)
Particulates						
TSP[c]	40-986 $\mu g/m^3$ (7)	<10-486 $\mu g/m^3$ (11)	9.1-92 $\mu g/m^3$ (3)	<10-55 $\mu g/m^3$ (5)	41-73 $\mu g/m^3$ (1)	
RSP[d]	10-1,140 $\mu g/m^3$ (3)	16.8-133 $\mu g/m^3$ (9)	6-118.9 $\mu g/m^3$ (3)	9-46 $\mu g/m^3$ (7)	1-63 $\mu g/m^3$ (3)	11.3-42.9 $\mu g/m^3$ (6)

[a]Adapted from National Research Council (1986).
[b]n = Number of different environments or studies. For references to individual studies, refer to the source document for this table.
[c]TSP = Total suspended particles.
[d]RSP = Respirable suspended particles.

Most of the studies measuring indoor levels of ETS have been conducted in a variety of public buildings; fewer investigations of home and office environments have been reported. The overall contribution of ETS to indoor air pollution in residences has been assessed primarily by site and personal monitoring for RSP (Moschandreas et al., 1981; Sexton et al., 1984; Spengler et al., 1981, 1985) and more recently by site monitoring for fine particles (effective aerodynamic diameter <2.5 μm) (Spengler et al., 1986, 1987). In all of these studies significant increases in RSP and fine-particle concentrations (over background or outdoor concentrations) have been measured in homes with smokers.

Concentrations of other ETS constituents have also been found to be significantly elevated in residences with smokers. Recent large-scale studies in over 500-600 homes have found benzene concentrations to be significantly higher (30-50%) in homes with smokers (Krause et al., 1987; Pellizzari et al., 1987a,b; Wallace, 1987). In a survey of over 300 homes, Lebret et al. (1986) found significantly elevated (35-50%) concentrations of both straight-chain and aromatic hydrocarbons in homes with smokers. A large study of indoor CO concentrations in the United States (Akland et al., 1985) is the first to give reliable estimates of the effect of smoking on indoor CO concentrations; in one city the average residential, indoor mean exposure of non-smokers (from personal exposure monitors) was increased 84% from 1.89 to 3.48 ppm, by the presence of smokers in the home—a statistically significant increase of about 1.5 ppm. Moschandreas et al. (1981) have found that indoor iron, arsenic, and cadmium concentrations exceed outdoor levels only for those homes with smokers. Lebret et al. (1987) also found significantly elevated levels of cadmium in homes with smokers and a high correlation between cadmium and fine-particle concentrations. These results suggest the possible use of cadmium as a marker compound for ETS.

ASBESTOS

Average concentrations of asbestos in urban ambient air are typically less than 1 ng/m^3 and rarely exceed 5 ng/m^3. Concentrations of 100 ng/m^3 to 1,000 ng/m^3 have been measured in ambient air near specific asbestos emissions sources and in schools and office buildings containing visibly damaged or deteriorating friable asbestos materials. Buildings with intact asbestos-containing materials seldom show increased concentrations of airborne asbestos over ambient levels (U.S. Environmental Protection Agency, 1987b).

Comparison of the data from different studies of asbestos concentrations in indoor air is complicated by the different analytical methods used for airborne asbestos. The most reliable data come from a number of independent, well-documented transmission electron microscopy (TEM) studies conducted to evaluate airborne asbestos concentrations in a variety of different building types and circumstances. Results of these studies are summarized in Table 4. Differences can be attributed to variations in sampling and analytical protocols, building types and conditions, and study objectives. The earlier studies (prior to 1980) were directed primarily toward evaluating extreme exposure conditions and thus were not representative of average or normal indoor exposures. Nevertheless, the overall results are consistent. In buildings with severely damaged or deteriorated asbestos surfacing materials, elevated concentrations of airborne asbestos (often 100 times greater than ambient air levels) were usually found. In buildings with intact asbestos surfacing or insulating materials, elevated concentrations of airborne asbestos were rarely detected.

A serious potential source of indoor non-occupational asbestos exposure is contamination from asbestos abatement operations, although this can be minimized by adhering to proper procedures. Recent studies (U.S. Environmental Protection Agency, 1986; Chesson et al., 1985) monitored the effectiveness of abatement and cleaning procedures in five schools and found little residual contamination (1.2 ng/m^3, maximum geometric mean concentration) after completion of the work.

Several potential sources of indoor airborne asbestos exist other than friable surfacing and insulation materials. These include weathering and entrainment indoors of asbestos cement wall and roofing materials, wearing of vinyl asbestos tile, and emissions from

TABLE 4. SUMMARY OF INDOOR AIRBORNE ASBESTOS CONCENTRATION DATA MEASURED BY TEM[a]

Type of site sampled	Number of samples analyzed	Arithmetic mean ng/m³ (range)	Arithmetic mean f>5μm/L[b] (range)	Arithmetic mean f/L[c] (range)	Reference
Outdoor ambient	23	83% <20 52% <7			Nicholson et al. (1975)
2 U.S. control buildings	12	92% <20 33% <7			
8 U.S. buildings with cementitious asbestos material in plenums or as surfacing materials (no visible damage)	28	15 C[d]			
9 U.S. buildings with friable asbestos material in plenums or as surfacing materials (no visible damage)	54	48 C			
Outdoor ambient	3	14			Nicholson et al. (1978)
10 U.S. public schools with visibly damaged friable sprayed asbestos surfacing materials	27	217 C			
Outdoor ambient	128	<1			Sebastien et al. (1980)
7 control buildings in Paris, France	16	(0.1-4)			
21 buildings with friable sprayed asbestos in Paris, France (visible damage)	135	35; 25 C, 10 A (0.1-70 C)			
Outdoor ambient	31	6			Constant et al. (1983)
Rooms not containing asbestos surfacing materials (in 19 randomly-selected U.S. schools with friable asbestos material)	31	61; 53 C, 8 A			
Rooms containing friable asbestos surfacing materials (in 25 randomly-selected U.S. schools)	54	183; 179 C, 4 A			
Outdoor ambient	24	<0.1			Ontario Royal Commission (1984)
19 Ontario buildings with friable sprayed asbestos	63	2.1 (0.1-11)			

TABLE 4 (cont'd). SUMMARY OF INDOOR AIRBORNE ASBESTOS CONCENTRATION DATA MEASURED BY TEM[a]

Type of site sampled	Number of samples analyzed	Arithmetic mean ng/m³ (range)	Arithmetic mean f>5μm/L[b] (range)	Arithmetic mean f/L[c] (range)	Reference
8 Ontario office and school buildings	55	1.1[f] (ND-17)	[e,g]		Chatfield (1985)
Outdoor ambient	13	<0.1 C, 0.3 A			Burdett and Jaffrey (1986)
11 UK buildings with friable sprayed asbestos insulation (1 with visible damage)	103	<0.1 C, 1.5 A (<0.1-0.2 C) (ND-15A)[i]	(<0.1-2 C+A)[h]	(<1-40 C+A)	
23 UK houses and flats with warm air heaters containing asbestos	72	<1 C	(<0.1-2 C+A)	(<1-15 C+A)	
4 UK control houses, warm air heaters without asbestos	19	<1 C	(<0.3-1 C)	(<0.5-15 C)	
Outdoor ambient	7	0.9 (0.0-4.3)			Nicholson (1989)
U.S. houses with air conditioning units with asbestos paper ducts and asbestos in textured paint (no visible damage)	24	4.5	(0.0-12.7)		
U.S. houses with air conditioning units with asbestos paper ducts with no asbestos in textured paint (no visible damage)	6	3.3	(0.4-5.4)		

TABLE 4 (cont'd). SUMMARY OF INDOOR AIRBORNE ASBESTOS CONCENTRATION DATA MEASURED BY TEM[a]

Type of site sampled	Number of samples analyzed	Arithmetic mean ng/m³ (range)	Arithmetic mean f>5μm/L[b] (range)	Arithmetic mean f/L[c] (range)	Reference
5 U.S. houses with friable asbestos materials in basement (1 with visible damage)					Perkins (1987)
-basement	5		24.2 (0.0-115)	339.8 (0.0-1253)	
-living area	5		0.8 (0.0-4.0)	68.6 (4.0-312)	
-outdoor ambient	8			10.3 (0.0-27)	
1 U.S. control house					
-living area	2				
-outdoor ambient	1				

[a]Adapted from Nicholson (1989).
[b]Aspect ratio >3:1, where the aspect ratio is the fibre length to width.
[c]All lengths with aspect ratio >3:1.
[d]C, chrysotile; A, amphibole.
[e]Less than a detection limit of approximately 4 f> 5μm/L.
[f]Two additional samples had concentrations of 640 and 360 ng/m³. The 360 ng/m³ was from a single fibre.
[g]One sample had a concentration of 20 f> 5μm/L. All others were less than the detection limit of approximately 4 f> 5μm/L.
[h]Most sample sets had an average concentration less than a set detection limit of 0.3 f> 5μm/L.
[i]Amosite detected in 9 of 103 samples; at 5 of 11 sites.

asbestos brake pads. Concentrations ranging from 20 ng/m^3 to 4,500 ng/m^3 (and as high as 5 fibers/L for fibers $>5\mu$m long) have been measured in a variety of enclosed spaces (i.e., schools, buildings, subways, and traffic tunnels) (Nicholson, 1989). While most of these sources represent infrequent exposures, the high concentrations measured indicate that in some instances they may pose substantial risk.

Unfortunately, none of the measures of airborne asbestos concentration (i.e., mass, fibers of all lengths, fibers $>5\mu$m) has been found to correspond directly to increased cancer risk. Nicholson (1989) points out that mass measurements may better relate to carcinogenic risk than do total fiber counts, since they better account for the length dependence of carcinogenic risk. However, mass measurements may not be meaningful if they are dominated by large bundles of fibrils of low carcinogenic potential. Given the size dependency of the carcinogenic potential of asbestos fibers, the best measurement of airborne asbestos concentration is one in which every fiber is identified and sized (Nicholson, 1989). Where practical, inclusion of such information in reported results of future studies is recommended.

ORGANIC COMPOUNDS

Gas Phase Organic Compounds

Gas phase organic (GPO) compounds include semivolatile (SVOC), volatile (VOC), or very volatile (VVOC) organic compounds. The indoor concentration data presented here are taken primarily from studies of indoor VOC concentrations, although some SVOC and VVOC are also included because of the overlap of these categories.

Several studies conducted over the last decade (De Bortoli et al., 1986; Gammage et al., 1984; Handy et al., 1987; Jarke, 1979; Krause et al., 1987; Lebret et al., 1984, 1986; Molhave and Moller, 1978; Monteith et al., 1984; Pellizzari et al., 1987a,b; Seifert and Abraham, 1982; Wallace, 1987) provide a substantial body of data characterizing the sources and levels of indoor VOC in residential environments. The results of these studies, conducted in more than 1,500 homes in Europe and the United States under widely differing protocols, show remarkable agreement in the following areas: (a) an extremely wide variety of VOC was found in all indoor residential environments, with more than 300 different compounds detected in some studies; (b) a number of these VOC were detected consistently in all studies; (c) concentrations of most VOC varied widely within and among homes (often differing by two or more orders of magnitude), and more than 250 VOC were found at concentrations higher than 1 ppb (Sterling, 1985); (d) except in the case of extreme outdoor pollution (Wallace, 1987; Pellizzari et al., 1987a,b), indoor VOC concentrations were higher than outdoor concentrations, with median indoor/outdoor concentration ratios normally ranging between 2 and 5, and occasionally up to several orders of magnitude for some compounds; (e) indoor sources, which varied widely in number and type, were the most important contributors to indoor VOC concentrations.

Among the most comprehensive studies of exposure to indoor VOC is the Total Exposure Assessment Methodology (TEAM) Study recently conducted by the U.S. Environmental Protection Agency (Handy et al., 1987; Pellizzari et al., 1987a,b; Wallace, 1987) in which 12-h integrated personal exposures and corresponding breath and outdoor concentrations of 11 to 19 target VOC were determined in 650 households at five sites. Estimated frequency distributions of personal air exposures, outdoor air concentrations, and

exhaled breath concentrations were determined for all target VOC; examples are presented in Figure 2 for two VOC that are known or probable human carcinogens, determined for one target population. Nighttime personal exposures were considered to be best estimates of indoor air concentrations. Weighted estimates of the population frequency distributions determined at one site for 11 target VOC (five aromatic compounds and six chlorinated hydrocarbons) are shown in Figure 3. Breath concentrations correlated more closely with personal exposures than did outdoor concentrations—a result also observed in a concurrent study of personal exposures and breath concentrations of halogenated organic compounds for 146 residents in two United States studies (Hartwell et al., 1984; Pellizzari et al., 1983). Benzene concentrations were found to be significantly (30-50%) higher in homes of smokers than of non-smokers.

The results of the TEAM study are supported by two other large studies conducted in the Federal Republic of Germany (57 VOC measured in 500 randomly selected homes) (Krause et al., 1987) and the Netherlands (45 VOC measured in more than 300 randomly selected homes) (Lebret et al., 1986), and by a more limited study conducted in Italy (35 VOC measured in 14 homes) (De Bortoli et al., 1986). A working group of the World Health Organization has recently used the data from these studies and the TEAM study to derive overall concentration distributions for the individual VOC measured as a basis for a tentative population risk assessment for VOC (World Health Organization, 1987a). Summary data are shown in Tables 5 and 6, respectively, on indoor concentrations of VOC found in the large surveys in the Federal Republic of Germany and the Netherlands.

Formaldehyde

Numerous monitoring studies have been conducted to measure the concentration of formaldehyde in indoor environments. The results for a variety of housing types in several different countries are summarized in Table 7. Much of this data was collected in older homes, homes in which urea formaldehyde foam insulation (UFFI) had been installed or homes in which occupants had filed complaints of formaldehyde irritant symptoms. Data appropriate for describing current residential exposures are obtained from studies evaluating randomly selected, non-complaint homes constructed after 1980, when builders began using more energy-efficient construction, and most pressed wood manufacturers began using resins

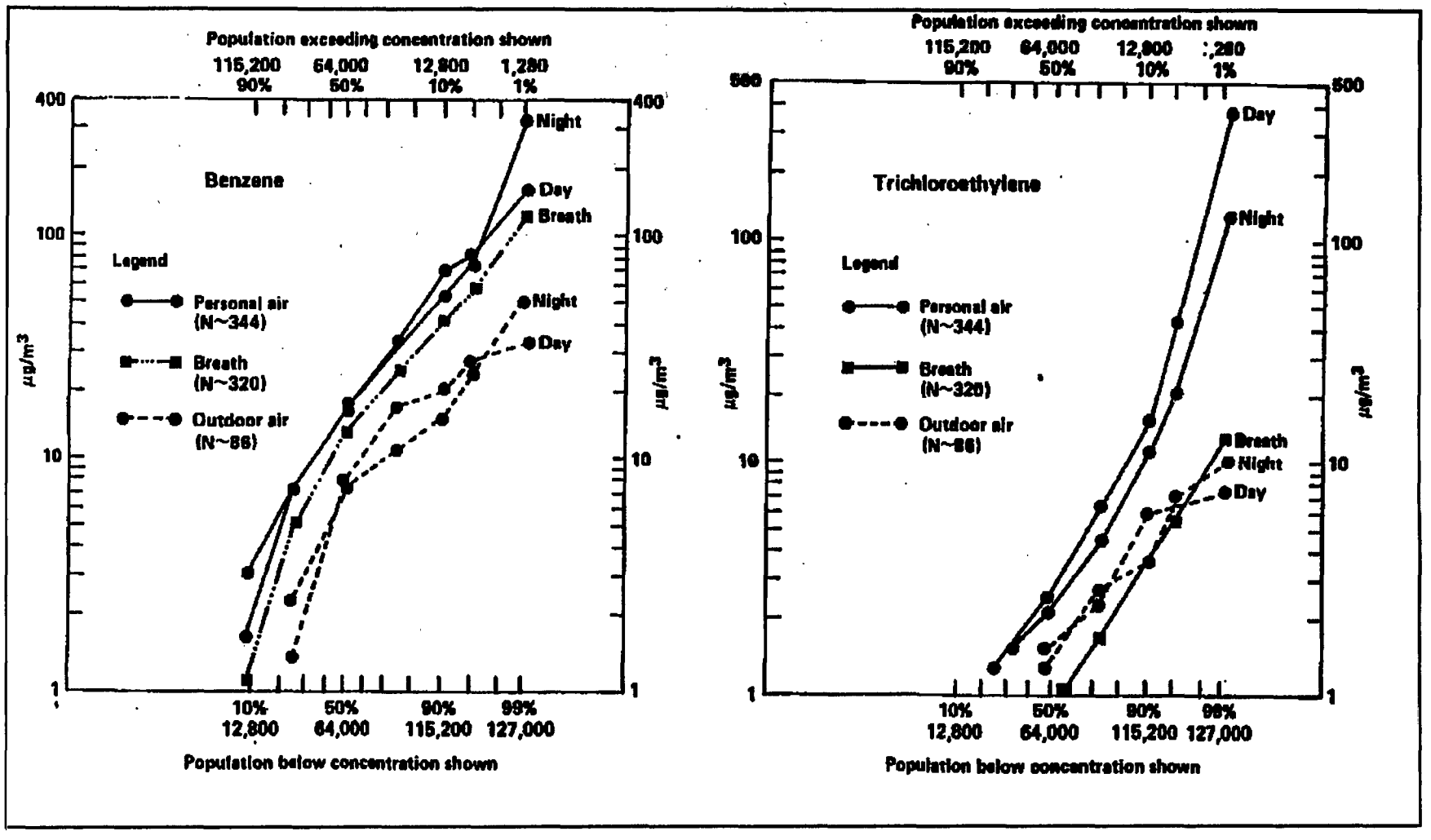

Figure 2. Benzene and trichloroethylene: estimated frequency distributions of personal air exposures, outdoor air concentrations, and exhaled breath values for the combined Elizabeth-Bayonne target population (128,000).[a]

[a]Source: Wallace (1987). All air values are 12-h integrated samples. The breath value was taken following the daytime air sample (6:00 am - 6:00 pm). All outdoor air samples were taken in the vicinity of the participants' homes. Nighttime personal samples give approximate indoor air concentrations.

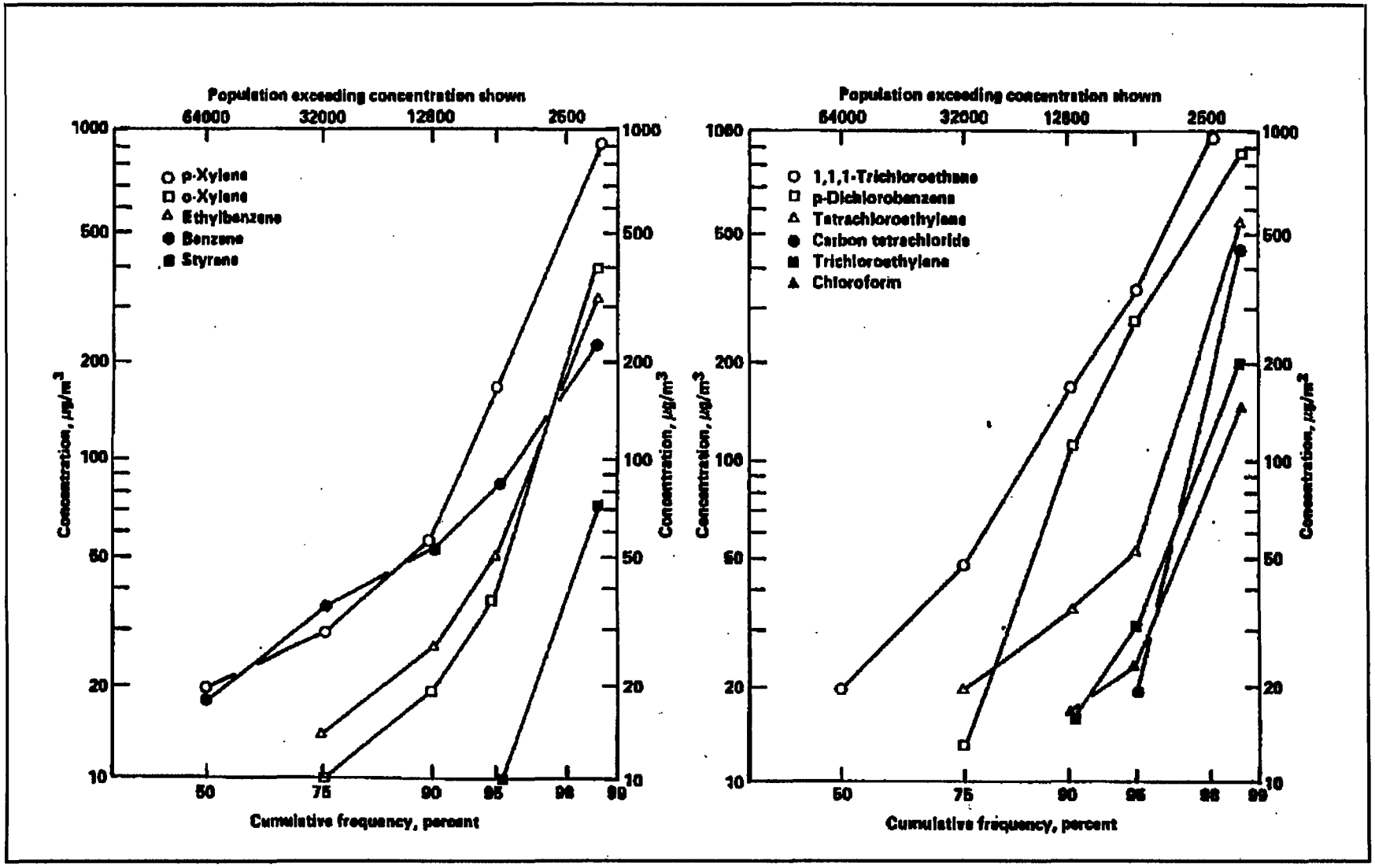

Figure 3. Weighted frequency distributions for 24-h exposures of 355 New Jersey residents to aromatic and chlorinated hydrocarbons (Fall 1981).[a]

[a]Source: Wallace (1987)

TABLE 5. SUMMARY OF VOC CONCENTRATIONS IN 230 HOMES IN THE FEDERAL REPUBLIC OF GERMANY[a]

Compound	Mean conc. [$\mu g/m^3$]	50 percentile [$\mu g/m^3$]	90 Percentile [$\mu g/m^3$]	Range [$\mu g/m^3$]
Σ *n*-Alkanes	67	44	139	8.7 - 432
n-Hexane	9.0	7.9	15	2.0 - 46
n-Heptane	7.0	7.9	11	1.5 - 82
n-Octane	4.9	2.8	8.3	< 1.0 - 64
n-Nonane	9.7	4.2	26	< 1.0 - 101
n-Decane	14	6.8	37	< 1.0 - 136
n-Undecane	10	5.7	24	< 1.0 - 88
n-Dodecane	5.6	3.7	12	< 1.0 - 35
n-Tridecane	6.3	4.7	10	< 1.0 - 79
Σ *i*-Alkanes (C_6 - C_9)[b]	30	24	52	5.2 - 231
Σ Cycloalkanes	15	13	27	2.1 - 79
Methylcyclopentane	2.8	2.4	4.7	< 1.0 - 15
Cyclohexane	7.4	6.8	14	< 1.0 - 29
Methylcyclohexane	5.5	3.6	8.8	1.1 - 51
Σ Aromatics	166	126	283	16.0 - 1260
Benzene	9.3	7.8	17	< 1.0 - 39
Toluene	76	62	127	11.0 - 578
Ethylbenzene	10	6.6	16	1.5 - 161
m+*p*-Xylene	23	16	41	3.3 - 304
o-Xylene	7.0	4.9	13	1.2 - 45
i+*n*-Propylbenzene	4.5	3.0	9.7	< 1.0 - 89
Styrene	2.5	1.2	4.2	< 1.0 - 41
1-Ethyl-2-methylbenzene	4.4	2.3	8.5	< 1.0 - 103
1-Ethyl-(3+4) methylbenzene	8.9	5.0	16	< 1.0 - 229
1,2,3-Trimethylbenzene	3.5	1.9	6.6	< 1.0 - 83
1,2,4-Trimethylbenzene	11	5.4	18	< 1.0 - 312
1,3,5-Trimethylbenzene	3.9	2.0	7.5	< 1.0 - 111
Naphthalene	2.3	2.1	3.9	< 1.0 - 14
Σ Chlorinated Compounds	48	21	60	3.5 - 1630
1,1,1-Trichloroethane	7.9	4.3	13	< 1.0 - 264
Trichloroethylene	13	4.6	12	< 1.0 - 1200
Tetrachloroethylene	12	4.5	14	< 1.0 - 617
1,4-Dichlorobenzene	22	4.7	17	< 1.0 - 1270
Σ Terpenes	42	26	97	2.1 - 362
α-Pinene	11	7.7	20	< 1.0 - 97
β-Pinene	1.3	<1.0	2.0	< 1.0 - 11
α-Terpinene	4.1	2.9	9.0	< 1.0 - 37
Limonene	25	11	67	< 1.0 - 315
Σ Carbonyl Compounds	29	21	44	5.2 - 347
Ethylacetate	12	6.8	19	1.0 - 204
n-Butylacetate	6.1	3.1	10	< 1.0 - 125
i-Butylacetate	2.0	1.0	4.0	< 1.0 - 33
Methylethylketone	6.2	5.3	11	< 1.0 - 25
4-Methyl-2-pentanone	1.0	< 1.0	1.9	< 1.0 - 12
Hexanal	2	1.0	3	< 1.0 - 11
Σ Alcohols	7	6	13	< 1.0 - 25
n-Butanol	1	<1	3	< 1.0 - 11
i-Butanol	3	2	7	< 1.0 - 20
i-Amylalcohol	1	<1	2	< 1.0 - 10
2-Ethylhexanol	2	<1	3	< 1.0 - 10
Σ All Calibrated Compounds	394	312	665	72.0 - 2670

[a]Source: Krause et al. (1987)
[b]This group includes twelve individual compounds

TABLE 6. SUMMARY OF VOC CONCENTRATIONS IN 319 HOMES IN THE NETHERLANDS[a]

Compound	Indoor concentration ($\mu g/m^3$)		Outdoor concentration($\mu g/m^3$)	
	Range of geometrical means for three age-group homes	Maximum	Geometrical mean	Maximum
n-Alkanes (C_6 - C_{16})	39-76	1781	5	21
i-Alkanes[b]	7-9	515	4	10
Cycloalkanes[c]	4-6	687	2	5
Aromatic hydrocarbons[d]	63-100	4149	15	57
Chlorinated hydrocarbons[e]	6-7	300	1	22

[a]Homes divided into three age groups (built before World War II, built after World War II, built after 1976). Adapted from Lebret et al. (1986).
[b]3-methylpentane; 2-methylhexane; 3-methylhexane.
[c]cyclohexane; methylcyclohexane; dimethylcyclopentane.
[d]benzene; toluene; xylenes; ethylbenzene; *n*-propylbenzene; *i*-propylbenzene; *o*-methylethylbenzene; *m*-methylethylbenzene; *p*-methylethylbenzene; 1,2,3-trimethylbenzene; 1,2,4-trimethylbenzene; 1,3,5-trimethylbenzene; *n*-butylbenzene; *p*-methyl-*i*-propylebenzene; naphthalene; 1-methylnaphthalene.
[e]tetrachloromethane; trichloroethene; tetrachloroethene; chlorobenzene; *m*-dichlorobenzene; *p*-dichlorobenzene; 1,2,3-trichlorobenzene; 1,2,4-trichlorobenzene; 1,3,5-trichlorobenzene.

TABLE 7. INDOOR CONCENTRATIONS OF FORMALDEHYDE

Building type	No.	Concentration (ppm) Range	Mean	Reference
With UFFI				
Canadian homes	~1850	10% >0.1 ppm	0.054	Gammage and Hawthorne (1985)
UK building	128	~0.01->1 (7% >0.1ppm)	0.093	Gammage and Hawthorne (1985)
Swiss residences	43	0.04-2.3	0.4	Rothweiler et al. (1983)
US homes	>1200	0.01-3.4	0.05-0.12	Gammage and Hawthorne (1985)
	>1200			U.S. Environmental Protection Agency (1987a)
Without UFFI				
Canadian homes	383	3% >0.1 ppm	0.036	Gammage and Hawthorne (1985)
UK buildings	50	<0.02->0.3	0.047	Gammage and Hawthorne (1985)
	50	(3%>0.1 ppm)		
Swiss building (new)	73	0.14-0.60		Wanner and Kuhn (1986)
US homes	131	0.01-0.17	0.025-0.07	Gammage and Hawthorne (1985)
Complaint				
Dutch buildings	–	60-80% >0.1 ppm		Van der Wal (1982)
US mobile homes (some non-complaint)	>500	0.00-4.2	0.1-0.9	Gammage and Hawthorne (1985)
Noncomplaint				
Italian homes (1 office)	14	0.007-0.042	0.022	De Bortoli (1988)
Yugoslavian buildings	35	0.007-0.345	0.027-0.091	Kalinic et al. (1986)
US homes, randomly selected	560	<0.005-0.48	0.091-0.62	U.S. Environmental Protection Agency (1987a); Stock (1987)
US mobile homes, randomly selected	~1200	<0.01-2.9		U.S. Environmental Protection Agency (1987a)
By Age				
US mobile homes				
New	260		0.86	Gammage and Hawthorne (1985)
Older, occupied	–		0.25	Gammage and Hawthorne (1985)
US homes				
0-5 years old	18		0.08	Hawthorne et al. (1986)
5-15 years old	11		0.04	Hawthorne et al. (1986)
>15 years old	11		0.03	Hawthorne et al. (1986)
Overall	40	<0.02-0.4	0.06	Hawthorne et al. (1986)

with low formaldehyde-to-urea ratios. More complete summaries of residential formaldehyde studies are contained in recent reviews on this topic (U.S. Environmental Protection Agency, 1987a; National Research Council, 1981b; Versar, Inc., 1986 a,b).

Despite the wide variety of conditions under which these residential formaldehyde studies were conducted, results for given types of housing tend to be consistent within certain broad ranges. Indoor residential concentrations of formaldehyde are generally found to be significantly higher than outdoor concentrations, which range from 0.002 to 0.006 ppm in remote, unpopulated regions to 0.010 to 0.020 ppm and sometimes 0.050 ppm in highly populated areas and industrial urban air. The range of formaldehyde concentration measured in complaint homes, mobile homes, and homes containing large quantities of particleboard or UFFI tends to be from 0.02 ppm to 0.80 ppm, with levels as high as 4 ppm in some instances. Older conventional homes tend to have the lowest indoor concentrations of formaldehyde, with values typically less than 0.05 ppm. Formaldehyde levels in new (less than one year old) conventional homes generally fall within the range of 0.05 ppm to 0.2 ppm; few measurements exceed 0.3 ppm.

Polynuclear Aromatic Hydrocarbons (PAH)

Exposure to polynuclear aromatic hydrocarbons (PAH) in air is related to the total amount of these compounds distributed between the gas and aerosol phases and to the particle size distribution. At present, the most reliable estimates of PAH exposures come from studies reporting total PAH concentrations from filter and sorbent extracts.

Recent evaluations of sampling and analysis methods for indoor airborne PAH have shown that, of the major variables influencing PAH exposure, smoking has the greatest effect on both PAH concentrations and mutagenicity (Lewtas et al., 1987; Wilson et al., 1985). The concentrations of PAH in tobacco smoke and smoke-polluted environments have been summarized in the IARC monograph series (World Health Organization, 1983); reported concentrations of several PAH (ananthrene, benzo[*a*]fluorene, benzo[*ghi*]perylene, benzo[*a*]pyrene, benzo[*e*]pyrene, coronene, dibenz[*aj*]anthracene, fluoroanthene) in various indoor environments ranged from 0.1 to 99 ng/m^3. The effect of smoking on indoor PAH levels was recently evaluated in a study of eight U.S. homes (Wilson and Chuang, 1989). Representative values of concentrations of several PAH and nitro PAH found in homes with

and without smokers are shown in Table 8. Additional data on PAH concentrations in smoky environments are presented in Table 2.

TABLE 8. POLYNUCLEAR AROMATIC HYDROCARBONS (PAH) AND NITRO PAH INDOOR AIR CONCENTRATIONS (NG/^{3})[a]

	Homes with smokers		Homes without smokers	
Compound	Living room	Outdoors	Living Room	Outdoors
Naphthalene	2200	330	1000	110
Acenaphthylene	120	8.9	10	4.6
Phenanthrene	210	54	59	29
Anthracene	1.5	1.6	2.0	0.64
Fluoranthene	23	9.4	7.2	4.3
Pyrene	17	9.4	5.6	5.1
Benz[*a*]anthracene	3.4	0.58	0.24	0.23
Chrysene	7.2	2.2	0.93	1.1
Benzofluoranthene	5.1	1.4	0.78	0.51
Benzo[*e*]pyrene	1.0	0.63	0.68	0.28
Benzo[*a*]pyrene	3.3	0.30	0.31	0.15
Benzo[*y,h,i*]pyrene	2.5	0.81	0.32	0.27
Coronene	0.64	0.68	0.31	0.18
9-Nitroanthracene isomer	0.95	0.51	0.45	0.57
9-Nitroanthracene	0.32	0.10	0.13	0.030
9-Nitrophenanthrene	0.25	0.014	0.043	0.027
2-Nitrofluoranthene	0.14	0.075	0.020	0.041

[a]Source: Wilson and Chuang (1989). Total PAH concentrations from filter (quartz) and sorbent (XAD-2 resin) extracts.

It is estimated that as a result of daily use of biomass fuels for cooking and heating under unvented conditions, about one-half of the world's population is exposed to concentrations of PAH that are orders of magnitude greater (102 - 10^3 $\mu g/m^3$) than those normally found in areas using more advanced combustion systems (Smith et al., 1984). In a recent study that investigated an etiological link between domestic burning of smoky coal (comparable to medium-volatile bituminous coal) and lung cancer in China (Mumford et al., 1987), the approximate ranges of measured concentrations in smoky coal environments of six PAH which are animal and suspect human carcinogens were: benzo[*a*]anthracene (15 - 25 $\mu g/m^3$); 5-methylchrysene (3 - 8$\mu g/m^3$); benzofluoranthene (12 - 23 $\mu g/m^3$);

benzo[*a*]pyrene (9 - 15 $\mu g/m^3$); indeno[1,2,3-*c*,*d*]pyrene (5 - 9 $\mu g/m^3$); and dibenzo[*a*,*e*]pyrene (5 - 12 $\mu g/m^3$).

Pesticides

Pesticides (including insecticides, rodenticides, termiticides, germicides, fungicides, and herbicides) are widely used in or in close proximity to indoor spaces. Results of numerous studies (e.g., Lewis and Lee, 1976; Lewis and MacLeod, 1982; Lewis et al., 1986; Lewis et al., 1988; U.S. Environmental Protection Agency, 1987b) indicate that the atmosphere in the average United States residence usually contains a number of pesticides at concentrations that are typically one to two orders of magnitude higher than ambient outdoor concentrations. Lewis (1988) has recently reviewed the literature evaluating human exposures to household pesticides and has documented much of the available data on indoor air concentrations of pesticides in United States residences. Some of these data are summarized in Table 9.

In an extensive survey of indoor pesticide exposures recently conducted by the U.S. Environmental Protection Agency to estimate the cumulative frequency distribution of nonoccupational exposures to pesticides via different routes of exposure, it was determined that 81% of the total respiratory exposures to 24 common household and garden pesticides occurred inside the home (Lewis et al., 1988). In the pilot phase of the Non-occupational Pesticides Exposure Study (NOPES), air concentrations of 31 of the most commonly used household pesticides and two oxidation products were measured inside nine residences and compared with corresponding outdoor concentrations and personal exposures. The pesticides monitored are shown in Table 10. Twenty-four pesticides were detected in the indoor air samples, with indoor concentrations ranging from 1.7 ng/m^3 to 15.0 $\mu g/m^3$. Permethrin; resmethrin; carbaryl; 2,4-D esters; atrazine; dacthal; and PCBs were not detected in any indoor air sample. Twenty-five pesticides were found in the outdoor samples. Outdoor concentrations ranged from < 1.0 ng/m^3 to 410 ng/m^3. Personal exposure measurements ranged from < 1.0 ng/m^3 to 8.8 $\mu g/m^3$ and, with few exceptions, exhibited the same profiles as indoor air samples. Chlorpyrifos, diazinon, chlordane, propoxur, and heptachlor were the most commonly occurring pesticides in indoor air samples. The concentrations of these pesticides were generally about one order of magnitude higher than those of any other pesticide found in the same samples; mean indoor air concentrations ranged from 0.16 to

TABLE 9. INDOOR AIR CONCENTRATIONS OF PESTICIDES IN UNITED STATES RESIDENCES[a]

Compound	NAS guideline[b] ($\mu g/m^3$)	Concentration ($\mu g/m^3$)	
		Overall range (n)[c]	Range of means (n)
Chlordane	5	0-264 (16)	0.2-10 (6)
Heptachlor	2	0-14.8 (8)	0.03-1.6 (5)
Aldrin	1	0-7.0 (4)	0.01 (1)
Dieldrin	1	0-0.17 (3)	0.04 (1)
Naphthalene		0.55-4.2 (1)	– (0)
p-Dichlorobenzene	–	0-1500 (1)	2.3 (1)
Pentachlorophenol	–	0.1-50 (3)	0.03 (1)
Chlorpyrifos	10	0-37 (8)	0.007-2.4 (5)
Diazinon	–	0-149 (8)	0.05-1.4 (4)
Propoxur	–	0-7.9 (4)	0.03-0.4 (3)
Dichlorvos	–	0-28 (3)	0.003-0.12 (2)
Malathion	–	0-13.7 (3)	0.003-0.02 (2)
Carbaryl	–	0-0.1 (1)	0.07 (1)

[a]Adapted from Lewis (1988), where references to the original studies are given.
[b]Values listed for the five termiticides covered by guidelines established by the National Academy of Sciences (1982).
[c]n = number of studies reporting range or mean value.

2.4 $\mu g/m^3$ and were almost always one to two orders of magnitude higher than outdoor concentrations. Other investigators have reported comparable indoor air concentrations for these pesticides (Leidy and Wright, 1987; Leidy et al., 1985; Lewis and MacLeod, 1982; Wright and Leidy, 1982; Wright et al., 1981). Preliminary results of a more extensive phase of the NOPES study (Lewis, 1988) are in general agreement with the pilot study results.

Several studies have been conducted to assess indoor exposures to specific pesticides. Chlordane and heptachlor received attention in the United States when it was discovered that measurable amounts of these highly persistent termiticides could be found inside housing where the underlying or surrounding soil had been treated with these chemicals (Livingston and Jones, 1981).

Large-scale surveys of U.S. Army and Air Force housing (Lillie and Barnes, 1987; Olds, 1987) indicated that 0.9% and 5%, respectively, of these housing units treated with chlordane had indoor air levels of this pesticide that exceeded U.S. National Academy of Science guidelines of 5.0 $\mu g/m^3$ (National Academy of Sciences, 1982). In the survey of

TABLE 10. PESTICIDES MONITORED IN INDOOR AIR IN U.S. EPA NON-OCCUPATIONAL PESTICIDES EXPOSURE STUDY (NOPES)[a]

Chlorpyrifos (Dursban[b])	Captan	Methoxychlor
Diazinon	Folpet	*p-p'*-DDT
Chlordane	Oxychlordane[c]	*cis*-Permethrin
Propoxur (baygon[b])	Malathion	*trans*-Permethrin
Heptachlor	Bendiocarb (Ficam[b])	Resmethrin
trans-Nonachlor	α-Hexachlorocyclohexane	Carbaryl (Sevin[b])
Lindane[b] (γ-BHC)	(α-BHC)	2,4-D esters
Heptachlor epoxide[c]	Ronnel	Atrazine
Aldrin	Chlorothalonil (Bravo[b])	Dacthal
o-Phenylphenol	Pentachlorophenol	PCBs (Aroclors 1242 and 1260)
Dieldrin	Dichlorvos (DDVP)	
	Dicofol	Hexachlorobenzene

[a]Lewis et al. (1988)
[b]Registered trademark.
[c]Pesticide oxidation product.

approximately 5,000 U.S. Air Force housing units, location of ventilation ducts and time of pesticide treatment (i.e., pre- or post-construction) appeared to influence the level of indoor contamination. Major seasonal shifts were also noted; concentrations were higher in winter for duct-in-slab type houses and in summer for crawl space houses. Houses at greatest risk were those constructed over a crawl space with post-construction treatment: 95% of these houses had a detectable level of chlordane (>0.5 $\mu g/m^3$) and 19% exceeded National Academy of Science guidelines compared to 5% for duct-in-slab type houses and 0% for slab houses with attic ducts (Lillie and Barnes, 1987).

Studies of nonmilitary residences in the United States have yielded similar results. Wright and Leidy (1982) have reported levels of chlordane ranging from 0.3 to 5.8 $\mu g/m^3$ and of heptachlor from 0.01 to 1.8 $\mu g/m^3$ in six houses for a period of one year after treatment. Maximum post-treatment indoor levels of chlordane ranging from approximately 100 to 400 $\mu g/m^3$ have been measured in some residences (Livingston and Jones, 1981; Louis and Kisselbach, 1987; Olds, 1987). Livingston and Jones (1981) found mean chlordane concentrations of 1 to 10 $\mu g/m^3$ in apartments 10 to 15 years after treatment. In one instance, after direct injection of 15 gallons of a 2% chlordane solution into a subslab duct,

an indoor airborne chlordane concentration of 1580 $\mu g/m^3$ was measured (Lillie and Barnes, 1987). Air concentrations of termiticides are generally significantly higher in basements than in upper floor rooms, often by a much as an order of magnitude (Lewis, 1988).

INORGANIC COMPOUNDS

In addition to asbestos, a number of inorganic pollutants, especially heavy metals, have been classified as carcinogens (World Health Organization, 1987b). The metals and metal compounds of most concern are arsenic (salts, arsenates, arsenites), beryllium, cadmium (oxide, bromide, chloride), chromium (hexavalent), nickel (carbonyl, subsulfide), and selenium (sulfide).

Few studies currently exist that provide a specific or exact profile of concentrations of these toxic metals in indoor environments. Some recent results from a small study conducted in the United States are shown in Table 11 (Lebret et al., 1987). A high correlation between cadmium and fine particle concentrations in this study indicated tobacco smoking to be a primary indoor source of cadmium.

The dusts found indoors originate from surface soil tracked into the building and from deposition of airborne particles originating outside. They also arise from mechanisms and activities indoors such as smoking and degradation and use of household products which contain heavy metals. Where the concentrations of metals, such as lead, have been measured indoors, alarmingly high levels of heavy metal contamination have been found, mainly arising from outside sources (Laxen et al., 1987). There is every reason to expect that concentrations of many metals exist at varying strengths indoors depending on the relation of the indoor environment to the outdoor pollutant source. Studies around smelters (Roberts et al., 1974) indicate that the contribution of specific particles indoors is greatest from surface soils. In some cases, the average metal concentration in house dusts remained close to the concentration level in the soil. Where indoor environments are relatively remote from a strong point source of pollution, indoor particle pollutant concentrations average 35% of those in airborne dusts outdoors and 75% of those in surrounding soils.

Important research needs are better source identification and better characterization of particular heavy metal concentrations indoors, especially for those metals and metal compounds that have been classified as carcinogens. Further research is also needed to assess the use of cadmium as a marker for ETS.

TABLE 11. ELEMENTAL CONCENTRATIONS OF FIVE CARCINOGENIC METALS IN 20 INDOOR SAMPLES[a]

Element	Indoor concentration (ng/m³)						Median outdoor concentration[b] (ng/my³)	Median indoor/outdoor ratio
	Median	Min.	90%	95%	MAX.	SD		
Cr	0.00	0.00	3.00	4.94	5.04	1.58	c	--
Ni	5.73	1.02	9.31	10.51	10.57	2.41	17.02	0.36
As	1.24	0.00	2.31	2.51	2.52	0.80	c	--
Se	0.56	0.00	0.93	1.09	1.10	0.34	1.18	0.44
Cd	1.29	0.00	2.87	2.94	2.94	1.05	c	--

[a]Fine particle samples (effective aerodynamic diameter <2.5 μm). Adapted from Lebret et al. (1987).
[b]Central-site monitoring.
[c]Below detection limit.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

In this report, indoor concentration data are presented for the following general categories of air pollutants: radon-222, environmental tobacco smoke (ETS), asbestos, gas phase organic compounds, formaldehyde, polycyclic aromatic hydrocarbons (PAH), pesticides, and inorganic compounds. these pollutants are either known or suspect carcinogens (i.e., radon-222, asbestos) or more complex mixtures or classes of compounds which contain known or suspect carcinogens. Concentration data for individual carcinogenic compounds in complex mixtures are usually far from complete. The data presented for complex mixtures often include compounds which are not carcinogenic or for which data are insufficient to evaluate carcinogenicity. Their inclusion is justified, however, by the possibility that further work may show them to be carcinogens, cocarcinogens, initiators or promotors, or that they may be employed as markers (e.g., nicotine, acrolein) for the estimation of exposure to complex mixtures.

17. KEY WORDS AND DOCUMENT ANALYSIS

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