Institute for Environment
and Health

Indoor air quality in the home: Final report on DETR contract EPG 1/5/12

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Written by Paul Harrison and Philip Holmes

Edited by Jean Emeny

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MRC Institute for Environment and Health
University of Leicester
94 Regent Road
Leicester
LE1 7DD

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Executive Summary

In 1994, the Department of the Environment (subsequently the Department of the Environment, Transport and the Regions, DETR*) commissioned the MRC Institute for Environment and Health (IEH) to undertake a major research programme on domestic indoor air pollution. The primary objectives were:

- to assess the consequences for health and well-being of the levels of various indoor pollutants found in homes, paying particular attention to the significance to potentially susceptible groups such as infants, children, the elderly and sick people;
- where appropriate, to prepare advice for householders on how they could improve the air quality in their homes; and
- to provide expert advice to facilitate the development of the DETR research and monitoring programmes.

This Final Report presents an overview of the various activities undertaken by IEH over the course of the research programme and summarises the key findings and recommendations arising from this work. Published literature on exposure and human health effects of a number of indoor pollutants has been critically evaluated, namely: airborne particles; bacteria; carbon monoxide (CO); formaldehyde; fungi; house dust mites (and other aeroallergens); medium density fibreboard (MDF); nitrogen dioxide (NO_2); pesticides; polycyclic aromatic hydrocarbons (PAHs); and volatile organic compounds (VOCs). The DETR also supported work on environmental tobacco smoke (ETS) which will contribute to a report to be prepared for the Department of Health (DH). The Institute has also assessed labelling schemes for household products relating to chemical emissions, and the influence of indoor air pollution on the health of young children. In addition a number of information leaflets have been prepared relating to various aspects of indoor air quality. IEH staff have provided expert advice to the department, represented the department at various meetings, and promoted awareness of the importance of indoor air quality to human health and well-being in the scientific community.

On the basis of the work undertaken by the Institute, it can be concluded that ETS, CO, and allergens are of particular importance to human health. In contrast, it appears that current levels of exposure to NO_2, VOCs and formaldehyde constitute a relatively low risk. The risks associated with exposure to pesticides, PAHs, moulds and endotoxins are as yet uncertain.

In addition to the detailed research recommendations arising from the individual reviews conducted by IEH over the course of this project (see Annex 1), a number of other potential areas for further investigation have been identified:

- Research into UK domestic exposure and the potential health effects of pesticides, PAHs, moulds and endotoxins;
- Clarification of the impact on health of interactions between various air pollutants;
- Assessment of the significance of airborne pollutant exposure in schools, hospitals and other public places;
- Further assessment of the role played by air pollutants in common childhood illnesses;
- Investigation of the importance of airborne pollutant exposures in syndromes such as multiple chemical sensitivity and sick building syndrome, compared with other factors such as temperature and humidity.

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*Now the Department for Environment, Food and Rural Affairs

1 Introduction

1.1 Background

Historically, interest and concern about air pollution have focused almost exclusively on outdoor air pollution, fuelled by the once frequent urban fogs in the UK associated with the burning of fossil fuels and, more recently, by the occurrence of episodes of traffic-related pollution. Over recent years, attention has turned to the importance of the quality of the air indoors, particularly in the home, where people (especially potentially vulnerable individuals such as the young, elderly or infirm) spend the majority of their time.

Following the publication in 1990 of the Government White Paper *This Common Inheritance*, which highlighted the importance to public health of indoor air pollution[a], the then Department of the Environment commissioned the Building Research Establishment (BRE) to undertake a study of pollutant levels in a sample of 174 normally occupied homes, in collaboration with the University of Bristol's project team responsible for the Avon Longitudinal Study of Pregnancy and Childhood (ALSPAC). To build on the findings from this work, and to provide the Department of the Environment, Transport and the Regions (DETR[b]) with the necessary additional scientific information for developing policy on air quality in the non-workplace indoor (domestic) environment, the MRC Institute for Environment and Health (IEH) was commissioned, in 1994, to undertake a major research programme into various aspects of this subject. The primary objectives have been to:

- assess the consequences for health and well-being of the levels of various air pollutants found in homes, paying particular attention to the significance to potentially susceptible groups such as infants, children, the elderly and sick people;

- where appropriate, to prepare advice for householders on how they could improve the air quality in their homes; and

- provide expert advice to facilitate the development of the DETR indoor air quality research and monitoring programmes.

1.2 Outline of activities conducted

This project has been conducted as a series of overlapping phases, each addressing a number of issues (see Table 1.1). The initial phase comprised a series of critical evaluations of the published literature on exposure and human health effects for a number of important indoor pollutants (formaldehyde, nitrogen dioxide (NO_2), volatile organic compounds (VOCs), house dust mites, bacteria and fungi) that were monitored in the BRE/ALSPAC survey. These papers were then subject to review at an expert workshop held in November 1994, and the report on these pollutants was subsequently published by IEH as Assessment A2 (IEH, 1996). In addition, information leaflets on gas cooking and VOCs and a lay summary of the pollutants covered in Assessment A2 were prepared.

In the second phase, reviews of carbon monoxide (CO) and airborne particles were undertaken supported by expert workshops held in June 1997 and January 1998, respectively. The work on CO has been published as IEH Assessment A5 (IEH, 1998a) while that on airborne particles has been published as a Special Report (IEH, 2000a). The DETR also supported work on environmental

[a] Also highlighted in a House of Commons Select Committee report published in 1991 (*Indoor Pollution*, Environment Select Committee Sixth Report, London, HMSO)
[b] Now the Department for Environment, Food and Rural Affairs

tobacco smoke (ETS) which will contribute to a report to be prepared for the Department of Health (DH).

The third phase of the project included two scoping studies, on domestic exposure to pesticides and aeroallergens. The latter study updated and extended previous work on house dust mites, bacteria and fungi reported in Assessment A2 and included, in addition, pet and insect allergens. Although not associated with an expert workshop, these comprehensive reports were subjected to external peer review before issue to DETR. A number of concise 'status' reports were also produced. These identified key issues relating to medium density fibreboard (MDF) and polycyclic aromatic hydrocarbons (PAHs), the labelling of household products for chemical emissions, and the influence of indoor air pollution on the health of young children. A follow-up meeting to discuss the implications of the IEH assessment on carbon monoxide was held in October 1998, with the support of both DETR and DH.

Table 1.1 Summary of review activities undertaken, by phase (with outputs)

Phase	Activity
I	Review of NO_2, formaldehyde, VOCs, house dust mites, fungi and bacteria (Published as IEH Assessment A2; IEH, 1996)
	Preparation of gas cooking leaflet
	Preparation of summary leaflet of Assessment A2
	Preparation of VOCs leaflet
II	Review of CO (Published as IEH Assessment A5; IEH, 1998a)
	Review of ETS (Contributing to a report being prepared for DH)
	Review of airborne particles (Published as an IEH Special Report; IEH, 2000)
III	MDF status report (Internal report; IEH, 1998b)
	Labelling of household products for chemical emissions (Internal report; IEH, 1999a)
	CO follow up meeting (Internal report; IEH, 1999b)
	Allergens scoping study (Internal report; IEH, 1999c)
	Pesticides scoping study (Internal report; IEH, 1999d)
	PAH status report (Internal report; IEH, 1999e)
	Childhood health status report (Internal report; IEH, 2000b)

In addition, running through each of the phases, IEH staff have undertaken a number of additional tasks (see Sections 3 and 4), including research promotion and co-ordination, the provision of expert advice to the Department, representing the Department at various national and international meetings, and promoting awareness, in the scientific community, of the importance of indoor air quality to human health and well-being.

2 Specific Pollutants and Issues Addressed

As outlined in Section 1, critical reviews of the published literature on exposure and human health effects have been conducted for a wide range of airborne pollutants that are of potential significance to human health within the context of the indoor (home) environment. The specific pollutants addressed were:

Airborne particles

Allergens

Bacteria

Carbon monoxide (CO)

Formaldehyde

Fungi

House dust mites

Medium density fibreboard (MDF)

Nitrogen (NO_2)

Pesticides

Polycyclic aromatic hydrocarbons (PAHs)

Volatile organic compounds (VOCs)

In addition, work was undertaken on factors influencing childhood health, and labelling schemes for household products with regard to their chemical emissions. Work was also conducted on environmental tobacco smoke (ETS) under this project; however, since this is to be published in a report commissioned by the Department of Health (DH), detailed findings are not presented here.

Other activities undertaken by IEH as part of this project include the production of text for:

- a summary of the conclusions from Assessment A2, published by IEH for use by Environmental Health Officers;
- a leaflet giving advice to householders on cooking with gas, published by the Department of Environment, Transport and the Regions (DETR); and
- a leaflet on VOCs, published by DETR for use by Environmental Health Professionals.

The main findings and research recommendations arising from the Institute's reviews are summarised below. The full reference citations and the detailed executive summaries for each of the reports are presented in Annex 1.

2.1 Airborne particles

The review of data on outdoor, indoor and personal exposures to airborne particles and the likely effects on health (IEH, 2000a) concluded that there was considerable epidemiological evidence that airborne particles of 10 µm diameter or less (PM_{10}) may exert significant adverse effects on health. Short-term variations in outdoor (ambient) particle level are strongly associated with changes in mortality, morbidity, and hospital/emergency room admission rates. Cardiopulmonary impairment is the predominant effect, with the elderly or infirm at particular risk. Short-term changes in pulmonary function and respiratory symptoms have also been noted, particularly in asthmatics. Less certainly, long-term exposure may increase mortality and morbidity rates and levels of respiratory symptoms, and impair pulmonary function. There is some suggestion that smaller particles (<2.5 µm) may be particularly important. Experimental studies have identified several potential mechanisms of toxicity by which such local (respiratory) and systemic effects may be mediated.

Indoor particle levels are generally lower than, but correlated with, outdoor levels, except when a significant indoor source is present; the relative contribution to the health effects of indoor sources compared with outdoor sources is unclear. However, it should be noted that those subgroups at particular risk spend the majority of their time indoors. Potential indoor particle sources include cooking (both from the food and from the cooker in the case of gas), certain heating appliances, and human activity. The role of ETS and allergenic (biological) particles must also be recognised. A number of research needs were identified, including aspects of epidemiology and human experimental research, exposure assessment, and mechanistic studies.

2.2 Bacteria and fungi

In Assessment A2 published in 1996 (IEH, 1996) it was noted that although a wide range of fungal and bacterial species can be isolated from indoor air, the few epidemiological studies conducted up to that time had shown no convincing specific association between exposure to indoor airborne fungi and respiratory disease. However, a consistent link has been established between damp/mouldy housing and respiratory symptoms in children, suggesting that these pollutants may exert a significant effect on the health and well-being of the population. No relevant studies were identified on bacteria and their potential adverse health effects. A need to improve methods of measuring exposure to mould and bacterial species (and their products) was identified. In addition, further research was recommended into the toxicological mechanisms by which bacteria and fungi may influence health.

2.3 Carbon monoxide

After examining the available data on indoor exposure and the potential health effects of CO, the Institute concluded that the impact of this pollutant on the health of the public may be greater than has been recognised historically.

The report (Assessment A5; IEH, 1998a) noted that although outdoor CO levels influence indoor exposure levels, the major determinants (where present) are indoor sources such as gas cookers and heating systems burning gas, wood, coal or paraffin. Environmental tobacco smoke, the presence of an attached garage and the proximity of heavily trafficked roads can also affect indoor levels. Poorly installed, inadequately ventilated or malfunctioning appliances and accidentally blocked flues can also increase levels. In a study of 14 UK homes, a maximum 1 hour concentration of 57.0 mg/m^3 (49.8 ppm) was recorded in one kitchen found to have a malfunctioning boiler. This finding suggests that air quality guidelines* may be exceeded in a number of UK homes and, while it is not valid to extrapolate from this small study to the overall housing stock, there is cause for concern.

The acute, and sometimes fatal, health effects of accidental exposure to CO are well documented. Consistent symptoms, such as headache, nausea and dizziness, have been reported following exposure to high levels. However, the review highlighted that these symptoms may be easily confused with those of other ailments (e.g. food poisoning or influenza) and that missed or misdiagnoses of CO intoxication almost certainly occur. A number of other possible health effects were identified including atherosclerosis promotion, changes in immune function and altered neuropsychological and neurotransmission functions.

It is probable that in some homes CO levels routinely occur that may cause chronic health effects, particularly among sensitive groups. The report concluded that the risk of adverse effects as a result of exposure was probably low under normal circumstances, but that there was sufficient cause for concern to warrant measures to minimise CO levels and increase awareness of the symptomatology of CO intoxication among health care professionals and others to whom the public look for advice and assistance. An extensive series of research recommendations were also proposed.

In the light of the significance of the findings, a meeting was held in October 1998 to discuss further potential strategies for tackling this issue. The experts who attended the meeting identified a number of specific research needs addressing exposure monitoring and health surveillance, and suggested a series of measures to increase awareness among health and related professionals and the general public.

2.4 Formaldehyde

Formaldehyde occurs ubiquitously in the environment. Indoors its principal sources are pressed wood constructions (e.g. MDF; see Section 2.6), urea–formaldehyde foam insulation and household cleaning agents.

A number of health effects of formaldehyde are known including sensory and airway irritation. In Assessment A2 (IEH, 1996) it was concluded that in most, but not all, UK homes formaldehyde levels are probably below the level causing effects. However, it was recognised that some individuals may be particularly sensitive. It was recommended that current mean indoor concentrations of formaldehyde should not be allowed to rise, and industry should be encouraged to reduce formaldehyde emissions from pressed wood products either by changing the manufacturing process or allowing off-gassing before sale.

2.5 House dust mites

The Institute's 1996 assessment (IEH, 1996), although recognising that exposure to house dust mite allergen represents a potential hazard to health, noted that relationships between exposure and development of allergic sensitisation are poorly defined. Nonetheless, because of the public health impact of exposure to house dust mite allergens, a general reduction in mite allergens in homes was encouraged, and it was suggested that lower indoor humidity could contribute to reducing house dust mite numbers and hence allergen exposure.

* Current World Health Organization guidelines for CO: 100 mg/m^3 for 15 minutes, 60 mg/m^3 for 30 minutes, 30 mg/m^3 for 1 hour and 10 mg/m^3 for 8 hours

2.6 Medium density fibreboard

A short status report (IEH, 1998b) addressed the toxicological and health data on MDF relevant to its domestic use. Concern was focused on the release of dust during work on the material, and the possibility that any fibres or dust particles released may be inhaled and persist in the lung. In addition, it was noted that formaldehyde would be released by off-gassing (see Section 2.4).

Data on occupational exposure to MDF were noted as being limited to two cross-sectional studies, and concerned only acute effects. The workers studied were not exclusively exposed to MDF dusts, making it difficult to reach clear conclusions about MDF dust alone. Overall, the health effects observed were consistent with the established acute effects of soft and hardwood dusts and/or free formaldehyde at comparable levels. Exposure to wood dusts during DIY was considered unlikely to pose any measurable health risk. The need for further research on the particle characterisation and toxicological properties of MDF was noted.

2.7 Nitrogen dioxide

In Assessment A2 (IEH, 1996) the extensive literature addressing indoor concentrations and health effects of NO_2 was reviewed. It was noted that outdoor levels influence indoor levels, but (where present) the major source of NO_2 indoors is cooking with gas. The evidence on health effects points most to increased respiratory illness in children, perhaps resulting from increased susceptibility to infection. Although the risk of significant respiratory ill-health from gas cooking appears small, it is prudent to encourage reductions in domestic exposure to NO_2 and other combustion products. A number of research recommendations were identified, including: determination of representative NO_2 levels in UK homes, including homes with indoor sources other than gas cookers; assessment of the effectiveness of remediation methods such as cooker extract hoods; investigation of the health effects of gas cooking, especially in potentially susceptible groups such as asthmatics and sufferers from chronic bronchitis; and study of the mechanisms of toxicity of NO_2, particularly the effects of levels representative of domestic exposure on pulmonary immune function and susceptibility to infection.

2.8 Pesticides

An unpublished IEH report (IEH, 1999d) concluded that, in the UK, little is known about domestic pesticide exposure, other than the information derived from the regulatory approval process (required by the Control of Pesticide Regulations, 1986). The main source of indoor pesticide exposure in the home is believed to be the direct application of pesticide products. Other, relatively minor, indoor sources include pre-treated products and materials and releases from pesticide products stored within the home.

Pesticide exposure in UK homes is likely to be extremely variable, and will depend on the type of property, the products or combination of products applied, the frequency and magnitude of application, and the degree of adherence to product use instructions. In addition, concentrations achieved will depend on the particular active ingredient, the method of application, the amount applied, the room size, and rates of ventilation and loss from the indoor environment. A particular cause for concern is the recognition that, in actual use situations, instructions accompanying the product are rarely followed and, hence, actual exposures may be markedly different from the patterns or frequencies predicted by the regulatory risk assessment process. Indeed, some estimates have suggested that the Reference Dose may, on occasion, be exceeded. The individuals considered at greatest risk of high exposures are infants and young children, who may be exposed not only through inhalation of pesticide vapour, but also by mouthing objects on which pesticides have been adsorbed, through dermal absorption of surface residues, and ingestion of residues adsorbed onto household dust.

At present there is insufficient evidence to conclude that indoor non-occupational exposure to pesticides is, or may be, associated with adverse health effects. Certainly, under normal use, it is very unlikely that acute toxicity would be elicited at domestic exposure levels. However, the potential impact of low-level, long-term exposure is poorly understood. In addition, it is possible that background or ambient pesticide levels may contribute to total pesticide exposure and although such exposures would be small, little is known about the potential consequences of long-term, low-level, exposure to multiple active ingredients or residues. Therefore, in addition to undertaking additional research to address the identified gaps in knowledge, it is appropriate to encourage the use of pesticides only within the context of an integrated pest management strategy that includes other measures to prevent or limit ingress or occurrence of pests, and that ways should be found to improve compliance with product usage instructions.

2.9 Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons are produced by the combustion of complex organic materials, and humans may be exposed to low levels of complex PAH mixtures from a variety of sources. An internal report (IEH, 1999e) determined that indoor levels of PAHs in air are heavily influenced by ambient levels, but significant domestic indoor sources do exist, for example smoking, fuel combustion (for cooking or heating) and cooking food. In 1999[a], the Expert Panel on Air Quality Standards (EPAQS), using benzo-*a*-pyrene (B[a]P) as a marker for total PAHs, established an ambient air quality standard of 0.25 ng/m^3 B[a]P, annual average. In the late 1990s, UK outdoor annual average concentrations of B[a]P ranged from 0.05 to 0.5 ng/m^3. Data on UK domestic levels were not available. However, US indoor levels were generally in the range of approximately 0.2 to 2.8 ng/m^3 (24 hour average) in the absence of obvious sources of PAHs.

Data on the potential hazard posed by PAHs are largely derived from animal and *in vitro* assay systems, and several individual PAHs have been established to be carcinogens. Occupational exposure to PAHs has been associated with excess deaths from lung cancer and, to a lesser extent, with skin and bladder cancer.

It was concluded that, although occurring at only ng/m^3 concentrations and having received little attention to date, PAHs may represent an important class of trace level indoor contaminants. A number of research recommendations to address the data gaps were identified.

2.10 Volatile organic compounds

IEH (1996) has reviewed the available information on indoor exposure to VOCs and their potential health effects and made a number of conclusions and recommendations.

Levels indoors are tenfold higher than outdoor levels. A number of indoor sources of VOCs have been identified including paints, glues and other household and home maintenance products. The levels of, and precise consequences of, exposure to VOCs are difficult to evaluate because of the complexity and variable nature of the mixture. For example, a Building Research Establishment (BRE) study[b] identified over 200 individual compounds, with mean concentrations of 0.2–0.4 mg/m^3 (total VOCs), although the levels of benzene found in the BRE study suggest that concentrations of this pollutant would be unlikely to exceed the EPAQS guideline figure of 16.2 µg/m^3 (5 ppb) as an annual running total. The main health effects of VOCs appear to relate to comfort and well-being; there is no evidence of a health risk at current levels in UK homes. However, it is important to note that some

[a] See http://www.defra.gov.uk/

[b] Berry RW, Brown VM, Coward SKD, Crump DR, Gavin M, Grimes CP, Higham DF, Hull AV, Hunter CA, Jeffrey IG, Lea RG, Llewellyn JW & Raw GJ (1996) *Indoor Air Quality in Homes: Parts 1 & 2* (BR299 & BR300), London, UK, Construction Research Communications

VOCs (e.g. benzene) are established carcinogens or genotoxins, for which safe levels cannot be defined, or may be allergenic, by mechanisms that are poorly understood.

2.11 Allergens

A short status report (IEH, 1999c) reviewed current knowledge of indoor exposure to and potential health effects of house dust mites, fungi and bacteria*, domestic pets and cockroaches.

The allergenicity of house dust is known to be related to the presence of house dust mites, which are a normal feature of the home environment. Fungi and bacteria can also be particularly numerous in homes, and their importance as allergens has probably been underestimated. Bacteria indoors mainly originate from the occupants but can also colonise and be released from surfaces, furniture and carpets. Several tissues and secretions from cats and dogs are allergenic, and the small size and stickiness of these allergens facilitate their transport between different areas and result in their presence in places such as schools or day-care centres where source animals are not present. Cockroach infestation is a greater problem in Asia and the Americas than in the UK. However, recent French and UK studies have suggested that sensitivity to cockroach allergens may be an issue in some locations. The major health effects associated with indoor allergens are asthma, atopic dermatitis and allergic rhinitis; most research has focused on the role of allergens in asthma. There appears to be a dose–response relationship between exposure and sensitisation, but the evidence is less strong for a relationship between exposure and symptoms.

Numerous risk factors may be responsible for the current increasing prevalence of allergic respiratory disease, and there is an on-going debate about their relative importance. Exposure to allergens is an essential prerequisite for sensitisation, and genetic predisposition is also important. Other possible factors are childhood infection, family size and structure, co-exposure to other air pollutants, gender, diet, race, socio-economics, pre- and perinatal factors, home dampness and pet ownership, although the evidence for these is mostly limited or equivocal.

The review concluded that, for individuals at risk of developing allergic disease or who already suffer from it, exposure to allergens should be reduced as much as practicable, although complete eradication of allergens from a home is impossible. A better understanding of allergen exposure, indoor distribution of allergens and the aetiology of allergic disease is considered essential for achieving improvements in the management of symptomatic asthma.

2.12 Labelling household products for chemical emissions

In addition to the review of specific pollutants, IEH has investigated how labelling schemes for chemical emissions from household and building products in the UK compare with those in Europe and the USA, including a comparison of the types of information appearing on labels and the way different labelling schemes are operated (IEH, 1999a). Relevant schemes for paints and varnishes, carpets, cleaning products, building materials, furniture and furnishings were identified, and it became apparent that it was only practicable to address schemes on a product group basis.

A role was recognised for both ‘single-issue’ and ‘multiple-issue’ labels or symbols, depending upon the type of product and the extent and nature of its chemical emissions. For both types of label, it was concluded that additional information may be needed to facilitate comparison of products by consumers, and that all wording and symbols used should comply with the principles of the *Green*

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* The review of information on house dust mites, fungi and bacteria was intended to update IEH Assessment A2 (IEH, 1996)

Claims Code[a]. The provision of such additional information is likely to make a labelling scheme more effective, particularly where the scheme is based on the use of only a logo.

It was noted that experience in the UK and abroad supports the development of labelling schemes through dialogue between government, trade associations and manufacturers on a voluntary basis, and can result in voluntary labelling schemes that manufacturers are comfortable with, and that can be operated effectively by trade associations. This approach is in agreement with proposals in the *Sustainable Business*[b] consultation document published by DETR in 1998. A number of specific recommendations relating to labelling schemes in the UK were made.

2.13 Childhood health

A number of common conditions of childhood are known to be influenced by environmental factors. A brief overview of the latest developments, statistical trends and initiatives relating to these conditions in young children (up to approximately 5 years of age) in the UK, has been prepared (IEH, 2000).

In the UK, asthma is the most common chronic disease of children and the cause of a high number of medical consultations. For children in this age range, asthma symptoms are usually triggered by extrinsic factors, such as infections, house dust mites, pet danders and pollens. Hence, the quality of indoor air to which the child is exposed may be very important. Pollutants of particular concern are ETS, VOCs and nitrogen oxides.

Middle ear infection (otitis media) is a very common childhood infection, usually of bacterial but occasionally of viral origin, which presents in an acute, rapidly resolving form but which can develop into a chronic condition. On the basis of current knowledge of the risk factors, ETS exposure may be the only factor open to amelioration.

Lower respiratory tract infection accounts for over 60% of all deaths from respiratory causes in this age group; upper tract infections account for a further 10%. A significant established extrinsic risk factor for lower tract infection is ETS exposure, again underlining the importance of this pollutant in relation to childhood health.

As its name implies, sudden infant death syndrome (SIDS) is not a condition but a syndrome, with multiple unrelated risk factors. Again, environmental tobacco smoke (ETS) may play a role in this condition, but it is by no means the only factor that can be addressed, and there has, for example, been a very successful government 'back to sleep' campaign on this issue.

[a] Available [September 2001] at http://www.defra.gov.uk/
[b] Available [September 2001] at http://www.defra.gov.uk/

3 Research Promotion and Co-ordination Activities

Throughout the period of this contract, the Institute has been actively engaged in supporting and directing research into indoor air quality, particularly through the involvement of the Programme Manager, Dr Harrison, in a number of expert committees and research liaison and co-ordinating groups. The various meetings attended are summarised in Table 3.1.

Table 3.1 Institute involvement in research promotion/co-ordination

Group	Task	Date
Interdepartmental Liaison Group on Indoor Air Quality (IDLGIAQ) and IAQ Research Steering Group	IDLGIAQ meetings	13 April 1994 13 October 1994 4 October 1995 24 April 1996 23 October 1996 16 April 1997 15 October 1997 19 May 1998 16 February 1999
	Research review meetings	6 April 1995 28 June 1995 31 January 1996 26 June 1997
	Building Research Establishment (BRE) programme & brainstorming sessions discussed	27 June 1996
	Brainstorming meeting on House Dust Mites	24 September 1996
	Brainstorming meeting on Particulate Matter	5 September 1996
European Concerted Action (ECA) Committee — Indoor Air Quality programme	Steering group meetings	16, 17 October 1994 8, 9 September 1995 8, 9 April 1997 12, 13 March 1998 7, 8 October 1998 5, 6 August 1999

4 National and International Representation

IEH staff have presented the findings and research recommendations arising from the critical reviews undertaken during this project at a number of major national and international venues. This included the presentation, by Dr Harrison, of three papers at the 1996 Indoor Air conference in Nagoya, Japan, a paper at the 1997 Healthy Building Conference in Washington, USA, and a paper on exposure and health risks of carbon monoxide at the ISBE/IUTOX meeting in Dijon, France in July 1998. Dr Tuckett also gave a poster presentation on indoor particles at a Health Effects Institute (HEI) conference in 1998. Other activities in the field of indoor air research include Dr Harrison’s attendance at several other international conferences and meetings, including Berzelius symposium 18, Health Aspects of Indoor Air, in Stockholm in September 1994, Healthy Buildings Conference 95 in Milan, and the World Health Organization (WHO) meeting on Smoking and Children’s Health in January 1999, and Dr Humfrey’s attendance at the meeting of the WHO working group on exposure assessment to pollutants in the indoor environment in Bilthoven in September 1995.

Dr Harrison also was rapporteur and editor of the final report on the WHO Working Group on Indoor Air Quality (IAQ) policy, and co-chaired a Building Research Establishment (BRE) seminar on product emissions in April 1999 at which both he and Dr Courage made presentations. In addition, in relation to her work for this and an associated Department of Health (DH) project on environmental tobacco smoke (ETS) and childhood health, Dr Courage took part in a meeting in Essen Germany entitled Passive Smoking and Children, Clinical and Experimental Focus in August 1998, and in the Working Group on Environmental and Children’s Health: Action for the 21st Century, in Dublin in September 1998. More recently, IEH staff gave a series of poster and/or oral presentations associated with outputs from this contract at the Indoor Air 99 conference in Edinburgh (see separate report to the Department of the Environment, Transport and the Regions (DETR); IEH, 1999f).

In addition to disseminating the findings of our work through presentations at conferences and IEH assessments, a number of papers have been published in the open scientific literature (see Annex 2).

5 Discussion and Conclusions

Throughout the 1990s the quality of the indoor environment, in particular air quality, has increasingly been recognised as important for the health and well-being of the UK population. Given the high percentage of time that people in developed countries spend in the indoor environment, a significant proportion of which is in their homes, it is essential that any airborne pollutants in the domestic environment which may pose a risk to health are identified, and that measures to reduce or eliminate exposure to them are developed.

Since 1994, IEH has undertaken reviews on exposure in the home and the potential health effects of a wide range of airborne pollutants. The findings from these reviews have contributed to scientific understanding of the potential risks posed by these pollutants, assisted in forming opinion as to their relative importance, and have generated an extensive series of recommendations intended to address gaps in knowledge and to assist in the development of practical measures leading to a reduction in risk (see Annex 1 for detailed recommendations). As part of this project, Institute staff have also been actively engaged in supporting and directing research into indoor air quality through participation in expert committees, research liaison and co-ordinating groups, and by acting as secretariat support for key UK Government advisory committees. As well as the two published IEH assessments (A2 and A5) and the various internal reports to the Department of the Environment, Transport and the Regions (DETR) (see Annex 1), IEH staff have published a number of papers in the open scientific literature (Annex 2), and have presented the findings and recommendations of the reviews at national and international venues, thereby raising awareness of the importance of indoor air pollution among the scientific and regulatory communities.

With regard to the risks posed by particular pollutants, it is well established that (where present) **environmental tobacco smoke** (ETS) is a major health risk, particularly for children, who have little or no control over their environment. The effects of ambient **particles** on mortality and morbidity are also now well established through epidemiological investigations, particularly with regard to the impact of acute exposures on the cardiopulmonary system. The elderly, infirm and, probably, the very young appear at particular risk, and these groups typically spend much time indoors. However, there remains considerable uncertainty regarding the relative importance of indoor and outdoor sources, and the potential impact of long-term, low-level particle exposures, an aspect that could have profound implications for public health.

In addition to stressing the well-established role of **carbon monoxide** (CO) as a potentially lethal acute toxicant, an IEH assessment, published in June 1998, emphasised the potential hazard posed by low-level, long-term exposure to this pollutant. Publication of this report led to the issue, in September of that year, of a joint letter from the Chief Medical Officer and Chief Nursing Officer to General Practitioners, Directors of Public Health, Consultants in Communicable Disease Control, Regional Directors of Public Health, Medical Directors of NHS trusts, Regional and District Nursing Directors, Obstetricians and Paediatric consultants on the importance of recognising the symptoms of CO poisoning. The report also led the Department of Health to instigate a series of review meetings to monitor and assess the implications of developments in scientific understanding of this important pollutant.

The apparent increase in incidence of allergic conditions among the UK population underlines the importance of allergens as a potential cause of ill-health. Given the range of allergens and their ubiquitous presence in the domestic environment, continued research into these pollutants should be considered a priority. In addition, the possible role played by moulds and endotoxins in non-allergenic disease is now recognised by the scientific community as an issue that requires detailed investigation.

Surprisingly little is known about the indoor use or concentrations of **pesticides** in homes in the UK despite there being 150 active ingredients in over 2100 pesticide products available for potential use.

Exposure patterns are likely to be highly individual since these will be influenced by location, application method and frequency. Although it is unlikely that proper use of pesticides in the home will lead to acute intoxication, the implications for health of low-level, long-term exposure are less clear. At present there is also inadequate information for an assessment of the significance to health of indoor exposure to **polycyclic aromatic hydrocarbons** (PAHs) in the UK but, given the established toxicity of some PAHs, further research into the sources and health impacts of this complex mixture of pollutants appears to be warranted. Although there is little evidence for acute effects, questions remain as to the possible consequences of low-level long-term exposure. Indoor exposure to **nitrogen dioxide** (NO_2) and **volatile organic compounds** (VOCs) appears to constitute a relatively low risk in the UK situation, but given the evidence of a link between NO_2 and respiratory illness in children, the development of exposure reduction strategies for this pollutant is nevertheless considered appropriate. Current levels of **formaldehyde** in UK homes also seem to warrant little concern other than ensuring that measures are taken to ensure that concentrations of this pollutant do not rise above current levels, such as may result, for example, from increased usage in homes of formaldehyde-containing materials.

The possibility that health effects may arise through interactions (e.g. additivity or synergism) between various pollutants, and the significance of airborne pollutant exposures in schools, hospitals and other public places, are areas for possible further study. The brief review on childhood health issues raised a number of questions regarding the role of indoor air pollutants in several common childhood conditions, while there remain outstanding gaps in knowledge with respect to the importance of indoor air pollutants in syndromes such as multiple chemical sensitivity (MCS) and sick building syndrome (SBS). The development of improved household product labelling schemes is also an important issue since this impinges on an individual's ability to make informed choices about their indoor environment.

In conclusion, the indoor air pollutants in the UK domestic environment studied by IEH that are of particular importance to human health are ETS, CO and allergens. In contrast, it appears that current levels of exposure to NO_2, VOCs and formaldehyde probably constitute a relatively low risk, although some individuals may be peculiarly susceptible. The risks associated with exposure to pesticides, PAHs, moulds and endotoxins are as yet uncertain. A number of other issues relating to indoor air pollution that could be the focus of future work have been identified, namely:

- Further research into UK domestic exposure and the potential health effects of pesticides, PAHs, moulds and endotoxins;
- Clarification of the impact on health of interactions between various air pollutants;
- Assessment of the significance of airborne pollutant exposure in schools, hospitals and other public places;
- Assessment of the role played by air pollutants in common childhood illnesses;
- Investigation of the importance of airborne pollutant exposures in syndromes such as MCS and SBS, compared with other factors such as ambient temperature and humidity.

Annex 1

Executive summaries of published and unpublished reports

Executive summaries are presented below for the following reports:

IEH publications

IEH (1996) *Indoor Air Quality in the Home: Nitrogen Dioxide, Formaldehyde, Volatile Organic Compounds, House Dust Mites, Fungi and Bacteria* (Assessment A2), Leicester, UK, Institute for Environment and Health

IEH (1998a) *Indoor Air Quality in the Home (2): Carbon Monoxide* (Assessment A5), Leicester, UK, Institute for Environment and Health

IEH (2000a) *Airborne Particles: Exposure in the Home and Health Effects* (Special Report SR17), Leicester, UK, Institute for Environment and Health

Internal reports to DETR

IEH (1998b) *Indoor Air Quality in the Home: Medium Density Fibreboard*, Leicester, UK, Institute for Environment and Health

IEH (1999a) *Indoor Air Quality in the Home: Labelling of Chemical Emissions from Household Products,* Leicester, UK, Institute for Environment and Health

IEH (1999b) *Carbon Monoxide Follow-up Meeting*[*]*,* Leicester, UK, Institute for Environment and Health

IEH (1999c) *Indoor Air Quality in the Home: Allergens,* Leicester, UK, Institute for Environment and Health

IEH (1999d) *Indoor Air Quality in the Home: Pesticides in the Home*, Leicester, UK, Institute for Environment and Health

IEH (1999e) *Indoor Air Quality in the Home: Polycyclic Aromatic Hydrocarbons*, Leicester, UK, Institute for Environment and Health

IEH (2000b) *Childhood Health,* Leicester, UK, Institute for Environment and Health

[*] Joint report to DETR and DH

Indoor air quality in the home: Nitrogen dioxide, formaldehyde, volatile organic compounds, house dust mites, fungi and bacteria (Assessment A2; IEH, 1996)

Executive summary

Background

While it is recognised that people spend the majority of time indoors, mostly at home, much of the attention to date relating to the health effects of air pollutants has focused on outdoor air quality. This report looks at the available data on exposure to some of the common indoor pollutants, namely nitrogen dioxide (NO_2), formaldehyde, volatile organic compounds (VOCs), house dust mites, fungi and bacteria, and assesses the likely impacts on health and well-being of occupants of the levels of these pollutants typically found in UK homes, making special reference to the monitoring data from the recent Building Research Establishment (BRE) survey of houses in the county of Avon. This assessment will contribute to the development of the Department of the Environment's strategy on indoor air quality and its advice to the public.

Review process

As a first stage in the review process, the Institute for Environment and Health (IEH) prepared reviews on exposure to the indoor air pollutants under consideration as well as their possible health effects. International experts, together with BRE scientists and representatives of relevant Government departments, were then invited to discuss the issues at a workshop held in Leicester in November 1994. The purpose of the workshop was to ensure that the IEH reviews were up to date, accurate, comprehensive and balanced, to obtain an expert assessment of the likely health consequences of exposure to the pollutants in UK homes, to identify the key gaps in knowledge and to make recommendations for further research. This assessment is based on the original reviews, the opinions of experts at the meeting, and additional text provided by workshop participants and IEH staff subsequent to the meeting.

Exposure and health effects evaluations

Nitrogen dioxide

There is a large body of literature addressing the indoor concentration and the health effects of NO_2. Outdoor levels are known to influence indoor levels but, where present, the major source of NO_2 indoors is cooking with gas. In the absence of actual measurements, the presence of a gas cooker in the home has frequently been used as a surrogate for NO_2 exposure.

Recent UK studies have shown one or two week averages to range from 25–70 $\mu g/m^3$ where there was gas cooking, and 13–40 $\mu g/m^3$ where there was no gas cooking. Continuous monitoring has indicated one hour averages of up to 1115 $\mu g/m^3$ in kitchens with gas cookers.

The published evidence on health effects points most to a hazard of respiratory illness in children, perhaps resulting from increased susceptibility to infection. Although the risk of significant respiratory ill-health from gas cooking appears small, it is prudent to encourage measures to reduce domestic exposure to NO_2 and other combustion products.

Formaldehyde

Formaldehyde occurs ubiquitously in the environment. Indoors its principal sources are pressed wood (particle board) constructions, urea–formaldehyde foam insulation and household cleaning agents. The BRE study showed annual mean indoor levels for all houses ranging from 0.020 to 0.025 mg/m^3 according to the room sampled; a comprehensive European survey in homes and schools reported levels between 0.01 and 0.1 mg/m^3.

Formaldehyde can produce sensory and airway irritation. At a maximum concentration of 0.1 mg/m^3 (averaged over 30 minutes), transient sensory effects would be avoided for most people, although some individuals may show effects at or below this level. In most but not all UK homes, formaldehyde levels are probably below this. For the protection of health and well-being, current mean indoor concentrations of formaldehyde should not be allowed to rise.

Volatile organic compounds

Sources of VOCs in the home include paints, glues and other household and home maintenance products. The extent of exposure and the respective health effects of VOCs are difficult to assess because non-standardised techniques have been used to measure numerous VOCs, often present at very low concentrations. The BRE study identified over 200 individual compounds, with mean concentrations of 0.2–0.4 mg/m^3 (total VOCs; TVOCs). Levels indoors were tenfold higher than outdoor levels. There was a significant relationship between elevated TVOC concentrations and recent painting and decorating activities. For benzene (a known carcinogen), the mean concentration was around 8 $\mu g/m^3$.

The precise consequences of exposure to VOCs are difficult to evaluate because of the complexity and variable nature of the mixture, but the main effects relate to comfort and well-being and there is no evidence of a health risk at current levels in UK homes. Although levels of benzene in UK homes are generally low, it is important to identify and eradicate or reduce potential indoor sources.

House dust mites

Exposure to house dust mites is usually expressed in terms of mite numbers or mite allergen per unit weight of dust or area sampled (e.g. mattress or carpet). The geometric mean mite count in the BRE study was 186 $mites/m^2$ in the living room carpet and 174 $mites/m^2$ in the bedroom carpet, with a marked seasonal variation due to temperature and humidity changes.

Although it is recognised that exposure to house dust mite allergen represents a potential hazard to health, the exposure–response relationship between exposure and development of allergic sensitisation remains poorly defined. A general reduction in mite allergen exposure in homes is nevertheless encouraged. Lower indoor humidity could contribute to reducing house dust mite numbers and hence allergen exposure.

Fungi and bacteria

A wide range of fungal and bacterial species can be isolated from indoor air. Although there is consistent evidence of a link between damp and mouldy housing and reports of respiratory symptoms in children, the few epidemiological studies conducted to date show no convincing specific association between exposure to indoor airborne fungi and respiratory disease; there are no relevant studies on bacteria and adverse health outcomes.

Main research recommendations

- Studies should be undertaken to ascertain what health benefit might result from an overall reduction in exposure to house dust mites.
- Studies are needed in homes with high levels of NO_2 to establish whether such conditions are associated with detectable health effects.
- Additional studies should be undertaken on the health effects of NO_2 and gas cooking, especially in potentially susceptible sub-groups.
- Further characterisation of exposure to formaldehyde and VOCs and the relation to static (area) measurements is encouraged.
- The definition of and techniques for the measurement of VOCs and TVOCs should be standardised.

- Better methods for the measurement of exposure to mould and bacterial species (and their products) should be developed.

Conclusions

Indoor air quality is an important area for research and public health policy.

Of the pollutants considered, house dust mites and NO_2 are the most important in terms of likely health effects following exposure in the home. Although the hazard to health resulting from exposure to house dust mite allergen cannot at present be quantified, a general reduction in exposure is recommended. Despite various uncertainties, there is some evidence for a link between NO_2 and respiratory illness in children. Although the health risk is probably small, measures to reduce exposure to NO_2 are appropriate.

For the other pollutants studied, whilst potentially a hazard, there is no evidence that they pose a risk to health at the levels typically found in UK homes. Lower indoor pollutant levels are nevertheless generally encouraged.

Indoor air quality in the home (2): Carbon monoxide (Assessment A5; IEH, 1998a)

Executive summary

Background

People spend the majority of time indoors, mostly in the domestic environment, where there may be significant air pollution sources. This assessment examines available data on exposure to carbon monoxide (CO) and evaluates the likely effects on health and well-being caused by levels of CO typically found in UK homes; it was commissioned by the Department of the Environment, Transport and the Regions to contribute towards the development of the Government's strategy on indoor air quality and the formulation of advice for the public.

Review process

As a first stage in this process, the Institute for Environment and Health (IEH) prepared an extensive literature review on exposure to CO in the home and the potential health effects relating to such exposure. International experts and representatives of relevant Government departments then discussed the key issues at a workshop held in Leicester in June 1997. The primary purpose of the workshop was to ensure that the IEH review was up to date, accurate, balanced and comprehensive. Expert opinion on the likely health effects of exposure to CO in UK homes was sought and key knowledge gaps and research recommendations were identified. This assessment, based on the original review, incorporates the opinions of the experts at the meeting along with some additional text and data provided by workshop participants and IEH staff subsequent to the meeting.

Exposure and health effects evaluation

There is a large body of literature concerning indoor concentrations and the health effects of CO. However, there have to date been very few studies conducted in the UK. Outdoor CO levels can be determinants of indoor levels but, where present, the major sources of CO in the home are gas cookers and certain types of heating systems which burn gas, wood, coal or paraffin. Environmental tobacco smoke, the presence of an attached garage and the proximity of heavily trafficked roads can also affect indoor CO levels.

A recent UK study has shown typical 1 week average CO concentrations to reach 2.7 mg/m^3 (2.4 ppm) in the kitchens of homes where there was gas cooking, compared with 0.9 mg/m^3 (0.8 ppm) in kitchens where there was no gas cooking. Continuous monitoring has indicated maximum 1 hour averages of 1.9–24.5 mg/m^3 (1.7–21.4 ppm) in homes with gas cooking; much higher peak levels of around 180 mg/m^3 (160 ppm) for a 15 minute average have been associated with the use of a gas cooker grill.

Poorly installed, inadequately ventilated or malfunctioning appliances and accidentally blocked flues can also contribute to increased CO levels. Even in a sample of only 14 UK homes, a maximum 1 hour concentration of 57.0 mg/m^3 (49.8 ppm) was recorded in the kitchen of one home in which the boiler was malfunctioning. It is apparent that existing air quality guidelines* are likely to be exceeded in a number of UK homes. While it is not statistically valid to extrapolate the data from the small study of 14 homes in the UK to the overall situation in the UK, there is an obvious cause for concern.

Exposure to CO is normally evaluated in terms of percentage of carboxyhaemoglobin (COHb) in the blood, but the validity of COHb as a biomarker of health effect is open to question. Although hypoxia, arising from preferential binding of CO to haemoglobin, is thought to be the main toxic mechanism by which CO acts, binding of CO to other blood components and enzymes may also play a part in its toxicity. A role in promoting atherosclerosis has been postulated for CO, although conclusive

* The current World Health Organization guidelines for CO are 100 mg/m^3 for 15 minutes, 60 mg/m^3 for 30 minutes, 30 mg/m^3 for 1 hour and 10 mg/m^3 for 8 hours

evidence is lacking, and immunological function and neurotransmission have also been investigated as possible targets for CO toxicity.

Carbon monoxide is an important pollutant with respect to likely health effects following exposure in the home. While many of the published clinical investigations of CO intoxication in the home originate outside the UK, this does not limit their applicability. There may be differences in the types of cooking and heating appliances used but the health effects of the CO emitted from them will be broadly the same. Accidental exposures leading to acute, and sometimes fatal, health effects are well documented. Clinical reports of CO intoxication following exposure to high levels of CO have shown consistent symptoms such as headache, nausea and dizziness in the majority of patients. However, these symptoms are easily confused with those of other ailments, such as food poisoning or influenza, and missed or misdiagnoses of CO intoxication can therefore occur.

Numerous and varied observations have been made of the health effects of CO in controlled exposure studies. These indicate that exposure to CO can cause performance decrements in certain neuropsychological tasks and that some people, primarily sufferers of cardiovascular disease, may be more susceptible to low-level exposure to CO associated with COHb levels as low as 2%. However, the question of the COHb level at which cardiovascular indices do not differ from the norm has not been satisfactorily answered. Perhaps the most prudent conclusion to draw is that there is no threshold of effect in patients suffering cardiovascular disease.

Observed reductions in exercise duration in both healthy subjects and sufferers of cardiovascular disease are reversible on removal of the individual from the exposure source. However, few studies have measured performance during the recovery period.

Conclusions

The published evidence on health effects after domestic exposure points most to a hazard of acute CO intoxication from malfunctioning, unflued or poorly ventilated fuel-burning appliances. It is also probable that in some homes CO levels routinely occur and persist that might possibly give rise to chronic health effects, particularly among sensitive groups (pregnant mothers, the fetus, children, the elderly and individuals suffering from anaemia and other diseases that restrict oxygen transport). Significant symptoms are generally experienced, even among normal healthy individuals, following exposure to CO concentrations high enough to produce COHb levels of about 20%. A great deal of importance would be attached to CO concentrations producing COHb levels above 10%, especially in sensitive individuals.

Although there is limited information from epidemiological studies on the health effects of CO at the low levels typically found in homes, the risk of adverse effects in healthy individuals as a result of exposure to CO in the home is thought to be low under normal circumstances (i.e. where appliances are installed and operated correctly). Nonetheless, it is prudent to continue to encourage measures which minimise CO levels, with particular attention being paid to gas combustion and other fuel-burning, especially unflued, appliances.

It is also essential to increase awareness of the symptomatology of CO intoxication among health care professionals and others to whom the public look for advice and assistance. Leaving a patient in, or returning them to, a situation from which adverse health effects might develop is unacceptable and, with vigilance, need not occur.

Main research recommendations

- More studies, primarily aimed at evaluating CO levels among representative samples of UK homes, are needed to ascertain the variability of indoor CO levels across the UK and in different types of housing.

- It would be prudent to develop strategies to ensure that representative samples of UK dwellings are included in future indoor air quality research programmes. The development of such strategies would be dependent on the specific objectives of each individual study, for example whether the research is aimed at determining the distribution of CO levels throughout the UK housing stock or whether it is aimed at targeting groups at high risk because of dwelling type or as a result of particular susceptibilities to CO exposure.

- More studies are required to determine the importance of indoor levels to overall personal exposure to CO, and particularly the significance of certain activities which may lead to high exposures. These studies should examine representative samples of the UK population and should employ methods such as relating fixed site monitoring to personal exposure measurements, questionnaire data and activity diaries. It would also be of value to investigate exposure to CO in susceptible populations such as expectant mothers and those suffering from cardiovascular disease.

- Alternative research approaches aimed at utilising new and existing data on CO exposure levels should be encouraged. Monte Carlo simulation modelling may provide a valuable means of improving the understanding of the predicted distribution of CO exposure levels in UK domestic environments.

- Studies aimed at assessing the relative contributions of various CO sources and confounding factors to indoor CO levels should be encouraged. It would seem appropriate at this stage to attempt a detailed assessment of the prevalence of malfunctioning fuel-burning appliances in relation to high levels of CO in UK homes and to assess the relative costs and benefits of remedying the problem if one is identified.

- Studies are required that combine measurements of indoor CO levels, personal exposure measurements, levels of CO in expired breath samples and related levels of COHb. The use of other, indirect means for determining exposure should also be explored, for example questionnaires, medical histories, biochemical parameters and so on. Comparison of measurement methods (single point CO level versus personal exposure studies versus breath analysis of CO and thereby COHb level) could also be performed.

- Studies aimed at assessing the extent and level of peak CO concentrations should be encouraged. The development and validation of models relating the magnitude and frequency of peak levels to mean levels and other factors such as CO sources, housing characteristics, ventilation methods and individuals' activity should be undertaken.

- Further study of long-term, low-level exposure to CO is required. Studies should be encouraged which assess the long-term CO levels typically found in UK homes. It would also be of value if the relative contributions of different CO sources to extended periods of low levels of CO in the home could be evaluated. Data obtained from such studies could usefully feed into investigations assessing the potential health effects in individuals who spend large amounts of time in the home environment.

- Analysis of donors' blood COHb level, in combination with a simple questionnaire probing smoking status, occupation, basic health status, and seeking limited socio-economic information, could be performed. This would help define the normal range of COHb levels in the UK population among healthy, adult smokers and non-smokers.

- Mechanisms of CO toxicity warrant further study, especially the possible consequences of CO acting as a transmitter substance and its possible involvement in vascular physiology.

- Studies aimed at defining more closely the relationship between COHb, exposure duration and symptom severity are required.

- A more structured approach to the controlled chamber assessment of health effects should be adopted in the UK in which variables such as COHb measurement, equipment type, quality assurance procedures, testing procedures and end-points are defined and a set protocol used across study groups. This approach would produce data that could more easily be compared between groups and would help in defining dose–response relationships and thresholds of effect for CO. The recovery period following exposure as COHb levels return to normal also warrants study.

- Further studies of the relationship between CO exposure and development of atherosclerosis are required.

- Studies, perhaps involving occupational exposures, which examine repeated exposure to CO at levels similar to those found in UK homes, are required. The health effects investigated could be both neuropsychological and cardiovascular in nature.

- It is necessary to design neuropsychological studies of CO exposure effects with specific goals in mind. For example, a better understanding is needed of the effect of CO on (1) monitoring and vigilance, (2) divided attention tasks, and (3) more complex information processing tasks. It may be useful to review the neuropsychological effects encountered in acute poisonings and determine from these the types of effects that can result from CO intoxication.

- In order to assess whether CO poisoning is missed or misdiagnosed, a study of patients presenting to general practitioners and accident and emergency departments with non-specific but potentially CO related symptoms is recommended. Samples of breath could serve as a clinical diagnostic tool. (A limitation in such a study is that COHb levels may have fallen between exposure and presenting to a medical practitioner.) A relative risk scoring system could be developed to aid in determining which individual’s symptoms are more likely to be related to CO exposure.

- More systematic studies aimed at investigating CO reducing factors should be undertaken. Examination of the potentially beneficial effects of the use of extractor hoods or fans in the kitchen on reducing CO levels would be of particular value owing to the link between high CO levels in the kitchen and gas cooking activity.

Airborne particles: Exposure in the home and health effects (Special report 17; IEH, 2000)

Executive summary

Background

A number of epidemiological studies have demonstrated apparent associations between ambient pollution by airborne particles (generally measured at fixed-site monitors) and various measures of mortality or morbidity. However, since people spend the majority of their time indoors, there are concerns that the outdoor exposure data may not reflect an individual's true level of exposure to airborne particles. In addition, the inter-relationship between outdoor, indoor and personal particle exposures and the factors affecting these relationships are currently poorly understood. This could lead to an inadequate assessment of the dose–response relationship between particle exposure and health effects, possibly with important consequences for the assessment of the public health significance of pollution by airborne particles.

Objectives of the report

This report summarises current understanding of the likely health effects of airborne particles and explores possible mechanisms by which such particles might impact on health, in order to assess the validity of the reported epidemiological associations. Available data on outdoor, indoor and personal exposure to airborne particles and the inter-relationships between these are extensively tabulated and reviewed. The report focuses on indoor air quality in the home and, in particular, attempts to evaluate data on UK indoor sources, levels and exposures, in order to assess the likely significance for health of indoor exposure to particles in the UK. This report was commissioned by the Department of the Environment, Transport and the Regions as part of a wider programme of work by the Institute for Environment and Health (IEH) on indoor air quality.

The report deals with non-biological particles, in particular those with an aerodynamic diameter of less than 10 µm (i.e. PM_{10}). Environmental tobacco smoke (ETS) and particles of biological origin are not addressed in detail in this report, although they are acknowledged to be important contributors to the indoor particulate load. These types of particle are the subject of separate reviews by IEH.

Review process

An extensive literature review was undertaken on exposure to airborne particles in ambient air and the home and on the potential health effects of such exposure. From this review, a background paper was developed which was used as a basis for discussions by international experts and representatives of relevant Government departments at a workshop held at IEH in January 1998. The primary purpose of the workshop was to ensure that the review had been comprehensive, accurate and balanced. Expert opinion was also sought to identify key knowledge gaps and to assist in the development of recommendations for future research, although the conclusions and recommendations presented in this report do not necessarily represent a consensus opinion of the meeting delegates. This report is based on the background paper presented at the workshop, and incorporates the output from the meeting along with additional material subsequently provided and produced by workshop participants and IEH staff.

Exposure and health effects assessment

Potential indoor sources of particles include cooking, certain heating appliances, and human activity. Although outside the scope of the current review, a major contributor to indoor particles is ETS, and the role of allergenic (biological) particles must also be recognised. Indoor particle levels (measured as a mass concentration) are generally lower than, but correlated with, outdoor levels, except when a significant indoor source is present. However, personal exposure levels are generally higher than either indoor or outdoor levels.

There is considerable epidemiological evidence that airborne particles may adversely affect human health. Short-term elevations in ambient particle levels have been strongly associated with increases in mortality, morbidity, and/or hospital or emergency room admissions: acute cardiopulmonary impairment is the predominant effect, and the elderly or infirm are particularly at risk. Short-term changes in pulmonary function and respiratory symptoms have also been detected, particularly in people with asthma. Long-term exposure to particles may increase mortality and morbidity rates and levels of respiratory symptoms, and impair pulmonary function, although the evidence for adverse effects being associated with long-term exposure is less certain.

There is a degree of mechanistic explanation for the observed toxicity of particles. Attention is increasingly being focused on the role of particles in the initiation or promotion of pulmonary inflammation. Several mechanisms by which pulmonary inflammation could lead to systemic effects have been proposed: inflammatory mediators released from the lungs into the systemic circulation could promote the release of blood coagulation factors and white blood cells from their sites of production and thereby increase the risk of blood clotting; cardiotoxic chemicals could be released during the inflammatory response; the systemic oxidant–antioxidant balance could be changed; or the central nervous system could be affected through stimulation of neural receptors in the lung. The validity and/or relative importance in humans of these hypothetical mechanisms at normal exposure levels is, as yet, uncertain.

Personal exposure is of considerable importance as it is the key determinant of the particle dose received by an individual and thus directly influences any impact on health. As indoor sources have been shown to raise personal exposure levels substantially, and the population subgroups most at risk from particle exposure are likely to spend the majority of their time indoors, it is considered possible that indoor sources of particles could play an important role in any health effects attributable to particle exposure, although information on the relative contribution of these sources is currently limited. Control of indoor sources could be a valuable component of possible remedial strategies to reduce total personal exposure to particles.

Conclusions

There is evidence to suggest that exposure to small airborne particles may have an adverse impact on human health, with those suffering from chronic obstructive pulmonary disease or other cardiopulmonary conditions and patients with asthma being at greatest risk. However, the mechanisms underlying the observed effects are at present far from certain. The relative importance of indoor sources of particles is not known but, as these have the potential to elevate personal exposures, it is important to advance understanding about their role and contribution to adverse human health impacts.

Principal research recommendations

Exposure assessment

- Improved monitoring devices to measure outdoor, indoor and personal particle composition should be developed.
- The size, number and composition of particles in the indoor air and the personal cloud should be better characterised, and particle movement into and through representative homes studied.
- Modelling of exposure should be undertaken.
- Biomarkers should be identified that permit identification of exposure to different types of particle.
- Effectiveness of possible strategies to reduce particle exposure indoors should be assessed.

Epidemiology and human volunteer studies

- The strength of the relationship between health endpoints and particle size, number and composition should be established, using epidemiological studies focusing on identified ‘at risk’ groups.
- The influence of indoor/outdoor activity and behaviour patterns and the role of indoor combustion sources should be systematically investigated.
- Research approaches should be developed and implemented that focus on chronic rather than shorter-term health endpoints.

Mechanistic studies

- Techniques capable of collecting environmentally-relevant samples of particles should be developed to providing sufficient quantities of material for use in *in vivo* studies.
- Mechanistic studies should be extended to size ranges, compositions and concentrations of particles relevant to normal human exposure.
- Bioavailability of chemicals (e.g polycyclic aromatic hydrocarbons and metals) present on or in particles should be investigated.
- Animal models of normal and susceptible human populations should be further developed.

Indoor air quality in the home: Medium density fibreboard (Internal report; IEH 1998b)

Summary (prepared for this report)

Concern about the use of medium density fibreboard (MDF), a bonded wood-fibre product, focuses primarily on the dust released during working on the material, and the possibility that any fibres or dust particles that can be inhaled and are persistent in the lung may be potentially harmful. In addition, formaldehyde, used in MDF production, may be released from the material by off-gassing.

Data on health effects of occupational exposure to MDF are limited to the findings of two cross-sectional studies in exposed workers, and provide information only about acute effects of exposure. Neither of the studies involved workers exclusively exposed to MDF dusts, which makes it difficult to reach clear conclusions about MDF dust alone. Overall, the data on health effects are consistent with the known acute effects of exposure to softwood and hardwood dusts and/or free formaldehyde at comparable levels, and it is reasonable to conclude that risks of occupational asthma and sino-nasal cancer from exposure to MDF dusts are the same as those associated with occupational exposure to softwood and hardwood dusts.

Available evidence suggests that DIY exposure to wood dusts is unlikely to pose any measurable health risk, although no studies specifically investigating this have been uncovered. Although there is a lack of detailed information about the dimensions of particles liberated from MDF, based on current knowledge it seems unlikely that fibres in the respirable range will be released. This is a question which merits further investigation. As a general principle, exposure to all dusts, especially fibrous dusts, should be minimised. Thus, while MDF (because of its composition) may produce more fine dust than does solid wood for the same operations, it is — as with wood — considered unlikely to pose any significant hazard.

The risks from formaldehyde exposure in the domestic situation are reviewed above, with the conclusion that, other than transient irritation in some individuals, there is no likelihood of health effects at the levels typically found in UK homes. However, the situation regarding the increasing use of MDF in homes and its impact on formaldehyde levels should be monitored. It is prudent to reduce exposure where possible; certainly current levels in homes should not be allowed to rise, and industry should be encouraged to reduce formaldehyde emissions from MDF either by changing the manufacturing process or allowing off-gassing before sale.

Firmer conclusions on the health effects of domestic MDF exposure will only be possible when further research on particle characterisation and toxicological properties has been conducted to:

- characterise better the number and nature of dust particles released during typical DIY operations using MDF; and
- investigate further the toxicological properties of the dusts, especially with regard to respirability, persistence in the lung and any carcinogenic potential.

Indoor air quality in the home: Labelling of chemical emissions from household products (Internal report; IEH, 1999a)

Summary (prepared for this report)

The aims of this status report were to: investigate how labelling schemes for chemical emissions from household and building products in the UK compare with those in Europe and the United States; compare the types of information appearing on labels and how different labelling schemes are operated; and evaluate the need for additional labelling schemes in the UK for paints, varnishes and cleaning products, and building materials, furniture and furnishings. Although the focus of the report is on labelling of products to provide consumers with information relevant to their health, this overlaps with the general issue of labelling products for environmental impact.

A number of labelling schemes were identified for paints and varnishes, carpets, cleaning products, building materials, furniture and furnishings. It was concluded that, since the contribution of chemical emissions to indoor air pollution (and therefore to potential adverse health effects) varies widely between products, it is necessary to address the requirements for emissions labelling schemes on a product group basis. Also, for symbols on labels to be of value in influencing product choice, they must be recognised and understood.

It is recognised that the extent and nature of chemical emissions from some products may warrant the introduction of a label or symbol that addresses a single aspect of the product's potential impact on human health or the environment (a so-called 'single-issue' label) but, for other products, a label that addresses multiple safety issues may be more appropriate. For single-issue schemes, consideration should be given to providing information on the actual content or emission of chemicals from a product (as well as any logo that may be present) to help consumers compare products. Where a multi-issue label is used on a product that is likely to have substantial chemical emissions, further information may be needed to allow comparison of products. This could be provided either by inclusion of useful phrases on the label or in additional to that on the label (see below). All wording and symbols used should comply with the principles of the *Green Claims Code*[a]. For some products, manufacturers should also be encouraged to include information on their safe use (with respect to potential adverse health effects) on the packaging. This is particularly important for products carrying the St. Andrew's cross or other hazard labels and devices. The provision of additional information was also considered likely to make a labelling scheme more effective, particularly where only a logo is used. However, the best method of information provision is likely to vary according to the product type, and requires careful consideration.

Experience in the UK and abroad has shown that dialogue between government, trade associations and manufacturers can lead to the development of useful voluntary labelling schemes that manufacturers are comfortable with, and that can be operated effectively by trade associations. Such an approach is in agreement with proposals in the *Sustainable Business*[b] consultation document published by the Department of the Environment, Transport and the Regions (DETR) earlier this year. Finally, it was noted that, while, consumers in the Nordic countries, Germany and the US appear currently to have greater access to labelling schemes for household products than those in the UK, information about the health aspects of chemical emissions is not usually included on the labels. A number of specific recommendations relating to labelling schemes in the UK were made.

[a] Available [September 2001] at http://www.defra.gov.uk/
[b] Available [September 2001] at http://www.defra.gov.uk/

Carbon monoxide follow-up meeting — October 1998 (Internal report to DH and DETR, IEH, 1999b)

Executive summary

The aim of this meeting, attended by departmental and non-departmental representatives and key stakeholders, was to follow up the findings from the IEH Assessment on carbon monoxide (CO) in the home (IEH, 1998) and to discuss potential needs and strategies for tackling this important issue in the future. The main area of discussion focused on knowledge gaps and needs for further research and included the following areas:

- Obtaining more detailed exposure data
- Improving the knowledge base regarding the health effects of chronic CO exposure
- Assessing the true extent of risks to health in the UK population
- Improving our understanding of the delayed neurological sequelae of CO poisoning
- Exploring the utility of carboxyhaemoglobin (COHb) as a biomarker of health effects
- Tackling the problem of missed or mis-diagnosis.

The relative priority and need for concerted action on specific areas was also discussed.

Secondary discussions focused on initiatives to raise awareness, educate and warn about CO in the home. Because the earlier discussion on research needs had been so fruitful, there was little time available to discuss these issues but nonetheless some recommendations were developed.

Recommendations

Recommendations were developed based on the discussions and are listed below.

Exposure and monitoring

1. Standardise procedures for CO monitoring by gas engineers and researchers, and develop standards for monitoring equipment.
2. Explore the possibility of CORGI[*] engineers measuring CO concentrations in homes and COHb levels in occupants *via* breath samples.
3. Investigate CO exposures of non-smoking delivery cyclists or taxi drivers in London and the effects on health of these exposures.
4. Investigate and if necessary develop safety-check criteria for non-boiler appliances.
5. Consider requiring CORGI engineers to do spillage tests on appliances only after they havebeen running for some time, and so are properly warmed-up.
6. Develop a standard methodology for the measurement of COHb.
7. Test the accuracy and consistency of COHb measurements in hospitals and chemical pathology laboratories across the UK by sending standard blood samples for testing.

[*] Council for Registered Gas Installers

8. Consider developing a targeted study employing health visitors to measure COHb in breath samples from pregnant women, mothers, toddlers and the elderly.

9. Develop a simple, cheap monitor for measuring COHb. For example, such a device could just show whether levels are greater than or less than, for example, 5% COHb. Accident and Emergency (A&E) Departments should be encouraged to take COHb breath measurements on casualties.

Health and surveillance

1. Develop standard questionnaires for CO poisoning casualties, the doctors who treat them and the engineers who investigate the cause of the problem.

2. Collate information on CO-related incidents across the UK. Begin with regional data collected by the National Poisons Unit, then expand to the whole of the UK via the National Focus. [N.B. The Loss Prevention Council may be in a position to assist here.]

3. Write to coroners for information on CO poisonings. Compare coroners reports on CO deaths with those collated by the Department of Trade and Industry (DTI) and with information collected by the fire brigade in order to investigate inaccurate reporting of CO fatalities.

4. Identify regions in the UK which have a higher than average incidence of CO poisoning and focus research in these regions.

5. Determine whether the chronic effects of CO poisoning are due to acute intermittent exposures or chronic, low-level exposures. This could be done through toxicological studies on experimental animals.

6. Promote studies on the biochemical mechanisms of CO poisoning at both high and low levels of exposure.

7. Perform psychometric assessments of different aspects of cognitive function affected by exposure to CO. This could be done by opportunistic studies on poisoned people using standard test batteries.

8. Study smokers for psychological effects of CO poisoning, for example mood swings.

9. Link the epidemiological studies which demonstrate cardiovascular effects of CO exposure to studies performed in the US which have investigated effects on the heart of CO exposure during exercise.

10. Investigate other factors which may have an additive effect with CO poisoning, for examplealcohol or drug use.

11. Develop a 'best practice' for CO treatment during pregnancy.

12. Follow up those treated with either hyperbaric oxygen or 100% oxygen delivered by masks to determine the relative efficacy of the two treatments.

13. Form a consensus on the value of hyperbaric treatment for CO poisoning, and develop a standard approach to administering such treatment.

Raising awareness

1. Run roadshows or stalls in shopping centres, etc. explaining the signs and dangers of CO in the home.

2. Set up displays in shops which sell gas appliances.

3. Develop computer-assisted learning packages on CO poisoning for medical students. [N.B. The National Poisons Unit is already doing outreach work for the Department of Health (DH), and so would be happy to assist in this type of work.]
4. Ask midwives and nurses to provide information to mothers on CO exposure.
5. Focus upon vulnerable types of dwelling, such as holiday homes, caravans and rented accommodation. Documents on gas appliance servicing could be required to be presented as part of the rent agreement.
6. Assess the uptake and use of the Chief Medical Officer's Newsletter on CO.
7. Improve surveillance for CO poisoning and training of health professionals.

Actions

1. General Practitioners or A&E staff should enquire about the cooking or heating fuel used in the home when patients present with flu-like symptoms. Include as part of the advice to General Practitioners. [Action Bob Maynard]
2. Encourage the MRC to fund studies on the mechanisms of CO poisoning [Action DH/ Department of the Environment, Transport and the Regions (DETR)/IEH].
3. Key Departments to consider all the above [Action DH/DETR/Health and Safety Executive (HSE)/DTI].
4. IEH to advertise/promote the findings of this meeting [Action IEH].

Further work

The general consensus of opinion was that a periodic re-visiting of the issue of CO in the indoor environment would be of great benefit.

Indoor air quality in the home: Allergens (Internal report; IEH, 1999c)

Executive summary

The home environment can contain many organisms that are sources of allergens. This review provides an overview of exposure to, and the hazards associated with, the major biological allergens that people may encounter in the home, namely house dust mites, fungi, bacteria, domestic pets and cockroaches.

House dust mites are a normal feature of the home environment but it was not until the mid-1960s that the allergenicity of house dust was related to house dust mites. The allergens they produce are carried in the faecal pellet or sac. Fungi and bacteria can be particularly numerous in the home environment but their importance is probably underestimated despite their early recognition as allergens. Not all fungi are allergenic but, of those that are, the most abundant in indoor air are *Cladosporium*, *Alternaria*, *Aspergillus*, and *Penicillium*. Bacteria indoors mainly originate from the occupants but can also colonise and be released from surfaces, furniture and carpets. Various tissues and secretions from cats and dogs are allergenic. The small size and stickiness of these allergens mean they are easily transported and can be detected in places where source animals are not present. Cockroach infestation is a greater problem in Asia and the Americas than in the UK. However, recent French and UK studies suggest that sensitivity to cockroach allergens may be an issue in some areas.

As allergens mainly impact on the respiratory system, the ideal way to assess exposure would be to measure inhaled allergen but no such method exists. Therefore air and/or dust reservoir sampling is employed. Fungi, bacteria and domestic pet allergens can be measured using air or dust sampling while house dust mites and cockroach allergens are best measured in dust samples.

The first of two stages in developing any allergic disease is sensitisation, when an allergen is internalised and, in some susceptible individuals (atopics), leads to the production of immunoglobulin E (IgE) antibodies. The second stage occurs, perhaps some time later, when the allergen is again internalised, encounters IgE antibodies and evokes an immune response causing symptoms such as coughing, sneezing and wheezing. The major health effects associated with allergens are asthma, where most research is focused, atopic dermatitis and allergic rhinitis. Inter-individual differences in sensitivity mean some atopics do not display symptoms while others are sensitive to very low allergen exposures. There appears to be a dose–response relationship between allergen exposure and sensitisation, but the evidence is less strong for a relation between exposure and symptoms because exposure measurements do not accurately reflect the allergen concentration in the lung, skin-prick tests do not correlate strongly with lung inflammatory responses and factors other than allergens can provoke asthmatic responses.

There is accumulating evidence that the prevalence of allergic respiratory disease, particularly asthma, is increasing. Numerous risk factors may be responsible for this increase and there is an on-going debate about which are most important. Exposure to allergens is an essential prerequisite before allergic responses can develop and genetic predisposition is also important. Other factors that may be important but for which evidence is limited or equivocal are childhood infections, family size and structure, co-exposure to other air pollutants, gender, diet, race, socio-economics, pre- and perinatal factors, home dampness and pet ownership.

Complete eradication of allergens from the home is impossible due to their ubiquity but, for individuals at risk of developing or who already suffer allergic disease, it is necessary to reduce exposure as much as is practicable. Efforts can be employed before sensitisation but all methods are applicable whether pre- or post-sensitisation. For allergens except those from domestic pets, the general approach is to make the home less habitable to the organism and involves combined, repeated and rigorous efforts to remove and then prevent the return of the organism. This often involves vacuuming to remove the allergens and then general housekeeping and hygiene to prevent their return,

though other methods, such as allergen denaturants, have variously been suggested. Domestic pet allergens are particularly difficult to control due to their easy transport from pet-owning households to non-pet-owning households or other areas.

The home is important in terms of potential allergen exposure and detrimental effects on health and well-being because of the large proportion of time individuals spend in that environment. House dust mites remain the most frequently studied of the indoor allergens and the highest priority because of their prevalence and sensitising potency. Domestic pet allergens, fungi and bacteria are of secondary importance and cockroach merit a low priority in the UK due to their low prevalence. A better understanding of allergen exposure, indoor distribution of allergens and the aetiology of allergic disease is essential in order to achieve improvements in the management of symptomatic asthma.

Based on this review and the suggestions of an expert group convened at its inception, the following recommendations for future research are proposed:

- Potential co-factors such as nitrogen dioxide and particulates may be of great importance. Total personal exposures and interactions between these pollutants warrant further assessment. Furthermore, allergens are known to be cross-reactive and potential additive or synergistic effects should be explored.
- 'Windows of exposure' during which sensitisation or symptoms are more likely require clarification.
- The mechanism by which a sensitised individual becomes symptomatic needs to be elucidated.
- The specific nature and identity of the agent(s) in fungi and bacteria that causes allergic or other health effects requires clarification.
- The potential benefits and costs — in health and economic terms — of control measures should be assessed.

Indoor air quality: Pesticides in the home (Internal report; IEH, 1999d)

Executive summary

Pesticides in indoor air have received little attention in the UK beyond the regulatory requirements for pesticide approval under the Control of Pesticide Regulations 1986. As part of a wider project on indoor air quality, the Department of the Environment, Transport and the Regions commissioned the MRC Institute for Environment and Health to conduct this scoping study to evaluate the exposure of the general UK population to pesticides in the domestic indoor environment.

Pesticides are used in homes to control unwanted pests which may spread disease or cause damage to a building. The main source of domestic exposure to pesticides in the UK is the direct application of pesticide products. Other sources of domestic exposure to pesticides may include the storage of pesticide products in the home and the use of products (e.g. timber and natural fibre textiles) pre-treated with pesticides as part of the manufacturing process. However, these latter sources are generally considered to be minor compared with the direct application of pesticides indoors.

Exposure to pesticides in the UK indoor environment is likely to be highly individual since exposure will depend on the product or combination of products applied, the frequency of applications and whether or not applications are made according to label instructions. These factors will in turn determine which pesticides an individual is exposed to and the frequency and magnitude of exposure.

The pesticide products most likely to be used indoors in the UK are non-agricultural surface biocides, insecticides and wood preservatives, vertebrate control agents and agricultural insecticides approved for amateur use. Currently these pesticides account for over 2100 products and contain over 150 different pesticide active ingredients (AIs). The most commonly occurring AIs in these products are the pyrethroids, which are present in 39% of products, and, in particular, permethrin and tetramethrin, which are present in 23% and 9% of products, respectively.

There are insufficient UK data to enable an accurate estimation of the exposure of the UK general population to pesticides from indoor sources. This is primarily due to the lack of usage data in terms of the type of pesticides used, their frequency and manner of use and a lack of information on the locations of such applications. However, there is some evidence to suggest that those on lower incomes and/or who live in tower blocks or low-rise flats in metropolitan areas may receive or make more frequent pesticide applications in their homes.

Studies of individual product applications have shown that concentrations of pesticides indoors vary considerably according to the pesticide, its formulation, the method of application, the amount applied, the size of the room and the rates of ventilation and loss from the indoor environment. Aerosol applications result in the rapid production of high air concentrations of pesticides due to the rapid evaporation of the aerosols produced and a wide deposition of pesticide due to the greater potential for the aerosol droplets to drift. In contrast, pressurised spray applications result in concentrations which are initially lower, but persist longer. Pressurised spray applications also result in higher concentrations of pesticide on target surfaces, but lower concentrations on non-target surfaces, due to the reduced tendency of the larger droplets produced to drift. The most effective means of reducing concentrations of pesticides indoors is by ventilation; cleaning with a surface cleaner is also effective. Studies invariably consider the application of the product as occurring according to label instructions. However, recent investigations have shown that rarely are label instructions read or followed, and this may lead to exposures of a different pattern or frequency than predicted from regulatory risk assessments.

Those with the greatest potential to receive high exposure indoors are infants and children. Infants and children can be exposed through inhalation of pesticide vapour, mouthing of objects to which pesticides are adsorbed, dermal absorption of pesticide residues on surfaces and ingestion of pesticide

residues adsorbed to house dust. The greatest potential for receiving high exposures occurs shortly after a pesticide application, with some exposure estimates suggesting that the Reference Dose may be exceeded. However, further research is required to assess better the contribution of ingestion and dermal absorption to total exposure.

Pesticides can persist for considerable periods of time indoors and hence background or ambient levels of pesticides indoors may also contribute to exposure. However, there are no data on background levels of pesticides in the UK indoor environment. The available evidence, from studies in the USA and Germany, suggests that such exposure will be low. Exposure to background levels may, however, be potentially long-term, and result in exposure to numerous pesticide residues simultaneously.

Pesticides have a clear potential to cause acute toxic effects at sufficiently high exposures, due to their inherent biological activity. However, in normal use it is unlikely that pesticides in the home will lead to incidents of acute intoxication. The health effects of low-level, long-term exposure are less clear and although carcinogenesis and endocrine disruption are potential concerns, there is insufficient evidence to conclude that exposure to pesticides from indoor air is implicated in either.

Pesticides are one of many methods for controlling pests in the home. There appears to be a low risk of any adverse health effects resulting from exposure to pesticides indoors. However, more data are required to enable better characterisation of exposure and the effects of low-level, long-term exposure.

Recommendations

Further research is needed to assess better general population exposure to pesticides from indoor sources in the UK. In particular:

- There is a need for data on pesticide usage in UK homes. The data should identify which products are used indoors, the manner and frequency of use, the locations of the applications and the variability in these factors. Such data should cover the general population and examine specific sub-groups which may receive high or frequent exposure.
- The location, frequency and contribution of applications by professionals to indoor pesticide exposure should be determined. This should not be limited to Local Authorities, but should include private pest control firms.
- Further information is required on concentrations of pesticides in the UK indoor environment resulting directly from applications, and also background or ambient levels, in order to characterise better the exposure of occupants.
- Further research is required to understand better the potential health effects of low-level and long-term exposure to pesticides.
- Currently there appears to be a comparative lack of data on pyrethroid AIs indoors, compared with organophosphate AIs. Given that pyrethroids are likely to be widely used and encountered indoors in the UK, further research should focus on pyrethroid AIs to address this imbalance.
- Greater emphasis should be placed on assessing the total exposure to pesticides from all sources (water, food, indoor air etc.), so as to evaluate better the potential effects of such exposure, and assess better the contribution of individual sources to total exposure. This would enable more effective action to be taken, should exposure need to be reduced.

There are also several areas which should be considered further, in order to limit pesticide to the minimum required for pest control compatible with protecting human health and the environment. Specifically:

- Given the potential susceptibility of infants to high exposure levels and the absence of data on the potential long-term effects of pesticide exposure, it is considered prudent to identify and implement methods to optimise (minimise) pesticide use in the indoor environment. This might be achieved by placing more emphasis on the education of the public, particularly where a household has received a pest control treatment, as to why the pest problem has occurred and how to prevent further infestations using non-pesticidal methods.

- There should be development of better labelling of pesticide products, to encourage compliance with statutory conditions of use, and consideration given to providing some items of personal protective equipment (e.g. disposable gloves) with products, so as to encourage safer use.

- Labelling of products pre-treated with pesticides as part of the manufacturing process should also be considered, in order to inform the public of sources and allow them to make informed decisions about their exposure.

Indoor air quality in the home: Polycyclic aromatic hydrocarbons (Internal report; IEH, 1999e)

Executive summary

Background

Polycyclic aromatic hydrocarbons (PAHs) are widely distributed in the air environment as a result of their formation and release during a variety of coal, oil, petrol and wood combustion processes. Humans are exposed to low levels of PAH mixtures in air, food and drinking water, and attention is now being focused on the possible importance of indoor (domestic) exposure.

This status report reviews data on PAHs in the home environment. The major sources are identified and the possible relationship between indoor and outdoor levels discussed. The influence of indoor sources of PAHs on total personal exposure is examined and the potential risks to health are assessed. Finally, the report identifies the knowledge gaps and priorities for future research on PAHs in indoor air.

This report was commissioned by the Department of the Environment, Transport and the Regions (DETR) as part of a wider programme of work on indoor air quality.

Review process

A literature review was undertaken to investigate PAH concentrations in air (occupational, ambient and domestic) and the likely health effects. Relevant literature was identified using a number of databases (Medline, Toxline, Embase and Biosis), from 1996 for health effects and 1991 for exposure data. Owing to the sparsity of information on PAHs, previous literature reviews, occupational data and results from outdoor air studies were collated and used for extrapolation for domestic exposure.

Exposure and health effects evaluation

A positive correlation has been found between the level of particulates in the atmosphere and the concentration of PAHs, providing a possible method for estimating PAH levels. However, at sites directly influenced by traffic, a statistically significant correlation has not been established. Benzo[a]pyrene (B[a]P) has been identified as a good marker compound and is frequently used as an index of exposure to PAH mixtures. Around 98% of B[a]P exists as particles less than 7 μm aerodynamic diameter. Annual average urban background concentrations of B[a]P in the UK range from 0.5 to 0.8 ng/m^3, with the higher values usually reflecting heavily trafficked urban areas. The Expert Panel on Air Quality Standards (EPAQS) has recommended a standard of 0.25 ng/m^3 B[a]P in ambient air as an annual average (taking B[a]P as the marker compound for total PAHs) (DETR, 1999*). The Panel considers that this concentration would reduce the risk to the UK's population from PAH exposure to one that would be undetectable.

There are currently no UK data available on domestic levels of PAHs. However in the US, B[a]P is most commonly found in the indoor environment at concentrations ranging from approximately 0.2 to 2.8 ng/m^3 (24 hour average) in the absence of an obvious source. Levels of PAHs are influenced by outdoor levels of PAHs. In homes without indoor sources and with a low level of 'human activity', a linear indoor/outdoor relationship has been observed. Where an obvious source is present (e.g. cigarette smoking or wood-burning stove), short-term concentrations of several hundred nanograms per cubic metre have been detected.

Data on the risks posed by PAHs are largely derived from animal and in vitro assay systems; several individual PAHs are established carcinogens in experimental animals, B[a]P being the most studied. Epidemiological studies of aluminium refinery workers have shown that heavy, prolonged exposure to mixtures of PAHs is associated with a substantial risk of lung, skin, or bladder cancer — the lungs

* Available [September, 2001] at http://www.defra.gov.uk

being the major target site. However, the potential health effects from domestic exposure have not been given the same attention. Nevertheless, there is clear evidence that PAH mixtures are potentially carcinogenic in humans, and studies have shown a high incidence of lung cancer in Chinese women in a domestic setting, who do not smoke and are highly exposed to cooking fumes.

Conclusion

Tobacco smoke is the most significant indoor source of PAHs, with the highest levels consistently recorded in the homes of smokers. Cooking fumes are also a major source.

Nearly all information on the potential health effects from exposure to PAHs is derived from occupational or experimental studies. Extrapolation to the domestic scenario is problematic and the significance to health of such exposures is currently uncertain.

Principal research recommendations

- The validity of B[a]P as a marker of total PAH exposure should clarified, to overcome current difficulties in measuring levels of complex (and variable) PAH mixtures.
- Further research is required to establish the current indoor levels of PAHs in UK homes.
- The influence of outdoor PAH concentration on indoor levels should be clarified.
- Extensive further research is required to identify and quantify the risk to health from indoor exposure to PAH, and determine the impact of confounding factors, such as smoking (focusing on lung cancer).

Childhood health (Internal report; IEH, 2000)

Executive summary

This status report provides an overview of the latest developments, statistical trends and health care/environmental initiatives regarding the health care of young children (up to approximately 5 years of age) in the UK, and sets this within the context of other developed regions such as the USA and Europe. A number of common conditions of childhood which may be influenced by air quality are addressed including asthma, middle ear infection, upper and lower respiratory tract infections, and sudden infant death syndrome (SIDS).

Internationally, and especially in the developed countries, asthma has shown progressive increases in prevalence in recent decades, particularly since the 1970s. In the UK, asthma is recognised as the most common chronic disease of children and is the cause of a high number of medical consultations, underlining its importance as a public health issue. For children in this age range, asthma symptoms are usually triggered by extrinsic factors, such as infections, house dust mites, pet danders and pollens. Hence, the quality of indoor air to which the child is exposed may be very important; pollutants of particular concern are environmental tobacco smoke (ETS), volatile organic compounds (VOCs) and nitrogen oxides. It is increasingly being recognised that exposure to allergens, pathogens and toxicants during early life may influence the immune system and hence play an important role (both positive and negative) in the later development of asthma.

Lower respiratory tract infections have been shown to account for over 60% of all deaths from respiratory causes in this age group; upper tract infections account for a further 10%. As for middle ear disease, an established extrinsic risk factor for lower tract infection is ETS exposure (children of smoking parents are almost twice as likely to contract such an infection as those not exposed), again underlining the importance of this pollutant in relation to childhood health.

Middle ear infection (otitis media) is a very common childhood infection, usually of bacterial but occasional of viral origin, that can occasionally, lead to temporary or permanent hearing loss. It may present as an acute, rapidly resolving form or may develop into a chronic condition. Identified risk factors include length of pregnancy and birth weight, gender and family history of this condition, as well as extrinsic factors such as ETS exposure, day-care attendance and season. On the basis of the identified risks, it would appear that exposure to ETS may be the only risk factor that can be ameliorated.

When considering SIDS it is important to recognise that it is a syndrome not a condition and is believed to have multiple, unrelated risk factors, including season, age and socio-economic status of the mother, exposure to ETS, and the child's sleeping position, sex, age and birth weight. Thus, although ETS may again play a role in this condition, it is not the only factor that requires consideration. Reassuringly, following a campaign by the Department of Health to increase public awareness of this syndrome and the importance of the infant's sleeping position, there appears to be a downward trend in incidence in the UK. However, it is not yet known if this will continue to fall or plateau.

On a broader note, attention is also drawn in the report to the potential impact on child health of recent developments in immunisation programmes, the influence of nutritional status, disorders of mental and behavioural development, and non-traffic related injuries.

Annex 2

Bibliography of journal papers and other documents produced

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In addition, IEH has published the following summary leaflet on indoor air quality:

IEH (1997) *Indoor Air Quality in the Home* (IEH Lay Summary), Leicester, UK, Institute for Environment and Health

Annex 3

IEH research and editorial staff contributing to the projects

Programme Manager: Paul TC Harrison
Project Leader: Charles Humfrey (Phase I)
Philip Holmes (Phases II & III)

Phase	Subject	Lead Scientist	Other researchers/editors
I	Nitrogen dioxide, formaldehyde, volatile organic compounds (VOCs), house dust mites, fungi & bacteria (IEH Assessment A2)	CDN Humfrey	PTC Harrison, LK Shuker
	Gas cooking leaflet	S Badley	LK Shuker, P Forster
	Summary leaflet of Assessment A2	CDN Humfrey	PTC Harrison, LK Shuker, P Forster
	VOCs leaflet	C Tuckett	S Badley
II[a]	Carbon monoxide (IEH Assessment A5)	E Green	SD Short, PTC Harrison, L Shuker
	Airborne Particles (IEH Special Report 17)	P Holmes	C Tuckett, PTC Harrison, LK Shuker, P Forster
III	Carbon monoxide follow-up meeting (Internal report[b])	E Green	S Short, C Tuckett, PTC Harrison
	Medium density fibreboard (Internal report)	PTC Harrison	
	Polycyclic aromatic hydrocarbons (Internal report)	P Fryer	PTC Harrison, J Emeny
	Allergens (Internal report)	S Short	P Holmes, PTC Harrison, J Emeny
	Pesticides (Internal report)	S Short	A Capleton, PTC Harrison, P Holmes, J Emeny
	Childhood health (Internal report)	C Courage	F Warren, P Harrison

[a] In addition, as part of Phase II, work was undertaken on the exposure to and health effects of environmental tobacco smoke by C Courage, P Holmes and S Badley; this will be incorporated into a report to be produced for the Department of Health

[b] Joint report to DETR and DH