THE HEALTH CONSEQUENCES OF INVOLUNTARY SMOKING

a report of the Surgeon General

1986

DEC 15 1986

The Honorable George Bush
President of the Senate
Washington, D.C. 20510

Dear Mr. President:

It is my pleasure to transmit to the Congress the 1986 Surgeon General's
Report on the health consequences of smoking, as mandated by Section 8(a) of
the Public Health Cigarette Smoking Act of 1969. The current volume, entitled
The Health Consequences of Involuntary Smoking, examines the scientific
evidence on the health effects resulting from nonsmoker exposure to
environmental tobacco smoke.

The issue of whether or not tobacco smoke is carcinogenic for humans was
conclusively resolved more than 20 years ago when the first report on smoking
and health was issued in 1964. Based on the current report, the judgment can
now be made that exposure to environmental tobacco smoke can cause disease,
including lung cancer, in nonsmokers. It is also clear that simple separation
of smokers and nonsmokers within the same airspace may reduce but cannot
eliminate nonsmoker exposure to environmental tobacco smoke.

The report also reviews an extensive body of evidence which establishes an
increased risk of respiratory illness and reduced lung function in infants and
very young children of parents who smoke. This effect is more pronounced if
both parents smoke than if only one parent smokes. As a physician, I believe
that parents should refrain from smoking around small children both as a means
of protecting their children's health and to set a good example for the child.

Today, only 30 percent of the adult population in the United States are
smokers--the lowest level of smoking in the country since World War II,
reflecting that the great majority of the population has never smoked or has
successfully quit.

Accompanying this decline in overall prevalence of cigarette smoking has
been an increased concern for protecting the health and well being of
nonsmokers, as evidenced by the number of laws and regulations restricting
smoking in public places. Today, 40 States and the District of Columbia have
enacted some form of legislation to restrict smoking in public. Increasingly,
these laws pertain to protecting nonsmokers in many different settings,
including the workplace.

Based on the evidence presented in this report, the choice to smoke should
not interfere with the nonsmoker's choice for an environment free of tobacco
smoke.

Sincerely,

Otis R. Bowen, M.D.
Secretary

Enclosure

DEC 5

The Honorable Thomas P. O'Neill, Jr.
Speaker of the House
  of Representatives
Washington, D.C. 20515

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FOREWORD

The data reviewed in 17 previous U.S. Public Health Service reports on the health consequences of smoking have conclusively established cigarette smoking as the largest single preventable cause of premature death and disability in the United States.

The question whether tobacco smoke is harmful to smokers was answered more than 20 years ago. As a result, many scientists began to question whether the low levels of exposure to environmental tobacco smoke (ETS) received by nonsmokers could also be harmful.

The current Report, The Health Consequences of Involuntary Smoking, examines the evidence that even the lower exposure to smoke received by the nonsmoker carries with it a health risk. Use of the term "involuntary smoking" denotes that for many nonsmokers, exposure to ETS is the result of an unavoidable consequence of being in proximity to smokers. It is the first Report in the health consequences of smoking series to establish a health risk due to tobacco smoke exposure for individuals other than the smoker, and represents the work of more than 60 distinguished physicians and scientists, both in this country and abroad.

After careful examination of the available evidence, the following overall conclusions can be reached:

1. Involuntary smoking is a cause of disease, including lung cancer, in healthy nonsmokers.

2. The children of parents who smoke, compared with the children of nonsmoking parents, have an increased frequency of respiratory infections, increased respiratory symptoms, and slightly smaller rates of increase in lung function as the lung matures.

3. Simple separation of smokers and nonsmokers within the same air space may reduce, but does not eliminate, exposure of nonsmokers to environmental tobacco smoke.

Exposure to environmental tobacco smoke occurs at home, at the worksite, in public, and in other places where smoking is permitted.

The quality of the indoor environment must be a concern of all who control and occupy that environment. Protection of individuals from exposure to environmental tobacco smoke is therefore a responsibility shared by all:

- As parents and adults we must protect the health of our children by not exposing them to environmental tobacco smoke.

- As employers and employees we must ensure that the act of smoking does not expose the nonsmoker to tobacco smoke.

- For smokers, it is their responsibility to assure that their behavior does not jeopardize the health of others.

- For nonsmokers, it is their responsibility to provide a supportive environment for smokers who are attempting to stop.

Actions taken by individuals, employers, and employee organizations reflect the growing concern for protecting nonsmokers. The number of laws and regulations enacted at the national, State, and local level governing smoking in public has increased substantially over the past 10 years, and surveys conducted by numerous organizations show strong public support for these actions among both smokers and nonsmokers.

As a Nation, we have made substantial progress in addressing the enormous toll inflicted by active smoking. Efforts to improve and protect individual health must be not only continued but strengthened. On the basis of the evidence presented in this Report, it is clear that actions to protect nonsmokers from ETS exposure not only are warranted but are essential to protect public health.

Robert E. Windom, M.D.
Assistant Secretary for Health

PREFACE

This, the 1986 Report of the Surgeon General, is the U.S. Public Health Service's 18th in the health consequences of smoking series and the 5th issued during my tenure as Surgeon General.

Previous Reports have documented the tremendous health burden to society from smoking, particularly cigarette smoking. The evidence establishing cigarette smoking as the single largest preventable cause of premature death and disability in the United States is overwhelming—totaling more than 50,000 studies from dozens of cultures. Smoking is now known to be causally related to a variety of cancers in addition to lung cancer; it is a cause of cardiovascular disease, particularly coronary heart disease, and is the major cause of chronic obstructive lung disease. It is estimated that smoking is responsible for well over 300,000 deaths annually in the United States, representing approximately 15 percent of all mortality.

Thirty years ago, however, the scientific evidence linking smoking with early death and disability was more limited. By 1964, the year the Advisory Committee to the Surgeon General issued the first report on smoking and health, a substantial body of evidence had accumulated upon which a judgment could be made that smoking was a cause of disease in active smokers. Subsequent reports over the last 20 years have expanded our understanding and knowledge about smoking behavior, the toxicity and carcinogenicity of tobacco smoke, and the specific disease risks resulting from exposure to this agent.

This Report is the first issued since 1964 that identifies a chronic disease risk resulting from exposure to tobacco smoke for individuals other than smokers. It is now clear that disease risk due to the inhalation of tobacco smoke is not limited to the individual who is smoking, but can extend to those who inhale tobacco smoke emitted into the air. This Report represents a detailed review of the health effects resulting from nonsmoker exposure to environmental tobacco smoke (ETS). ETS is the combination of smoke emitted from a burning tobacco product between puffs (sidestream smoke) and the smoke exhaled by the smoker. The 1986 Report, The Health Consequences of Involuntary Smoking, is a critical review of all the available scientific evidence pertaining to the health effects of ETS exposure on nonsmokers. The term "involuntary smoking" is used to

note that such exposures often occur as an unavoidable consequence of being in close proximity to smokers.

Lung Cancer and Environmental Tobacco Smoke

The appropriate framework for an examination of the lung cancer risk from involuntary smoking is that of a low-dose exposure to a known human carcinogen. Over 30 years of research have conclusively established cigarette smoke as a carcinogen. This Report presents evidence that the chemical composition of sidestream smoke is qualitatively similar to the mainstream smoke inhaled by the active smoker, and that both mainstream and sidestream smoke act as carcinogens in bioassay systems. Data related to environmental levels of tobacco smoke constituents and from measures of nicotine absorption in nonsmokers suggest that nonsmokers are exposed to levels of environmental tobacco smoke that would be expected to generate a lung cancer risk; epidemiological studies of populations exposed to ETS have documented an increased risk for lung cancer in those nonsmokers with increased exposure.

It is rare to have such detailed exposure data or human epidemiologic studies on disease occurrence when attempting to evaluate the risk of low-dose exposure to an agent with established toxicity at higher levels of exposure. The relative abundance of data reviewed in this Report, their cohesiveness, and their biologic plausibility allow a judgment that involuntary smoking can cause lung cancer in nonsmokers. Although the number of lung cancers due to involuntary smoking is smaller than that due to active smoking, it still represents a number sufficiently large to generate substantial public health concern.

It is certain that a substantial proportion of the lung cancers that occur in nonsmokers are due to ETS exposure; however, more complete data on the dose and variability of smoke exposure in the nonsmoking U.S. population will be needed before a quantitative estimate of the number of such cancers can be made.

Children and Infants

This Report also documents a relationship between parental smoking and the respiratory health of infants and children (under 2 years of age). Infants of parents who smoke have an increased risk of hospitalization for bronchitis and pneumonia when compared with infants of nonsmoking parents. There is a relationship between parental smoking and an increased frequency of respiratory symptoms in children. A slower rate of growth in lung function has been observed in children of smoking parents. In many studies, if both

parents smoke, a stronger relationship exists than if only one parent smokes.

What future respiratory burden these findings may represent for these children later in life is not known. As a former pediatric surgeon, I strongly urge parents to refrain from smoking in the presence of children as a means of protecting not only their children's current health status but also their own.

Diseases Other Than Lung Cancer

Several studies have provided data on the relationship between ETS and cancers other than lung cancer and on ETS exposure and cardiovascular disease. However, further research in these areas will be required to determine whether an association exists between ETS exposure and an increased risk of developing these diseases.

Policies Restricting Smoking in Public Places

The growth in our understanding of the disease risk associated with involuntary smoking has been accompanied by a change in the social acceptability of smoking and by a growing body of legislation, regulation, and voluntary action that addresses where smoking may occur in public. Forty States and the District of Columbia now have some form of legislation controlling or restricting smoking in various public settings. Some States limit smoking to only a few designated areas; however, States are increasingly developing and implementing comprehensive legislation that restricts smoking in many public settings, including the workplace. Nine States have restrictions that cover smoking not only by public employees but also by employees in the private sector.

No systematic evaluation of the effects these measures may have on smoking behavior has been conducted, but there is little doubt that strong public sentiment exists for implementing such restrictions. A number of national surveys conducted by voluntary health organizations, government agencies, and even the tobacco industry have documented that an overwhelming majority of both smokers and nonsmokers support restricting smoking in public.

Public Health Policy and Involuntary Smoking

The 1986 Surgeon General's Report on the Health Consequences of Involuntary Smoking clearly documents that nonsmokers are placed at increased risk for developing disease as the result of exposure to environmental tobacco smoke.

Critics often express that more research is required, that certain studies are flawed, or that we should delay action until more conclusive proof is produced. As both a physician and a public health

official, it is my judgment that the time for delay is past; measures to protect the public health are required now. The scientific case against involuntary smoking as a health risk is more than sufficient to justify appropriate remedial action, and the goal of any remedial action must be to protect the nonsmoker from environmental tobacco smoke.

The data contained in this Report on the rapid diffusion of tobacco smoke throughout an enclosed environment suggest that separation of smokers and nonsmokers in the same room or in different rooms that share the same ventilation system may reduce ETS exposure but will not eliminate exposure. The responsibility to protect the safety of the indoor environment is shared by all who occupy or control that environment.

Changes in smoking policies regarding the workplace and other environments necessitated by the data presented in this Report should not be designed to punish the smoker. Successful implementation of protection for the nonsmoker requires the support and cooperation of smokers, nonsmokers, management, and employees and should be developed through a cooperative effort of all groups affected. In addition, changes are often more effective when support and assistance is provided for the smoker who wants to quit.

Cigarette smoking is an addictive behavior, and the individual smoker must decide whether or not to continue that behavior; however, it is evident from the data presented in this volume that the choice to smoke cannot interfere with the nonsmokers' right to breathe air free of tobacco smoke. The right of smokers to smoke ends where their behavior affects the health and well-being of others; furthermore, it is the smokers' responsibility to ensure that they do not expose nonsmokers to the potential harmful effects of tobacco smoke.

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TABLE OF CONTENTS

CHAPTER 1

INTRODUCTION, OVERVIEW, AND SUMMARY AND CONCLUSIONS

CONTENTS

Introduction

Development and Organization of the 1986 Report

The 1986 Report was developed by the Office on Smoking and Health of the U.S. Department of Health and Human Services as part of the Department's responsibility, under Public Law 91-222, to report new and current information on smoking and health to the United States Congress.

The scientific content of this Report reflects the contributions of more than 60 scientists representing a variety of disciplines. Individual manuscripts were written by experts known for their understanding of and work in specific content areas. These manuscripts were refined through a series of meetings attended by the authors, Office on Smoking Health staff and consultants, and the Surgeon General.

Upon receipt of the final manuscripts from the authors, the Office and its consultants edited and consolidated the individual manuscripts into appropriate chapters. These draft chapters were subjected to an extensive outside peer review (see Acknowledgments for individuals and their affiliations) whereby each was reviewed by up to seven experts. Their comments were integrated and the entire volume was assembled. This revised edition of the Report was resubjected to review by 17 distinguished scientists outside the Federal Government, both in this country and abroad. Parallel to this review, the entire Report was also submitted to various institutes and agencies within the U.S. Public Health Service for review and comment.

The 1986 Report contains a Foreword by the Assistant Secretary for Health, a Preface by the Surgeon General of the U.S. Public Health Service, and the following chapters:

Chapter 1. Introduction, Overview, and Summary and Conclusions
Chapter 2. Health Effects of Environmental Tobacco Smoke Exposure
Chapter 3. Environmental Tobacco Smoke Chemistry and Exposures of Nonsmokers
Chapter 4. Deposition and Absorption of Tobacco Smoke Constituents
Chapter 5. Toxicity, Acute Irritant Effects, and Carcinogenicity of Environmental Tobacco Smoke
Chapter 6. Policies Restricting Smoking in Public Places and the Workplace

Overview

Inhalation of tobacco smoke during active cigarette smoking remains the largest single preventable cause of death and disability

5

for the U.S. population. The health consequences of cigarette smoking and of the use of other tobacco products have been extensively documented in the 17 previous Reports in the health consequences of smoking series issued by the U.S. Public Health Service. Cigarette smoking is a major cause of cancer; it is most strongly associated with cancers of the lung and respiratory tract, but also causes cancers at other sites, including the pancreas and urinary bladder. It is the single greatest cause of chronic obstructive lung diseases. It causes cardiovascular diseases, including coronary heart disease, aortic aneurysm, and atherosclerotic peripheral vascular disease. Maternal cigarette smoking endangers fetal and neonatal health; it contributes to perinatal mortality, low birth weight, and complications during pregnancy. More than 300,000 premature deaths occur in the United States each year that are directly attributable to tobacco use, particularly cigarette smoking.

This Report examines in detail the scientific evidence on involuntary smoking as a potential cause of disease in nonsmokers. Nonsmokers' exposure to environmental tobacco smoke is termed involuntary smoking in this Report because the exposure generally occurs as an unavoidable consequence of being in proximity to smokers, particularly in enclosed indoor environments. The term "passive smoking" is also used throughout the scientific literature to describe this exposure.

The magnitude of the disease risks for active smokers secondary to their "high dose" exposure to tobacco smoke suggests that the "lower dose" exposure to tobacco smoke received by involuntary smokers may also have risks. Although the risks of involuntary smoking are smaller than the risks of active smoking, the number of individuals injured by involuntary smoking is large both in absolute terms and in comparison with the number injured by some other agents in the general environment that are regulated to curtail their potential to cause human illness.

This Report reviews the evidence on the characteristics of mainstream tobacco smoke and of environmental tobacco smoke, on the levels of exposure to environmental tobacco smoke that occur, and on the health effects of involuntary exposure to tobacco smoke. The composition of the tobacco smoke inhaled by active smokers and by involuntary smokers is examined for similarities and differences, and the concentrations of tobacco smoke components that can be measured in a variety of settings are explored, as is smoke deposition and absorption in the respiratory tract. The studies that describe the risks of environmental tobacco smoke exposure for humans are carefully reviewed for their findings and their validity. The evidence on the health effects of involuntary smoking is reviewed for biologic plausibility, and compared with extrapolations of the risks of active

6

smoking to the lower dose of exposure to tobacco smoke found in nonsmokers. This review leads to three major conclusions:

1. Involuntary smoking is a cause of disease, including lung cancer, in healthy nonsmokers.

2. The children of parents who smoke compared with the children of nonsmoking parents have an increased frequency of respiratory infections, increased respiratory symptoms, and slightly smaller rates of increase in lung function as the lung matures.

3. The simple separation of smokers and nonsmokers within the same air space may reduce, but does not eliminate, the exposure of nonsmokers to environmental tobacco smoke.

The subsequent chapters of this volume describe in detail the evidence that supports these conclusions; the evidence is briefly summarized here.

Environmental Tobacco Smoke Constituents

Important considerations in examining the risks of involuntary smoking are the composition of environmental tobacco smoke (ETS) and its toxicity and carcinogenicity relative to the tobacco smoke inhaled by active smokers. Mainstream cigarette smoke is the smoke drawn through the tobacco into the smoker's mouth. Sidestream smoke is the smoke emitted by the burning tobacco between puffs. Environmental tobacco smoke results from the combination of sidestream smoke and the fraction of exhaled mainstream smoke not retained by the smoker. In contrast with mainstream smoke, ETS is diluted into a larger volume of air, and it ages prior to inhalation.

The comparison of the chemical composition of the smoke inhaled by active smokers with that inhaled by involuntary smokers suggests that the toxic and carcinogenic effects are qualitatively similar, a similarity that is not too surprising because both mainstream smoke and environmental tobacco smoke result from the combustion of tobacco. Individual mainstream smoke constituents, with appropriate testing, have usually been found in sidestream smoke as well. However, differences between sidestream smoke and mainstream smoke have been well documented. The temperature of combustion during sidestream smoke formation is lower than during mainstream smoke formation. As a result, greater amounts of many of the organic constituents of smoke, including some carcinogens, are generated when tobacco burns and forms sidestream smoke than when mainstream smoke is produced. For example, in contrast with mainstream smoke, sidestream smoke contains greater amounts of ammonia, benzene, carbon monoxide, nicotine, and the carcinogens

7

2-napthylamine, 4-aminobiphenyl, N-nitrosamine, benz[a]-anthracene, and benzo-pyrene per milligram of tobacco burned. Although only limited bioassay data comparing mainstream smoke and sidestream smoke are available, one study has suggested that sidestream smoke may be more carcinogenic.

Extent of Exposure

Although sidestream smoke and mainstream smoke differ somewhat qualitatively, the differing quantitative doses of smoke components inhaled by the active smoker and by the involuntary smoker are of greater importance in considering the risks of the two exposures. A number of different markers for tobacco smoke exposure and absorption have been identified for both active and involuntary smoking. No single marker quantifies, with precision, the exposure to each of the smoke constituents over the wide range of environmental settings in which involuntary smoking occurs. However, in environments without other significant sources of dust, respirable suspended particulate levels can be used as a marker of smoke exposure. Levels of nicotine and its metabolite cotinine in body fluids provide a sensitive and specific indication of recent whole smoke exposure under most conditions.

Widely varying levels of environmental tobacco smoke can be measured in the home and other environments using markers. The time-activity patterns of nonsmokers, which indicate the time spent in environments containing ETS, also vary widely. Thus, the extent of exposure to ETS is probably highly variable among individuals at a given point in time, and little is known about the variation in exposure of the same individual at different points in time.

Lung Cancer

The American Cancer Society estimates that there will be more than 135,000 deaths from lung cancer in the United States in 1986, and 85 percent of these lung cancer deaths are directly attributable to active cigarette smoking. Therefore, even if the number of lung cancer deaths caused by involuntary smoking were much smaller than the number of lung cancer deaths caused by active smoking, the number of lung cancer deaths attributable to involuntary exposure would still represent a problem of sufficient magnitude to warrant substantial public health concern.

Exposure to environmental tobacco smoke has been examined in numerous recent epidemiological studies as a risk factor for lung cancer in nonsmokers. These studies have compared the risks for subjects exposed to ETS at home or at work with the risks for people not reported to be exposed in these environments. Because exposure to ETS is an almost universal experience in the more developed countries, these studies involve comparison of more exposed and less

8

exposed people rather than comparison of exposed and unexposed people. Thus, the studies are inherently conservative in assessing the consequences of exposure to ETS. Interpretation of these studies must consider the extent to which populations with different ETS exposures have been identified, the gradient in ETS exposure from the lower exposure to the higher exposure groups, and the magnitude of the increased lung cancer risk that results from the gradient in ETS exposure.

To date, questionnaires have been used to classify ETS exposure. Quantification of exposure by questionnaire, particularly lifetime exposure, is difficult and has not been validated. However, spousal and parental smoking status identify individuals with different levels of exposure to ETS. Therefore, investigation has focused on the children and nonsmoking spouses of smokers, groups for whom greater ETS exposure would be expected and for whom increased nicotine absorption has been documented relative to the children and nonsmoking spouses of nonsmokers.

Of the epidemiologic studies reviewed in this Report that have examined the question of involuntary smoking's association with lung cancer, most (11 of 13) have shown a positive association with exposure, and in 6 the association reached statistical significance. Given the difficulty in identifying groups with differing ETS exposure, the low-dose range of exposure examined, and the small numbers of subjects in some series, it is not surprising that some studies have found no association and that in others the association did not reach a conventional level of statistical significance. The question is not whether cigarette smoke can cause lung cancer; that question has been answered unequivocally by examining the evidence for active smoking. The question is, rather, can tobacco smoke at a lower dose and through a different mode of exposure cause lung cancer in nonsmokers? The answer must be sought in the coherence and trends of the epidemiologic evidence available on this low-dose exposure to a known human carcinogen. In general, those studies with larger population sizes, more carefully validated diagnosis of lung cancer, and more careful assessment of ETS exposure status have shown statistically significant associations. A number of these studies have demonstrated a dose–response relationship between the level of ETS exposure and lung cancer risk. By using data on nicotine absorption by the nonsmoker, the nonsmoker's risk of developing lung cancer observed in human epidemiologic studies can be compared with the level of risk expected from an extrapolation of the dose–response data for the active smoker. This extrapolation yields estimates of an expected lung cancer risk that approximate the observed lung cancer risk in epidemiologic studies of involuntary smoking.

9

Cigarette smoke is well established as a human carcinogen. The chemical composition of ETS is qualitatively similar to mainstream smoke and sidestream smoke and also acts as a carcinogen in bioassay systems. For many nonsmokers, the quantitative exposure to ETS is large enough to expect an increased risk of lung cancer to occur, and epidemiologic studies have demonstrated an increased lung cancer risk with involuntary smoking. In examining a low-dose exposure to a known carcinogen, it is rare to have such an abundance of evidence on which to make a judgment, and given this abundance of evidence, a clear judgment can now be made: exposure to ETS is a cause of lung cancer.

The data presented in this Report establish that a substantial number of the lung cancer deaths that occur among nonsmokers can be attributed to involuntary smoking. However, better data on the extent and variability of ETS exposure are needed to estimate the number of deaths with confidence.

Respiratory Disease

Acute and chronic respiratory diseases have also been linked to involuntary exposure to tobacco smoke; the evidence is strongest in infants. During the first 2 years of life, infants of parents who smoke are more likely than infants of nonsmoking parents to be hospitalized for bronchitis and pneumonia. Children whose parents smoke also develop respiratory symptoms more frequently, and they show small, but measurable, differences on tests of lung function when compared with children of nonsmoking parents.

Respiratory infections in young children represent a direct health burden for the children and their parents; moreover, these infections, and the reductions in pulmonary function found in the school-age children of smokers, may increase susceptibility to develop lung disease as an adult.

Several studies have reported small decrements in the average level of lung function in nonsmoking adults exposed to ETS. These differences may represent a response of the lung to chronic exposure to the irritants in ETS, but it seems unlikely that ETS exposure, by itself, is responsible for a substantial number of cases of clinically significant chronic obstructive lung disease. The small magnitude of the changes associated with ETS exposure suggests that only individuals with unusual susceptibility would be at risk of developing clinically evident disease from ETS exposure alone. However, ETS exposure may be a factor that contributes to the development of clinical disease in individuals with other causes of lung injury.

Cardiovascular Disease

A few studies have examined the relationship between involuntary smoking and cardiovascular disease, but no firm conclusion on

10

the relationship can be made owing to the limited number of deaths in the studies.

Irritation

Perhaps the most common effect of tobacco smoke exposure is tissue irritation. The eyes appear to be especially sensitive to irritation by ETS, but the nose, throat, and airway may also be affected by smoke exposure. Irritation has been demonstrated to occur at levels that are similar to those found in real-life situations. The level of irritation increases with an increasing concentration of smoke and duration of exposure. In addition, participants in surveys report irritation and annoyance due to smoke in the environment under real-life conditions.

Determinants of Exposure

Exposure to ETS has been documented to be common in the United States, but additional data on the extent and determinants of exposure are needed to identify individuals within the population who have the highest exposure and are at greatest risk. Studies with biological markers and measurements of ETS components in indoor air confirm that measurable exposure to ETS is widespread. However, within exposed populations, levels of cotinine excretion and presumably ETS exposure vary greatly.

In a room or other indoor area, the size of the space, the number of smokers, the amount of ventilation, and other factors determine the concentration of tobacco smoke in the air. The technology for the cost-effective filtration of tobacco smoke from the air is not currently available, and because of their small size, the smoke particles remain suspended in the air for long periods of time; thus, the only way to remove smoke from indoor air is to increase the exchange of indoor air with clean outdoor air. The number of air changes per hour required to maintain acceptable indoor air quality is much higher when smoking is allowed than when smoking is prohibited.

Environmental tobacco smoke originates at the lighted tip of the cigarette, and exposure to ETS is greatest in proximity to the smoker. However, the smoke rapidly disseminates throughout any airspace contiguous with the space in which the smoking is taking place. Dissemination of smoke is not uniform, and substantial gradients in ETS levels have been demonstrated in different parts of the same airspace. The time course of tobacco smoke dissemination is rapid enough to ensure the spread of smoke throughout an airspace within an 8-hour workday. In the home, the presence of even one smoker can significantly increase levels of respirable suspended particulates.

These data lead to the conclusion that the simple separation of smokers and nonsmokers within the same airspace will reduce, but

11

not eliminate, exposure to ETS, particularly in those settings where exposure is prolonged, such as the working environment.

The exposure of an individual nonsmoker to ETS is also determined by that person's time-activity pattern; that is, the amount of time spent in various locations. For adults, the duration of time spent in smoke-contaminated environments at work or at home is the principal determinant of ETS exposure, along with the levels of smoke in those environments. For infants and very young children, the smoking habit of the primary caretaker, as well as that person's time-activity pattern, is likely to play a major role in determining ETS exposure.

Policies Restricting Smoking

Policies regulating cigarette smoking with the objective of reducing explosion or fire risk, or of safeguarding the quality of manufactured products, have been in force in a number of States since the late 1800s. More recently, and with steadily increasing frequency, policies regulating smoking on the basis of the health risk or the irritation of involuntary smoking have been promulgated.

State and local governments have enacted laws and regulations restricting smoking in public places. These policies have been implemented with few problems and at little cost to the respective governments. The public awareness of these policies that results from the media coverage surrounding their implementation probably facilitates their self-enforcement. Public awareness may best be fostered by encouraging the establishment of these changes at the local level.

Policies limiting smoking in the worksite have also become increasingly widespread and more restrictive. However, changes in worksite policies have evolved largely through voluntary rather than governmental action. In a steadily increasing number of worksites, smoking has been prohibited completely or limited to relatively few areas within the worksite. The creation of a smoke-free workplace has proceeded successfully when the policy has been jointly developed by employees, employee organizations, and management; instituted in phases; and accompanied by support and assistance for the smokers to quit smoking.

This trend to protect nonsmokers from ETS exposure may have an added public health benefit—helping those smokers who are attempting to quit to be more successful and not encouraging smoking by people entering the workforce.

Summary and Conclusions of the 1986 Report

The three major conclusions of this report are the following:

12

1. Involuntary smoking is a cause of disease, including lung cancer, in healthy nonsmokers.

2. The children of parents who smoke compared with the children of nonsmoking parents have an increased frequency of respiratory infections, increased respiratory symptoms, and slightly smaller rates of increase in lung function as the lung matures.

3. The simple separation of smokers and nonsmokers within the same air space may reduce, but does not eliminate, the exposure of nonsmokers to environmental tobacco smoke.

Individual chapter summaries and conclusions follow.

Health Effects of Environmental Tobacco Smoke Exposure

1. Involuntary smoking can cause lung cancer in nonsmokers.
2. Although a substantial number of the lung cancers that occur in nonsmokers can be attributed to involuntary smoking, more data on the dose and distribution of ETS exposure in the population are needed in order to accurately estimate the magnitude of risk in the U.S. population.
3. The children of parents who smoke have an increased frequency of hospitalization for bronchitis and pneumonia during the first year of life when compared with the children of nonsmokers.
4. The children of parents who smoke have an increased frequen cy of a variety of acute respiratory illnesses and infections, including chest illnesses before 2 years of age and physician-diagnosed bronchitis, tracheitis, and laryngitis, when compared with the children of nonsmokers.
5. Chronic cough and phlegm are more frequent in children whose parents smoke compared with children of nonsmokers. The implications of chronic respiratory symptoms for respiratory health as an adult are unknown and deserve further study.
6. The children of parents who smoke have small differences in tests of pulmonary function when compared with the children of nonsmokers. Although this decrement is insufficient to cause symptoms, the possibility that it may increase susceptibility to chronic obstructive pulmonary disease with exposure to other agents in adult life, e.g., active smoking or occupational exposures, needs investigation.
7. Healthy adults exposed to environmental tobacco smoke may have small changes on pulmonary function testing, but are unlikely to experience clinically significant deficits in pulmo-

13

nary function as a result of exposure to environmental tobacco smoke alone.

8. A number of studies report that chronic middle ear effusions are more common in young children whose parents smoke than in children of nonsmoking parents.

9. Validated questionnaires are needed for the assessment of recent and remote exposure to environmental tobacco smoke in the home, workplace, and other environments.

10. The associations between cancers, other than cancer of the lung, and involuntary smoking require further investigation before a determination can be made about the relationship of involuntary smoking to these cancers.

11. Further studies on the relationship between involuntary smoking and cardiovascular disease are needed in order to determine whether involuntary smoking increases the risk of cardiovascular disease.

Environmental Tobacco Smoke Chemistry and Exposures of Nonsmokers

1. Undiluted sidestream smoke is characterized by significantly higher concentrations of many of the toxic and carcinogenic compounds found in mainstream smoke, including ammonia, volatile amines, volatile nitrosamines, certain nicotine decomposition products, and aromatic amines.

2. Environmental tobacco smoke can be a substantial contributor to the level of indoor air pollution concentrations of respirable particles, benzene, acrolein, N-nitrosamine, pyrene, and carbon monoxide. ETS is the only source of nicotine and some N-nitrosamine compounds in the general environment.

3. Measured exposures to respirable suspended particulates are higher for nonsmokers who report exposure to environmental tobacco smoke. Exposures to ETS occur widely in the non-smoking population.

4. The small particle size of environmental tobacco smoke places it in the diffusion-controlled regime of movement in air for deposition and removal mechanisms. Because these submicron particles will follow air streams, convective currents will dominate and the distribution of ETS will occur rapidly through the volume of a room. As a result, the simple separation of smokers and nonsmokers within the same airspace may reduce, but will not eliminate, exposure to ETS.

5. It has been demonstrated that ETS has resulted in elevated respirable suspended particulate levels in enclosed places.

14

Deposition and Absorption of Tobacco Smoke Constituents

1. Absorption of tobacco-specific smoke constituents (i.e., nicotine) from environmental tobacco smoke exposures has been documented in a number of samples of the general population of developed countries, suggesting that measurable exposure to environmental tobacco smoke is common.
2. Mean levels of nicotine and cotinine in body fluids increase with self-reported ETS exposure.
3. Because of the stability of cotinine levels measured at different times during exposure and the availability of noninvasive sampling techniques, cotinine appears to be the short-term marker of choice in epidemiological studies.
4. Both mathematical modeling techniques and experimental data suggest that 10 to 20 percent of the particulate fraction of sidestream smoke would be deposited in the airway.
5. The development of specific chemical assays for human exposure to the components of cigarette tar is an important research goal.

Toxicity, Acute Irritant Effects, and Carcinogenicity of Environmental Tobacco Smoke

1. The main effects of the irritants present in ETS occur in the conjunctiva of the eyes and the mucous membranes of the nose, throat, and lower respiratory tract. These irritant effects are a frequent cause of complaints about poor air quality due to environmental tobacco smoke.
2. Active cigarette smoking is associated with prominent changes in the number, type, and function of respiratory epithelial and inflammatory cells; the potential for environmental tobacco smoke exposure to produce similar changes should be investigated.
3. Animal models have demonstrated the carcinogencity of cigarette smoke, and the limited data that exist suggest that more carcinogenic activity per milligram of cigarette smoke concentrate may be contained in sidestream smoke than in mainstream cigarette smoke.

Policies Restricting Smoking in Public Places and the Workplace

1. Beginning in the 1970s, an increasing number of public and private sector institutions have adopted policies to protect individuals from environmental tobacco smoke exposure by restricting the circumstances in which smoking is permitted.
2. Smoking in public places has been regulated primarily by government actions, which have occurred at Federal, State,

15

and local levels. All but nine States have enacted laws regulating smoking in at least one public place. Since the mid-1970s, there has been an increase in the rate of enactment and in the comprehensiveness of State legislation. Local governments have enacted smoking ordinances at an increasing rate since 1980; more than 80 cities and counties have smoking laws in effect.

3. Smoking at the workplace is regulated by a combination of government action and private initiative. Legislation in 12 States regulates smoking by government employees, and 9 States and more than 70 communities regulate smoking in the private sector workplace. Approximately 35 percent of businesses have adopted smoking policies. The increase in workplace smoking policies has been a trend of the 1980s.

4. Smoking policies may have multiple effects. In addition to reducing environmental tobacco smoke exposure, they may alter smoking behavior and public attitudes about tobacco use. Over time, this may contribute to a reduction in smoking in the United States. To the present, there has been relatively little systematic evaluation of policies restricting smoking in public places or at the workplace.

5. On the basis of case reports and a small number of systematic studies, it appears that workplace smoking policies improve air quality, are met with good compliance, and are well accepted by both smokers and nonsmokers. Policies appear to be followed by a decrease in smokers' cigarette consumption at work and an increase in enrollment in company-sponsored smoking cessation programs.

6. Laws restricting smoking in public places have been implemented with few problems and at little cost to State and local government. Their impact on smoking behavior and attitudes has not yet been evaluated.

7. Public opinion polls document strong and growing support for restricting or banning smoking in a wide range of public places. Changes in attitudes about smoking in public appear to have preceded legislation, but the interrelationship of smoking attitudes, behavior, and legislation are complex.

16

CHAPTER 2

HEALTH EFFECTS OF ENVIRONMENTAL TOBACCO SMOKE EXPOSURE

CONTENTS

20

Introduction

In 1964, the first Report of the Surgeon General on smoking and health (US PHS 1964) determined that cigarette smoking was a cause of lung cancer in men and probably a cause of lung cancer in women. That Report also noted causal relationships between smoking and other cancers, as well as chronic lung disease. Subsequent Reports have described associations, both causal and noncausal, between tobacco smoking and a wide range of acute and chronic diseases. Epidemiological investigations have documented the effects of tobacco smoking in humans; complementary laboratory investigations have elucidated some of the mechanisms through which tobacco smoke causes disease.

More recently, the effects of the inhalation of environmental tobacco smoke by nonsmokers have become a pressing public health concern. Nonsmokers, as well as active smokers, inhale environmental tobacco smoke, the mixture of sidestream smoke and exhaled mainstream smoke. Various terms have been applied to the inhalation of environmental tobacco smoke by nonsmokers; the terms "involuntary smoking" and "passive smoking" are the most prevalent and are often used interchangeably by researchers and the public.

Many of the known toxic and carcinogenic agents found in mainstream cigarette smoke have also been demonstrated to be present in sidestream smoke. Furthermore, the combustion conditions under which sidestream smoke is produced result in the generation of larger amounts of many of these toxic and carcinogenic agents per gram of tobacco burned than the conditions under which mainstream smoke is generated (see Chapter 3). The characteristics of environmental tobacco smoke also differ from those of mainstream smoke because the sidestream smoke ages before it is inhaled and the mainstream smoke exhaled by the active smoker is modified during its residence in the lung. There is no evidence to suggest that environmental tobacco smoke has a qualitatively lower toxicity or carcinogenicity than mainstream smoke per milligram of smoke inhaled. In fact, the available evidence suggests that sidestream smoke contains higher concentrations of many known toxic and carcinogenic agents per milligram of smoke and is more tumorgenic than mainstream smoke in animal testing (Wynder and Hoffmann 1967). As a result, involuntary smoking should not be viewed as a qualitatively different exposure from active smoking, but rather as a low-dose exposure to a known hazardous agent—cigarette smoke.

Evaluation of Low-Dose Tobacco Smoke Exposures

Assessment of the health effects of any environmental exposure poses methodological problems, particularly when exposure levels

are low and therefore the magnitude of the expected effect is small. The evaluation of an effect due to a low-dose exposure such as environmental tobacco smoke requires the investigation of populations with differences in exposure large enough so that an effect could be anticipated. The population studied must also be of sufficient size to quantitate the effects in the range of interest with precision. Failure to fulfill these requirements may produce a false-negative result in a study of a low-dose exposure.

Exposure to environmental tobacco smoke is a nearly universal experience in the more developed countries, so the identification of a truly unexposed population is very difficult. Epidemiological studies of involuntary smoking have attempted to identify populations with lower exposure and higher exposure to environmental tobacco smoke, most notably by examining nonsmokers exposed to tobacco smoke generated by the smokers of their family. The effects of environmental tobacco smoke have been investigated in a number of populations throughout the world. The diversity of these populations is likely to be accompanied by a similar diversity of their exposure to environmental tobacco smoke. Thus, the gradient in exposure to environmental tobacco smoke between the "exposed" and "nonexposed" groups is likely to vary widely among the reported studies. For example, the husband's smoking status may be a strong predictor of total exposure to ETS in traditional societies, such as Japan and Greece, where the wife's exposure outside the home is limited. In contrast, the husband's smoking status in the United States, where substantial exposure may occur outside the home, may not be as predictive.

Sample size considerations are of particular concern for the epidemiological studies of lung cancer and involuntary smoking. Because the frequency of lung cancer in nonsmokers is low, many of these studies often included small numbers of nonsmokers and lacked the statistical power necessary to find the modest effect expected from this low-dose exposure. Given the constraints of sample size and the varying gradients of exposure, it would be expected that some studies would find no association between involuntary smoking and lung cancer, and that other studies would find associations that lacked statistical significance. Nonuniformity of the data, however, does not imply a lack of effect; rather, it is the coherence and trends of the evidence that must be judged. Thus, this Report examines the entire body of evidence on the health effects of involuntary smoking, as the basis for its conclusions.

In evaluating the hazards posed by an air pollutant such as environmental tobacco smoke, laboratory, toxicological, human exposure, and epidemiological investigations provide relevant data. Each approach has limitations, but the insights each provides are complementary. Epidemiological investigations describe the effects

22

in human populations, but their results must be interpreted in the context of the other types of investigations.

Risk assessment techniques have also been used to characterize the potential adverse health effects of human exposures to environmental pollutants, particularly those at low levels. The four steps of risk assessment have been described by the National Academy of Sciences as hazard identification, dose–response assessment, exposure assessment, and risk characterization (NAS 1983). Risk assessment has also been used to describe the consequences of exposure to ETS. However, unlike many environmental exposures for which risk assessment represents the only approach for estimating human risk, the health effects of ETS exposure can be examined directly using epidemiological methods. Although this Report reviews several risk assessments done by individual researchers on ETS, its conclusions are based on the laboratory, toxicological, and epidemiological evidence.

Extrapolation of Active Smoking Data to Environmental Tobacco Smoke Exposure

Comparison of Mainstream Smoke and Sidestream Smoke

A detailed comparison of mainstream and sidestream smoke can be found in Chapter 3. Mainstream smoke (MS) is the term applied to the complex mixture that is inhaled by the smoker from the mouthpiece of a cigarette, cigar, or pipe with each puff. Sidestream smoke (SS) is the aerosol that comes from the burning end of the cigarette, pipe, or cigar between puffs. Environmental tobacco smoke (ETS) is the term applied to the combination of SS and exhaled MS, which is diluted and aged in an area where smoking has taken place. Most of the existing data on mainstream and sidestream smoke characteristics relate to cigarette smoking and relatively little information is available pertaining to cigar and pipe smoking.

Because both MS and SS are generated from the tip of the burning tobacco product, it is not surprising that their compositions are similar. Of the thousands of compounds identified in tobacco smoke, many have been identified as present in both MS and SS. Among these are carcinogens, gases such as carbon monoxide and the oxides of nitrogen, and nicotine. Since there is a wealth of information relating to the toxicity and carcinogenicity of MS, it should be emphasized again that ETS cannot be treated as a new environmental agent for the purpose of assessing health risks. The presence of the same agents in MS and SS leads to the conclusion that ETS has a toxic and carcinogenic potential that would not be expected to be qualitatively different from that of MS. Quantitative differences between the active smoker's exposure to MS and the involuntary smoker's exposure to ETS are likely to be the more important

23

determinant of the differing magnitudes of risks associated with these two exposures.

Differences in the composition of MS and SS primarily reflect their generation at different temperatures in different oxygen environments. Also, SS is diluted very rapidly, under most circumstances, and has the opportunity to age before inhalation. The involuntary smoker usually inhales ETS, not SS, the aerosol that comes from the tip of a burning cigarette. In considering the characteristics of SS, it must be emphasized that much of the existing data about the composition of MS and SS is derived from studies carried out in special chambers rather than by sampling MS and SS generated by smokers. In these chamber studies, SS has been sampled by a probe located close to the burning tip. This experimental situation clearly differs from that of a room with one or more smokers freely smoking. In that situation, SS is mixed with exhaled MS, diluted and aged. Nevertheless, these chamber studies provide very useful information about the compounds present in the SS. These studies have established that SS in comparison with MS has a higher pH, smaller particle size, and more carbon monoxide, benzene, toluene, acrolein, acetone, pyridine, ammonia, methylamine, nicotine, aniline, cadmium, radon daughters, benzo[a]pyrene and benz[a]anthracene.

Comparison of the relative concentrations of the various components of SS and MS smoke provides limited insights concerning the toxicological potential of ETS in comparison with active smoking. As described above, SS characteristics, as measured in a chamber, do not represent those of ETS, as inhaled by the nonsmoker under nonexperimental conditions. Further, the dose–response relationships between specific tobacco smoke components and specific diseases are not sufficiently established for the necessary extrapolations from active smoking to environmental tobacco smoke exposure for individual agents. For that reason the extrapolations in this section are confined to the dose–response relationships of whole smoke for those diseases with established dose–response relationships.

With regard to the potential of ETS to cause lung cancer, undiluted SS has 20 to 100 times greater concentrations of highly carcinogenic volatile N-nitrosamines than MS (Brunnemann et al. 1978) as well as higher concentrations of benzopyrenes and benz[a]anthracenes.

For nonmalignant effects on airways and the lung parenchyma, the agents responsible for the development of acute and chronic respiratory disease have not been identified, although many tobacco smoke components have been shown to cause lung injury (US DHHS 1984). Presumably, both vapor phase (gaseous) and particulate phase (solid) components of MS are involved. Both airways disease and

24

parenchymal disease are probably a response to the total burden of respiratory insults, some of which, like active smoking, may be sufficient by themselves to cause physiologic impairment and ultimately, clinical disease. Others, such as ETS, may contribute to the total burden but be insufficient, individually, to cause clinical disease.

Deposition of Mainstream Smoke and Sidestream Smoke and Environmental Tobacco Smoke Dose Estimates

The dose of tobacco smoke delivered to the airways and alveoli depends, among other factors, on the volume of MS, SS, or ETS inhaled, on the rate and depth of inhalation, and on the size, shape, and density of the individual particles or droplets. Patterns of deposition of MS in the lungs have been described, but similar information about deposition patterns for ETS is not yet available. Without such data, it is necessary to extrapolate from the information on MS.

The major factors that affect the pattern of deposition and retention for particles are particle size distribution and breathing pattern. The particle size range and mean aerodynamic diameter for particulates in sidestream smoke are similar to those of mainstream smoke (particle size range of 0.01 to 0.8 μm for sidestream smoke and 0.1 to 1.0 μm for mainstream smoke, and mean aerodynamic diameter 0.32 μm for sidestream smoke and 0.4 μm for mainstream smoke) (see Chapters 3 and 4). The deposition site is determined largely by the size of the particles, with large particles being deposited preferentially in the nasopharynx and large conducting airways. Smaller particles are deposited more peripherally, and very small particles tend to be exhaled and to have a very low deposition fraction. The particulates of ETS, because of their size range, are likely to be deposited peripherally.

The breathing patterns for the inhalation of MS and ETS are also different; MS is inhaled intermittently by the smoker with an intense inhalation, often followed by a breathhold that results in a more equal distribution. Environmental tobacco smoke, on the other hand, is inhaled continuously with tidal breaths when the passive smoker is at rest and with deeper inhalations when the passive smoker is physically active. Breathholding does not normally occur with tidal breathing.

Estimates of the equivalent exposure, in terms of cigarettes per day, resulting from ETS, as compared with MS, vary quite widely and depend on the way in which the estimates were made. Repace and Lowrey (1985) estimated that nonsmokers in the United States are exposed to from 0 to 14 mg of tobacco tar (average 1.4 mg) per day. Vutuc (1984) estimated that the exposure to environmental cigarette smoke is equivalent to 0.1 to 1 cigarette per day actively

smoked. Estimates of ETS exposure, based on cotinine measurements, suggest that involuntary smokers absorb about 0.5 to 1 percent of the nicotine that active smokers absorb (Jarvis et al. 1984; Haley and Hoffmann 1985; Wald et al. 1984; Russell et al. 1986).

Dose–Response Relationships and Threshold for Risk

Dose–response relationships for active smoking can provide insights into the expected magnitude of disease resulting from the exposure of nonsmokers to ETS. These data are reviewed to determine whether disease can be expected in association with ETS.

Data from cohort and case–control studies demonstrate dose-response relationships for lung cancer, which extend to the lowest levels of reported active smoking. The dose–response relationship of active smoking with lung cancer risk has been described by several investigators in several different data sets (Whittemore and Altshuler 1976; Doll and Peto 1978; Pathak et al. 1986). Although the mathematical forms of these models vary, none have included a threshold level of active smoking that must be passed for lung cancer to develop.

The dose–response relationship for active smoking and lung cancer has been used to project the lung cancer risk for nonsmokers (Vutuc 1984). Such projections yield risk estimates of 1.03 to 1.36 for exposures, considered to be reasonable estimates of involuntary smoking exposures, i.e., 0.1 to 1.0 cigarettes per day. The reference population for these risk estimates is the risk for nonsmokers as a group, including those with higher and those with lower exposures to environmental tobacco smoke. In contrast, the reference population for the risk estimates in studies of involuntary smoking is the lung cancer risk in only that group of nonsmokers who have lower exposure to ETS. Comparisons of lung cancer risk estimates from active smoking studies with those from involuntary smoking studies require reference to the same exposure group for proper interpretation. In general, the lung cancer experience of all nonsmokers (i.e., those with higher and lower involuntary smoking exposure combined) has been used to establish the reference rate of lung cancer occurrence (i.e., set as a risk of 1) in studies of active smoking. The use of all nonsmokers as the reference group averages the lower risks of nonsmokers with less ETS exposure with the higher risks of those with more ETS exposure. Thus, with the relative risk for the entire group of nonsmokers set to unity, the relative risk for nonsmokers with lower exposure is below 1 and that for the group with higher exposure is above 1. As a consequence, relative risk estimates from studies of involuntary exposure cannot be directly compared with risk estimates extrapolated from active smoking, unless comparison to a single level of exposure is possible. Failure to

consider the differences between the reference populations explains the apparent discrepancy noted by Vutuc.

Consider, for example, the mortality study reported by Hirayama (1981a). In this study, the relative risk of lung cancer for nonsmoking wives of smoking husbands (current and former) compared with nonsmoking wives of nonsmoking husbands (as calculated from Figure 1 in Hirayama 1981a) was 1.78. If the relative risk for nonsmoking wives of nonsmoking husbands were expressed in relation to the combined group of nonsmoking women, then a value of 0.63 is obtained, while with a similar calculation, that for nonsmoking wives of smoking husbands (both current and former), yields a value of 1.12. Thus, when the appropriate comparison is made, the risk estimates developed by extrapolation of the active smoking data (1.03 to 1.36) closely approximate those actually found in a study of lung cancer risk due to involuntary smoking.

Dose–response relationships between active smoking and the level of lung function, the rate of decline of lung function in adult life, and the development of chronic airflow obstruction are well established (US DHHS 1984). Different measures of dose have provided the strongest correlation with functional decline in different studies. Pack-years, a cumulative dose measure, was the strongest predictor of the level of forced expiratory volume in 1 second (FEV_1) in the Tucson epidemiologic study (Burrows, Knudson, Cline et al. 1977). Duration of smoking and the amount smoked were found to be the best predictors in male subjects in a study of three U.S. communities (Beck et al. 1981), and pack-years was the best predictor in female subjects. In both of these studies, however, the estimated dose accounted for only about 15 percent of the variation of age- and height-adjusted FEV_1 levels. The relatively low predictive capability of cigarette smoking variables in these studies most likely reflects a lack of information on the determinants of individual susceptibility to tobacco smoke. Further, exposure variables obtained by question-naire, such as the number of cigarettes smoked daily, may only roughly approximate the dose delivered to target sites in the respiratory tract. Many factors, such as puff volume, lung volume at which inhalation starts, and airways geometry will influence the smoke dose and its distribution within the lungs. Extrapolation from the results of these studies to the pulmonary effects of exposure to ETS is, therefore, likely to be inaccurate.

Another approach for assessing low-dose exposures is to consider the information available from studies involving children and teenagers who have recently taken up smoking. Even with brief smoking experience, cross-sectional studies of active cigarette smoking by children and adolescents have demonstrated an increased frequency of respiratory symptoms (Rawbone et al. 1978; Rush 1974; Bewley et al. 1973; Seely et al. 1971) and small but statistically

27

significant reductions in lung function (Seely et al. 1971; Peters and Ferris 1967; Lim 1973; Walter et al. 1974; Backhouse 1975; Woolcock et al. 1984). Longitudinal studies involving children and adolescents have demonstrated that a physiologic impairment attributable to smoking may be found in some children by age 14 and may be present after only 1 year of smoking 10 or more cigarettes per week in children with previously normal airways (Woolcock et al. 1984), and that relatively small amounts of cigarette use may lead to significant effects on FEV_1 and on the growth of lung function in adolescents (Figure 1) (Tager et al. 1985).

When considering the risk of low-dose exposures for the development of chronic respiratory disease, the existence of a spectrum of risk and a distribution of dose within the population should be taken into consideration. The characteristics of the part of the population most susceptible to involuntary smoke exposure is still being clarified. Evidence is accumulating that airways hyperresponsiveness, atopy, childhood respiratory illness, and occupational exposures may all influence response to ETS. Current understanding of lung injury suggests that individuals with one or more of these characteristics that place them at the most sensitive end of the susceptibility curve may be the most likely to develop symptoms or functional changes as a result of ETS exposure. Dose of ETS also varies in the population, and the coincidence of high dose and increased susceptibility may convey a particularly high risk. Furthermore, ETS exposure may damage lungs that are also affected by other insults.

Pathophysiologic Considerations

Cancer

Carcinogenesis refers to the process by which a normal cell is transformed into a malignant cell with uncontrolled replication. Carcinogenesis has been conceptualized as a multistage process involving a sequence of alterations in cellular DNA that terminate with the development of a malignant cell. Agents acting early in this sequence are referred to as initiators; those acting later are referred to as promoters. Compounds with both initiating activity and promoting activity have been identified in tobacco smoke.

Carcinogenesis reflects DNA damage; although some repair may take place, biological models have not suggested that there is a threshold of damage that must be exceeded. Rather, carcinogenesis has been considered to involve a series of changes, each occurring at a rate dependent on the dose of a damaging agent. Higher doses increase the probability that the entire sequence will be completed, but lower doses may also lead to malignancy.

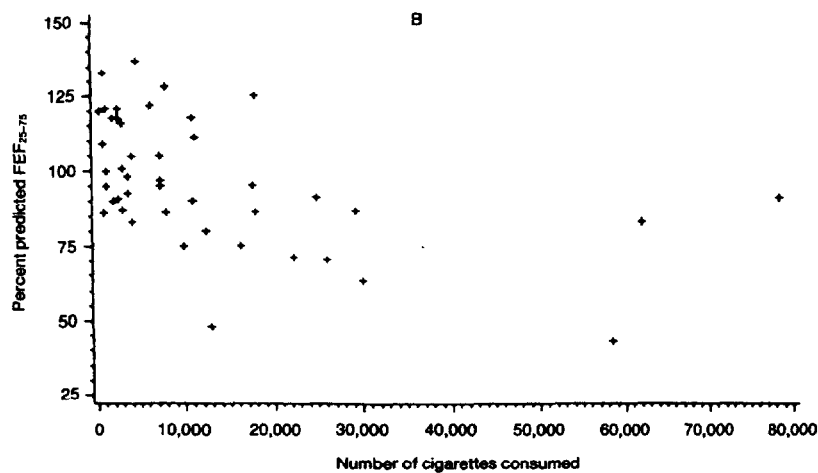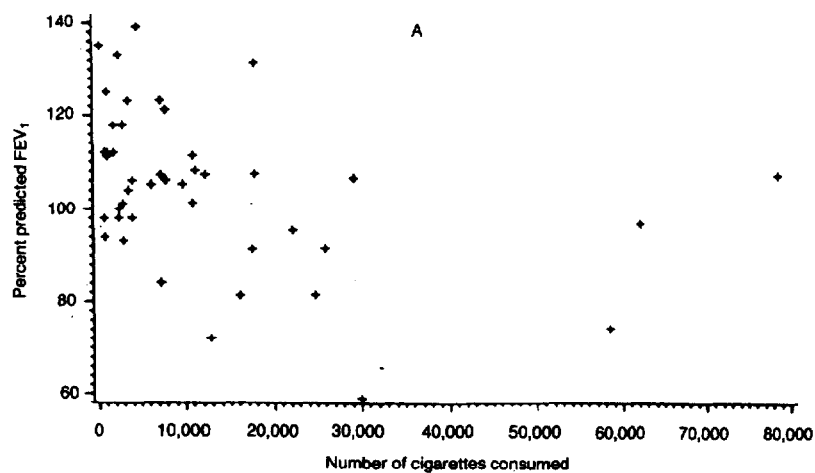28

FIGURE 1.—Relationship between levels of predicted for FEV₁ (A) and FEF₂₇₋₇₅ (B) at examination 8 and cumulative number of cigarettes smoked during examinations 4 through 8

NOTE: Men and women combined (N=44).
SOURCE: Tager et al. (1985).

with the PiZZ or other phenotypes, are modest particulate exposures likely to increase the risk for disease to an appreciable extent.

The development of acute and chronic *airway* disease or symptoms of cough, phlegm production, and wheeze may require a considerably smaller exposure than changes in the lung parenchyma, and it is not unreasonable to hypothesize that these symptoms may be related to repeated and continuous exposure to ETS in the susceptible individual. Strong evidence that low-dose active smoking causes increased rates of respiratory symptoms and functional impairment comes from the studies of children and adolescents discussed earlier (Woolcock et al. 1984; Tager et al. 1985). Because of the length of exposure, it is likely that these reflect airway rather than parenchymal effects.

Another pathophysiological mechanism by which exposure to ETS may increase an individual's risk for the development of chronic airflow obstruction is through respiratory viral infections. Mounting evidence indicates that the very young child (under 2 years of age) exposed to ETS is at increased risk for lower respiratory tract viral infections (Harlap and Davies 1974; Colley 1974; Colley et al. 1974; Leeder et al. 1976a; Fergusson et al. 1981; Dutau et al. 1979; Pedreira et al. 1985). There is also increasing, though still inconclusive, epidemiologic evidence that respiratory viral infections in early life may be associated with an accelerated decline in FEV_1 and, therefore, an increased risk for the development of chronic airflow obstruction in adult life in smokers (Burrows, Knudson, Lebowitz 1977; Samet et al. 1983). By increasing the occurrence of viral infections of the lower respiratory tract in early life, exposure to ETS in childhood may have an appreciable, but indirect, effect on the risk for the development of chronic airflow obstruction in adult life. The structural basis for this increased susceptibility has not yet been elucidated, however. Furthermore, the child whose parents smoke is also more likely to take up smoking than is the child of nonsmoking parents. Thus, the child made susceptible to the effects of active smoking by prior ETS exposure is also more likely to become an active smoker.

The possibility that exposure to constituents of tobacco smoke in utero may exert a prenatal effect must also be considered. This exposure is clearly not the same as ETS exposure, since the lungs of the fetus are not being exposed to ETS; rather, the developing fetal lung is exposed to compounds absorbed by the mother and delivered to the fetus transplacentally. Evidence of an in utero effect in pregnant rats has been reported by Collins and coworkers (1985). These investigators reported that pregnant rats exposed to smoke from day 5 to day 20 of gestation, in comparison with control rats, showed reduced lung volume at term and saccules that were reduced in number and increased in size as a result of the reduced formation

31

The noncarcinogenic pathophysiologic effects of active smoking on the respiratory tract can be separated into (1) effects on the airways and (2) effects on the lung parenchyma. In the airways, the structural changes include inflammation in the small airways and mucous gland hypertrophy and hyperplasia. In the parenchyma, the main structural change is alveolar wall destruction. Both the airways and the parenchymal changes are caused by active smoking, but the interrelationships of these changes are not clear. They may be independent pathophysiologic processes, linked only by their joint association with tobacco smoking.

As discussed earlier, there is evidence showing an approximately linear dose–response relationship between FEV_1 level and amount smoked; however, the dose–response relationships have not been as well described for the underlying pathophysiologic changes in the airways or in the lung parenchyma. Host factors and other environmental factors presumably interact with active smoking to affect an individual's risk for the development of disease. In this regard, present evidence would suggest that only 10 to 15 percent of smokers develop clinically significant airflow obstruction, although parenchymal and airways changes can be demonstrated in a substantially higher percentage at autopsy (US DHHS 1984).

Extrapolation from the evidence on active smoking to the likely effect of exposure to environmental tobacco smoke on the airways and parenchyma suggests that pathophysiologic effects on both the airways and the lung parenchyma might be expected. Because the dose of smoke components from ETS exposure is small in comparison with the dose from active smoking, the extent of lung injury would most likely also be much smaller than that found in active smokers. Small changes in the lung may be below the threshold for detection on pulmonary function testing. If clinically significant chronic airflow obstruction occurs in nonsmokers exposed to ETS, the risk is likely to be concentrated among those individuals highly susceptible to the airway or parenchymal effects of cigarette smoke. This susceptible group may include individuals with bronchial hyperresponsiveness and with other, as yet unidentified, genetic and familial risk factors. Identifying the risk factors for susceptibility to the airway and parenchymal effects of both mainstream smoke and ETS is an important priority. The dose of environmental tobacco smoke received by the nonsmoker is unlikely, by itself, to be sufficient to cause a clinically significant degree of *parenchymal* disease (emphysema) unless an individual is at the extreme end of the susceptibility distribution. Any particulate load is likely to increase the elastase burden in the lungs by causing an influx of neutrophils. However, only in the individual with very inadequate lung defenses, specifically severe deficiency of protease inhibitor (Pi) associated

30

of saccule partitions. These hypoplastic lungs showed an internal surface area that was decreased. Whether this study in rats has any relevance to humans is not yet clear, but this issue deserves further investigation.

Whether continued exposure to ETS during childhood, while the lung is remodeling and growing, affects the process of growth and remodeling is not yet clear. In general, rapidly dividing cells and immature organs are more susceptible to the effects of environmental toxins than are cells undergoing a normal rate of division and mature organs. Apart from the evidence, cited above, linking lower respiratory tract viral infections in very early life to an accelerated decline of FEV₁ in adult life, there is no information yet to link the rate of growth of lung function during childhood to the rate of decline of lung function in adult life because the necessary longitudinal studies have not been done. More information is needed to describe the relationship of exposure to ETS at various times during childhood to the maximal level of lung function achieved at full lung growth.

Methodological Considerations in Epidemiologic Studies

Measurement of Exposure

In assessing the health effects of ETS exposure, as with other environmental pollutants, accurate assessment of exposure is critical for obtaining estimates of this agent's effects. Both random and systematic misclassification of the exposures of subjects in an investigation are of concern. Random misclassification refers to errors that occur at random; the consequence of such random misclassification is to bias toward finding no effect. Systematic misclassification refers to nonrandom errors in exposure assessment; the consequence may be to bias toward a greater or lesser effect than is actually present. Biased answers in response to a questionnaire may introduce systematic misclassification.

Some misclassification occurs in most observational (nonexperimental) epidemiological studies, and is inherent in all epidemiological studies of ETS. Tobacco smoking is ubiquitous in nearly all environments; few people escape being exposed to ETS. Thus, the exposure variables for ETS in epidemiological studies do not separate nonexposed subjects from exposed subjects; rather, they identify groups with more or less exposure, or with a qualitative or semiquantitative gradient of exposure.

In assessing exposure to ETS, the information should cover the biologically appropriate time period for the health effect of interest and be collected in a form that permits the construction of biologically appropriate exposure measures. However, the collection of a full lifetime history of ETS exposure, as in a study of malignancy, may not be feasible, and the accuracy of the informa-

tion may be limited. In evaluating the effects of ETS exposure, cumulative exposure, duration of exposure, and intensity of exposure may each influence the magnitude of effects, as may the timing of exposure in relation to age and level of development.

Because of the difficulties inherent in assessing exposures through questionnaires, increased emphasis has been placed on measuring exposure through the use of molecular or biochemical markers. With available markers, this approach is limited to providing an indication of recent (within 48 hours) exposure, which may not necessarily correlate with past exposure. A marker has not yet been devised for total integrated dose. Nevertheless, biological markers provide another method for classification of current exposure, and a standard for validating questionnaires.

The strengths and weaknesses of the existing methods of measuring exposure are further discussed below.

Atmospheric Markers

A number of different markers of atmospheric contamination by tobacco combustion products can be feasibly measured. Ideally, the atmospheric levels of the air contaminant or class of contaminants that are implicated in producing the adverse health effects would be measured. A variety of contaminants have been measured as indicators of ETS, but no single measure can adequately index all of its myriad components. Further, some contaminants are produced by sources of environmental contamination other than tobacco smoke. Nicotine is absorbed only from tobacco and tobacco combustion products.

Some of the pollutants that have been measured include (1) carbon monoxide, (2) respirable suspended particulates (RSP), (3) nicotine, (4) a number of aromatic hydrocarbons, such as benzene, toluene, benzo-pyrene, and phenols, and (5) acrolein. Some of these are in the vapor phase and some in the particulate phase. Some, such as nicotine, may exist in one phase (particulate) in MS and in the other (gas) phase in SS. Until more is learned about the contaminants and their physical state in ETS, the results of monitoring for a particular ETS component will be difficult to relate to its disease-causing potential. At a practical level, the technology for measuring nicotine levels and RSP levels is available and accurate.

Personal Monitoring

Both active and passive personal monitors can be used to measure an individual's total exposure to an air contaminant at the breathing zone. Active personal monitoring systems employ pumps to concentrate the air contaminants on a collection medium for laboratory analysis or to deliver the air to a continuous monitor. Passive

33

personal monitoring systems use diffusion and permeation to concentrate gases on a collection medium for laboratory analysis. Personal monitoring should provide a more accurate estimate of the dose of a contaminant than area monitoring, because the actual air in the breathing zone is sampled and the subject's time-activity pattern is inherently considered.

As with area monitoring, the results for a particular component of ETS may not adequately characterize exposure to other components responsible for a particular disease or effect. Respirable suspended particulates can be measured with accuracy and give a reasonably accurate measurement of current exposure.

Questionnaires

The questionnaire has been the most frequently used means of estimating exposures for epidemiological investigations. Questionnaires typically have obtained information about the smoking habits of parents, spouses, or other family members and often about exposure outside the home. From this information, the subject is classified as exposed or not exposed to ETS, and the extent of exposure may be estimated.

The questionnaire approach for exposure estimation has several potential limitations. First, the information obtained cannot exhaustively cover lifetime exposure to ETS; therefore, a completely accurate reconstruction of integrated dose over the years cannot be achieved. Second, in evaluating ETS exposure in the home, the usual daily smoking of the smokers has often been used as a measure of exposure intensity at home. This assumption may not be correct, since smoking does not occur only in the home. For example, a one-pack-a-day smoker may smoke only five cigarettes a day in the home environment and smoke the rest at work or elsewhere outside the home. Third, quantitation of exposure in the workplace is inherently difficult because of changes in jobs and the varying exposure in any particular workplace.

Despite these shortcomings, the information obtained by questionnaires does discriminate between more exposed and less exposed subjects. The evidence validating the questionnaire method is strongest for domestic exposure. In several studies, levels of cotinine in body fluids have varied with reported exposure to tobacco smoke at home (Greenberg et al. 1984; Wald and Ritchie 1984; Matsukura et al. 1984; Jarvis et al. 1984). In fact, residence with a smoker may identify a population that is more tolerant of ETS, and therefore more likely to be exposed outside the home. Evidence in support of this speculation is provided by a study of urinary cotinine levels in nonsmoking men in the United Kingdom (Wald and Ritchie 1984). In this study, the men married to women who smoked reported a

34

greater duration of exposure outside the home than men married to women who did not smoke.

Until accurate and inexpensive exposure markers are available for cumulative ETS exposure, the questionnaire approach will remain the simplest means of obtaining exposure information. It is, therefore, important to consider the misclassification that can be introduced by using this indirect measure of exposure. In studies of the effect of ETS exposure, two types of misclassification are of concern: misclassification of current or former smokers as never smokers and misclassification of the extent of ETS exposure.

Because active smoking has a greater effect on the lungs than exposure to ETS, the inclusion of active smokers within a larger group of nonsmokers may lead to the finding of a significant effect on lung function, which is actually attributable to active smoking rather than to involuntary smoking. Misclassification of undeclared active smoking is a particularly important source of error in studies involving teenagers. Misclassification of smoking status is also of concern in case–control studies of the association between exposure to ETS and lung cancer. Information about smoking habits for these studies often comes from interviews with a surviving spouse or surrogate, who may have been a close family member, neighbor, or friend, or from a review of medical records. The smoking habits of the subject may be incorrectly reported. Classification of individuals who are current or former smokers as never smokers would lead to a spurious increase in the relative risk for lung cancer in nonsmokers exposed to ETS, because the smoking habits of spouses tend to be correlated. The extent of this bias in the case–control studies is uncertain. The proportion of people reported as never smokers, but who in fact did smoke in the past, is unknown. The proportion of current smokers who report themselves as nonsmokers can be estimated from studies using markers to validate questionnaires. Using biochemical markers of tobacco smoke absorption, the proportion would appear to be about 0.5 to 3 percent, depending on the population studied and the questionnaire used (Wald et al. 1981; Saloojee et al. 1982).

Misclassification of the extent of ETS exposure can also occur, and may reduce the observed risk if a nonsmoking spouse of a smoker is not exposed to smoke at home. Friedman and colleagues (1983), reporting on a survey of 38,000 subjects, noted that 47 percent of nonsmoking women married to smokers reported that they were not exposed to tobacco smoke at home.

Measurements of Absorption

The difficulties inherent in estimating exposure and dose have provided the impetus for the development of biological markers for exposure to both MS and ETS. The marker that at present holds the

highest promise is cotinine, the major metabolite of nicotine. Cotinine may be measured in saliva, blood, or urine. Numerous studies have demonstrated that there is good correlation between these measures of cotinine and the estimated exposure to tobacco smoke under laboratory conditions (Russell and Feyerabend 1975; Hoffmann et al. 1984) and under conditions of daily life (Russell and Feyerabend 1975; Feyerabend et al. 1982; Foliart et al. 1983; Wald et al. 1984; Wald and Ritchie 1984; Jarvis et al. 1984; Matsukura et al. 1984; Greenberg et al. 1984). Cotinine is probably the best marker for tobacco smoke intake because it is highly sensitive and specific for tobacco smoke and because it can be detected both in active smokers and in individuals exposed to ETS. Further details about cotinine and other markers are to be found in Chapter 4.

Potentially Confounding Variables

In any epidemiological study, the confounding factors must be considered and their effects controlled. Confounding refers to the biasing effect of a factor that independently influences the risk for the disease of concern and is also associated with the exposure under evaluation. Confounding is of particular concern when the effects of the exposure of interest are expected to be small.

The potential confounding variables depend on the health outcome of interest. For lung cancer, occupational exposures, diet, and exposure to other combustion products are of concern. For acute and chronic pulmonary effects, potential confounders include airways hyperresponsiveness, other indoor air pollutants, outdoor air pollution, respiratory tract infections, occupational exposure, and socioeconomic status, which may potentially influence disease risk through its environmental correlates. While this list is extensive, it may not be inclusive; in any single investigation it may not be possible to measure and control all potentially confounding variables.

Statistical Issues

In general, the evidence on active smoking in combination with the dosimetry of involuntary smoking leads to the conclusion that the effects of ETS on a population will be substantially less than the effects of active smoking. The effects of ETS on infants and young children are an important exception.

The association of ETS with an adverse effect in an individual study may reflect bias, chance, or a causal relationship. Statistical significance testing is used to quantitate the role of chance; by convention, a p (probability) value less than 0.05 is deemed statistically significant. A p value less than 0.05 means that the observed results would occur by chance less than 5 times out of 100, if there is

36

truly no association between ETS and the effect. The choice of 0.05 is arbitrary, and as the significance level declines, the probability that the observation could have occurred by chance lessens.

For effects of small magnitude, as may be anticipated for some consequences of exposure to ETS, a large study population may be necessary to demonstrate statistical significance. The absence of statistical significance for an association may reflect an inadequate sample size and is not always indicative of the absence of an association. In this regard, reports describing the absence of effects of ETS should provide the calculations needed to demonstrate the study's statistical power (ability to detect effects of the magnitude expected) or a confidence interval for the estimate of effect.

An additional statistical issue is the directionality of statistical significance testing. Either one-sided or two-sided tests may be used; in the first, only effects in one direction are considered a possibility, whereas two-sided tests consider the possibility of effects in opposing directions, i.e., increase or decrease of risk. Given the strength of the evidence on active smoking and disease risk, one-sided testing in the direction of an adverse effect seems appropriate for most potential consequences of ETS. However, one-sided tests have not been performed in all investigations of ETS; the use of two-sided tests makes these studies conservative, as statistical significance will less often be attained.

Respiratory System Effects of Involuntary Cigarette Smoke Exposure

This section reviews the evidence on involuntary smoking and the adverse physiologic effects, respiratory symptoms, and respiratory diseases in nonsmoking adults and children. Health effects related to fetal exposure in utero from active smoking by the mother are not discussed. Lung growth and development may be influenced by in utero exposure, and the effects of such exposures have not been separated from those of exposure after birth. More complete treatments of this issue have been published (US DHEW 1979; US DHHS 1980; Abel 1980; Weinberger and Weiss 1981).

This section begins with a review of the data on infants and children who are exposed primarily through parental smoking. The health effects examined are increased respiratory illnesses, of both the upper and the lower respiratory tracts, increased chronic respiratory symptoms and illnesses, and alterations in lung growth and development. Studies of adults, whose exposures to environmental tobacco smoke occur in a variety of settings, are examined with regard to symptoms and changes in measures of lung function. The potential for ETS to produce bronchoconstriction in asthmatic and nonasthmatic subjects is also examined.

37

Infants and Children

Acute Respiratory Illness

Longitudinal Studies

A number of studies, based on a variety of different designs, have examined the effects of involuntary smoking on the acute respiratory illness experience of children (Table 1). Several different end points have been evaluated in these investigations: hospitalization for bronchitis or pneumonia as assessed by hospital records (Harlap and Davies 1974; Rantakallio 1978); questionnaire assessment of hospitalization for bronchitis or pneumonia or of doctor's visits (Colley 1971; Leeder et al. 1976a) or both (Fergusson et al. 1981; Fergusson and Horwood 1985); questionnaire assessment of respiratory illness within the last year (Cameron et al. 1969; Schenker et al. 1983; Ware et al. 1984); chest illness before age 2 (Schenker et al. 1983); hospitalization for respiratory syncytial virus (RSV) infection (Sims et al. 1978; Pullan and Hey 1982); physician-diagnosed bronchitis, tracheitis, or laryngitis (Pedreira et al. 1985); and tonsillectomy as an indication of recurrent respiratory infection (Said et al. 1978). These diverse end points range from illnesses associated with a specific etiologic agent, e.g., RSV bronchiolitis, to clinician-diagnosed syndromes, e.g., bronchitis of undetermined etiology.

The possibility of reporting bias must be considered for the studies that have used questionnaires to measure illness experience. In most of these studies, parents, usually the mother, have responded for the child and reported on the child's illness experience. Some investigators have suggested that mothers with respiratory symptoms are more likely to report symptoms for their children and that stratification of subjects by the symptom status of their parents removes this element of recall bias (Lebowitz and Burrows 1976). Removal of symptomatic parents, however, may result in overcorrection for recall bias because cigarette smoking is associated with symptoms in the adult. This analytical strategy would not be expected to adjust for biased parental recall of early life events. Additionally, in all studies in which potential reporting bias was examined, control for parents' status reduced, but did not eliminate, associations of involuntary smoking with health outcomes (Colley et al. 1974; Leeder et al. 1976a,b; Schenker et al. 1983; Ware et al. 1984). Further, the consistency of these studies, in spite of differing study populations and methods, weighs against bias as the sole explanation for the effect of involuntary smoke exposure.

Harlap and Davies (1974) studied 10,672 births in Israel between 1965 and 1968 and observed that infants, whose mothers, at a prenatal visit, reported that they smoked, had a 27.5 percent greater hospital admission rate for pneumonia and bronchitis than children

TABLE 1.—Early childhood respiratory illness and involuntary cigarette smoking

Study	Subjects	Findings	Illness rates per 100				Comments
			By cigarettes per day				
			0	1-10	11-20	20+	
Harlap and Davies (1974)	10,672 births, 1965-1968, Israel	Hospitalized, bronchitis/pneumonia, first year of life RR=1.38	9.5	10.8	16.2	31.7	Prenatal smoking history; maternal smoking only Longitudinal study
Colley[1] (1971)	2,205 births, 1963-1965, England	Questionnaire, bronchitis/pneumonia, first year of life RR=1.73 for one parent smoker RR=2.60 for two parent smokers	7.6 10.3	10.4 15.1	11.1 14.5	15.2 23.2	= Asymptomatic parents = Symptomatic parents Neither controlled for sibling number or smoker sex Longitudinal study
Fergusson et al. (1981); Fergusson and Horwood (1985)[2]	1,265 births, 4 months, 1977, New Zealand	Questionnaire, doctor or hospital visits, bronchitis/pneumonia; hospital records checked; assessed at 4 months, 1, 2, 3, and 6 years; RR=2.04 if mother smoked	7.0 7.0	12.8 4.6	13.4 8.8	Maternal only Paternal only	Effect significant for maternal smoking in first year of life only; effect present in first 2 years of life
			By number of smoking parents				
			0	1	2		
Ware et al. (1984)	8,528 children, aged 5-9, with two parents' smoking status known, six U.S. cities	Respiratory illness in last year	12.9	13.7	14.8		Adjusted for age, sex, and city cohort effect; significant trends Longitudinal study

TABLE 1.—Continued

Study	Subjects	Findings	Illness rates per 100			Comments
Said et al. (1978)	3,920 children, aged 10–20, France	Tonsillectomy and/or adenoidectomy, generally before age 5, as indicator of frequent respiratory tract infection	28.2	41.4	50.9	Children self-reported; not clear parent smoking habit at report time directly related to exposure approx. 10+ years earlier; Cross-sectional study
Schenker et al. (1983)	4,071 children, aged 5–14, United States	Chest illness before age 2; Chest illness >3 days in past year	6.7 8.8	7.9 11.8	11.5 13.6	Trends for both significant; Cross-sectional study

			Parent status		
			Nonsmoker	Current smoker	
Cameron et al. (1969)	158 children, aged 6–9; parents' telephone questionnaire, United States	Respiratory illness, restricted activity and/or medical consultation in last year	1.33	7.4	Illness reported not verified; not clear how reporting adult related to child; Cross-sectional study
Leeder et al. (1976a, b)	2,149 infants, born 1963–1965, England	RR ~ 2.0 for infants with two smoking parents	Not provided		Parents' response bias unlikely, effects observed for infants of asymptomatic parents; maternal vs. paternal smoking effects not investigated; Longitudinal study
Sims et al. (1978)	35 children, hospitalized, RSV bronchiolitis; 35 controls, England	Borderline significant increase in maternal smoking, first year of life; RR=2.65	Not provided		No significant effect for paternal smoking; average amount smoked greater for parents of cases than controls; Case-control study

TABLE 1.—Continued

Study	Subjects	Findings	Illness rates per 100			Comments
Rantakallio (1978)	1,821 children of smoking mothers, 1,823 children of nonsmoking mothers, Finland	Significant increase in hospitalization for respiratory illness during first 5 years of life RR=1.74	Not provided			Prospective followup of doctor visits, hospitalizations, deaths up to age 5; only maternal smoking evaluated Longitudinal study
Pullan and Hey (1982)	130 children hospitalized, RSV infection, first year of life; 111 nonhospitalized controls, England	Significant effect of maternal (RR=1.96) and paternal (RR=1.53) smoking at time of study; significant maternal smoking effect during first year of life (RR=1.55)	Not provided			Case-control study
				Nonsmoker	Smoker	
Pedreira et al. (1985)	1,144 infants in pediatric practice, United States	Significant increase in respiratory illnesses among smoke-exposed children	Bronchitis	71	103	Pediatricians not blinded to exposure; no effect seen for croup, pneumonia, or bronchiolitis Longitudinal study
			Tracheitis	21	40	
			Laryngitis	4	7	

[1] These data are considered in a more expanded analysis provided by Leeder et al. (1976a, b).

[2] Relative risk for children of smoking mothers versus children of nonsmoking mothers calculated from data provided by J.M. Samet (personal communication).

41

of nonsmoking mothers. In addition, they demonstrated a dose-response relationship between the amount of maternal smoking and the number of hospital admissions for these conditions. The infants were classified by the mothers' prenatal smoking behavior and not by the mothers' smoking behavior during the first year of the child's life. Maternal smoking habits would probably have remained relatively stable across the short observation period.

British investigators (Colley et al. 1974) followed children born between 1963 and 1965 in London and also observed an increased frequency of bronchitis and pneumonia during the first year of life in the children of parents who smoked. This difference did not persist at 2 to 5 years of age. This effect was independent of the parents' personal reports of winter morning phlegm and increased with the amount of smoking by parents. The annual incidence of bronchitis and pneumonia during the first year of life also increased with a greater number of siblings. This variable was not controlled in the original analysis; however, Leeder and colleagues (1976b) subsequently reported that, in this same cohort, a dose-response relationship with parental smoking persisted for bronchitis and pneumonia in the first year of life, after control for parental respiratory symptoms, the sex of the child, the number of siblings, and a history of respiratory illness in the siblings.

Fergusson and colleagues (1981) studied 1,265 New Zealand children from birth to age 3. They demonstrated an increase in bronchitis and pneumonia and in lower respiratory illness during the first 2 years of life in children whose mothers smoked compared with children whose mothers did not smoke. Correction for maternal age, family size, and socioeconomic status did not affect the relationship between the amount of maternal smoking and the rate of respiratory illness. The effect of maternal smoking declined with increasing age of the child.

In a second report (Fergusson and Horwood 1985) the followup was extended to include the first 6 years of life. The results confirmed the initial findings. Maternal, but not paternal, smoking was associated with a statistically significant increase in lower respiratory illnesses during the first 2 years of life. However, after age 2 there was no significant effect of maternal smoking on respiratory illness occurrence.

Rantakallio (1978) followed more than 3,600 children during the first 5 years of life; half of the children had mothers who smoked cigarettes during pregnancy and half did not. The children of mothers who smoked had a 70 percent greater chance of hospitalization for a respiratory illness than the children of nonsmoking mothers.

Pedreira and associates (1985) prospectively studied 1,144 infants and their families in the greater Washington, D.C., area. Maternal

smoking was associated with an excess frequency of acute bronchitis, tracheitis, and laryngitis, as diagnosed by the pediatricians caring for these families. Episodes of croup, pneumonia, and bronchiolitis were not increased by maternal smoking. A family history of chronic respiratory symptoms was also associated with excess respiratory illness.

Ware and coworkers (1984) studied more than 10,000 children in six American cities. Maternal cigarette smoking was associated with increased parental reporting of a doctor-diagnosed respiratory illness before the age of 2 years and of an acute respiratory illness within the past year. The prevalence of positive questionnaire responses increased consistently with the current daily cigarette consumption of the mother; the dose–response relationships were unchanged by adjustment for maternal symptoms and educational status.

Cross-Sectional Studies

Schenker and coworkers (1983) studied 4,071 children between the ages of 5 and 14 years in a cross-sectional study in Pennsylvania. Both chest illness in the past year and severe chest illness before age 2 were more frequently reported in nonsmoking children of parents who smoked. These investigators found that symptom and illness rates were higher in children of parents with respiratory symptoms. However, a significant effect of maternal smoking on these illness variables remained after adjustment for the parents' own respiratory symptom history.

In a study of 1,355 children between 6 and 12 years of age in the Iowa public schools, Ekwo and coworkers (1983) found that the presence in the home of at least one parent who smoked was significantly associated with reported hospitalization of the child for a respiratory illness during the first 2 years of life. As in other studies, the effect was stronger for maternal smoking than for paternal smoking.

Case–Control Studies

In England, Sims and colleagues (1978) examined 35 children at 8 years of age who had been hospitalized during infancy for RSV bronchiolitis and compared them with 35 control children of similar age. Maternal smoking was associated with a relative risk of 2.65 for hospitalization due to bronchiolitis. The sample size was small, and this effect of maternal smoking was not statistically significant.

Pullan and Hey (1982) studied children who had been hospitalized with documented RSV infection in infancy. They found significantly greater smoking by their mothers at the time of the infection, compared with children hospitalized for other illnesses, including respiratory disease for which RSV infection was not documented. At

43

age 10, the children previously ill with RSV infection had an excess reported occurrence of wheeze and asthma and had lower levels of pulmonary function in comparison with the controls. The researchers could not determine whether the RSV infection had caused persistent damage that affected the maturation of the lung or whether these children were already more susceptible to severe RSV infection because of pulmonary problems that antedated the RSV infection.

In summary, the results of these studies show excess acute respiratory illness in the children of parents who smoke, particularly in children under 2 years of age. This pattern is evident in studies conducted with different methodologies and in different locales. The increased risk of hospitalization for severe bronchitis or pneumonia associated with parental smoking ranges from 20 to 40 percent during the first year of life. Young children appear to represent a more susceptible population for the adverse effects of involuntary smoking than older children or adults. The time-activity patterns of infants, which generally place them in proximity to their mothers, may lead to particularly high exposures to environmental tobacco smoke if the mother smokes.

Acute respiratory illnesses during childhood may have long-term effects on lung growth and development, and might increase the susceptibility of the lung to the effects of active smoking and to the development of chronic obstructive lung disease (Samet et al. 1983; US DHHS 1984).

Cough, Phlegm, and Wheezing

A number of cross-sectional studies from different countries (Table 2) have shown a positive association between parental cigarette smoking and the prevalence of chronic cough and chronic phlegm in children; some studies have shown a relationship for persistent wheeze. However, not all studies have shown a positive relationship for all symptoms. The results of some of these studies may have been confounded by the child's own smoking habits (Colley et al. 1974; Bland et al. 1978; Kasuga et al. 1979). The association with parental smoking was not statistically significant for all symptoms in all studies (Lebowitz and Burrows 1976; Schilling et al. 1977; Schenker et al. 1983). However, the majority of studies showed an increase in symptom prevalence with an increase in the number of smoking parents in the home.

A recent report (Charlton 1984) provides cross-sectional data on parent-reported cough for 15,000 children, 8 to 19 years of age, in northern England. Chronic cough in the children was related to their age and to their own cigarette smoking status. However, with control of these factors by stratification, the number of parental smokers in the home was positively associated with the occurrence of chronic

44

TABLE 2.—Chronic respiratory symptoms in children in relation to involuntary smoke exposure

Study	Subjects	Respiratory symptoms or illness	Rates per 100 by number of smoking parents			Comments
			0	1	2	
Colley et al. (1974)	2,426 children, aged 6–14, England	Chronic cough; questionnaire completed by parent	15.6	17.7	22.2	Trend significant; reporting bias possible result of parent symptoms or active smoking in children, unlikely to explain full effect of trend Cross-sectional study
Bland et al. (1978)	3,105 children, aged 12–13, did not admit to ever smoking cigarettes, England	Cough during day or at night	16.4	19.0	23.5	Children's self-reported symptoms and smoking history collected simultaneously; morning and daytime cough suggested as different diseases, could be difference in exposure (exposure more likely awake than asleep) Cross-sectional study, adjusted for child's own smoking habits
		Morning cough	1.5	2.8	2.9	
Weiss et al. (1980)	650 children, aged 5–9, United States	Chronic cough and phlegm	1.7	2.7	3.4	Trend not significant
		Persistent wheeze	1.8	6.8	11.8	Trend significant Cross-sectional study, adjusted for parental symptoms and child's own smoking
Charlton (1984)	15,000 children, aged 8–19 years, England	Any cough	40.0	45.0	55.0	Trend significant; percents not age adjusted Cross-sectional study, adjusted for child's own smoking, not parental symptoms

45

TABLE 2.—Continued

Study	Subjects	Respiratory symptoms or illness	Rates per 100 by number of smoking parents			Comments
			0	1	2	
Dodge (1982)	628 children, grades 3–4, two-parent households; parent questionnaire response, United States	Any wheeze	27.6	27.9	40.0	All trends significant; some effect might relate to parental symptoms, but no trend influence likely Cross-sectional study
		Phlegm	6.4	10.9	12.0	
		Cough	14.6	23.0	27.8	
Schenker et al. (1983)	4,071 children, aged 5–14, United States	Chronic cough	6.2	7.0	8.3	Trend not significant; not adjusted for parental symptoms, although parental symptom effect analyzed Cross-sectional study
		Chronic phlegm	4.1	4.8	4.0	
		Persistent wheeze	7.2	7.7	5.4	

Study	Subjects	Respiratory symptoms or illness	Never smoker	Parent smoker	Comments
Lebowitz and Burrows (1976)	1,525 children, <15 years old, United States	Persistent cough	3.7	7.2	Higher rates in symptomatic parent households; trends persisted for asymptomatic households; no adjustment for child's own smoking Cross-sectional study
		Persistent phlegm	10.0	12.8	
		Wheeze	23.4	24.1	
Schilling et al. (1977)	816 children, age 7+, United States	Cough, phlegm, wheeze	No significant effect		Specific data not provided Cross-sectional study
Kasuga et al. (1979)	1,937 children, aged 6–11, Japan	Wheeze, asthma	Increased prevalence in heavy smoker (>21 cig/day) family; less clear effect in light smoker (<21 cig/day) family		Adjusted for distance of home from main traffic, highway Cross-sectional study
Ekwo et al. (1983)	1,355 children, aged 6–12, United States	Coughs with colds	Odds ratios: 1.4 for smoker father, 1.5 for smoker mother		Gas stove use measured, not controlled for; no consistent dose-response
		Wheezing apart from colds	2 if only smoker mother		Cross-sectional study

cough. The mother's smoking had a greater effect than the father's smoking.

Burchfiel and colleagues (1986) have conducted a longitudinal study of 3,482 subjects from Tecumseh, Michigan. Subjects were initially between the ages of birth and 10 years and were followed up by questionnaire and examination 15 years after entry into the study. Age-specific incidence rates were calculated for a number of chronic respiratory symptoms, including cough, phlegm, wheeze, and bronchitis. Incidence rates for all symptoms were higher for children with two parental smokers when compared with children of non-smokers. Adjustment for potential confounding variables, including age, parental education, family size, and personal smoking, did not explain these results.

British researchers (Leeder et al. 1976b) studying a birth cohort over a 5-year period demonstrated an increased incidence of wheezing among nonasthmatic children with two parents who smoked in comparison with children whose parents did not smoke, one parent who smoked, or parents whose smoking changed during the study (Leeder et al. 1976a). However, when this association was examined by logistic regression with control for other factors, parental smoking was not a significant predictor of wheeze or of asthma.

McConnochie and Roghmann (1984) performed a retrospective cohort study to examine the influence of mild bronchitis in early childhood on wheezing symptoms 8 years later when the subjects had reached a mean age of 8.3 years. Involuntary smoking was a significant predictor of current wheezing (odds ratio 1.9). In a related study (McConnochie and Roghmann 1985) with these same children, involuntary smoking did not affect lower respiratory tract illness experience.

In a study of 650 children aged 5 to 10 years (Weiss et al. 1980), a significant trend in the reported prevalence of chronic wheezing with current parental smoking was found; the rates were 1.9 percent, 6.9 percent, and 11.8 percent for children with zero, one, and two parents who smoked, respectively. Although the data given are for all households, when the analysis was restricted to those households where neither parent reported symptoms, the results were identical. The stability of the findings with this restriction suggests that reporting bias introduced by parental symptoms was not responsible for the observed results.

Schenker and coworkers (1983) examined the influence of parental smoking and symptoms on the reporting of chronic respiratory symptoms of cough, phlegm, and persistent wheezing in children. These investigators found that the mothers were more likely than the fathers and symptomatic mothers were more likely than asymptomatic mothers to report these symptoms in their children.

Parental smoking had no significant effects on chronic respiratory symptoms.

Lebowitz and Burrows (1976) assessed the effects of household members' smoking on respiratory symptoms in 626 Tucson children younger than 15 years of age. Children from homes with current smokers had higher symptom rates than those from homes with ex-smokers and with never smokers. However, the effect of household smoking type was statistically significant only for persistent cough. In a general population study, Schilling and colleagues (1977) reported no association between wheeze and involuntary smoking.

Ware and associates (1984) enrolled 10,106 children between 6 and 9 years of age from six U.S. cities in a prospective study. The prevalence of persistent cough and persistent wheeze, measured at the second examination, was higher in children whose parents smoked. The effect was greater for maternal smoking than for paternal smoking. Symptom prevalence rates increased linearily with the number of cigarettes smoked daily by the mother. In a multiple logistic model, the effect of maternal smoking persisted after adjustment for reported illness in the parents.

Dodge (1982), studying third and fourth grade children in Arizona, found that symptoms, including wheeze, were related to both the presence of symptoms in the parents and the number of smokers in the household.

In summary, children whose parents smoke had a 30 to 80 percent excess prevalence of chronic cough or phlegm compared with children of nonsmoking parents. For wheezing, the increase in risk varied from none to over sixfold among the studies reviewed. Many studies showed an exposure-related increase in the percentage of children with reported chronic symptoms as the number of parental smokers in the home increased. Misclassification as nonsmokers of children who are actively smoking could bias the results of these studies. Adolescent smokers may be reluctant to accurately report their smoking habits, and more objective measures of exposure may not help to distinguish active experimentation with cigarettes from involuntary exposure to smoke (Tager 1986). Although misclassification of children who are actively smoking as nonsmokers must be considered, many studies showing a positive association between parental smoking and symptoms in children, including children at ages before significant experimentation with cigarettes is prevalent. In addition, many studies (Bland et al. 1978; Weiss et al. 1980; Charlton 1984; Schenker et al. 1983; Dodge 1982; Burchfiel et al. 1986) found significant effects of parental smoking after considering active smoking by the children.

Chronic respiratory symptoms represent an immediate health burden for the child. However, the long-term significance of chronic respiratory symptoms for the health of the child is unclear. Most

48

available data are cross-sectional, and followup studies of chronically symptomatic children are necessary to determine the long-term health consequences of chronic respiratory symptoms.

Pulmonary Function

In recent years, the effect of parental cigarette smoking on pulmonary function in children has been examined in cross-sectional studies (Table 3) and a few longitudinal studies. The cross-sectional studies have demonstrated lower values on tests of pulmonary function ($FEV_{75\%}$, FEV_1, FEF_{25-75}, and flows at low lung volumes) in children of mothers who smoked compared with children of non-smoking mothers. The longitudinal studies (Table 4) have confirmed the cross-sectional results and provide some insight into the implications of the cross-sectional data.

Dose–response relationships have been found in both cross-sectional and longitudinal studies (Tager et al. 1979; Weiss et al. 1980; Ware et al. 1984; Berkey et al. 1986); the level of function decreases with an increasing number of smokers in the home. As would be anticipated from the mother's greater contact time with the child, maternal smoking tends to have a greater impact than paternal smoking. Younger children seem to experience greater effects than older children (Tager et al. 1979; Weiss et al. 1980), and in older children the effects of personal smoking may be additive with those of involuntary smoking (Tager et al. 1979, 1985).

As noted by Tager (1986), the effect of maternal smoking on lung function may vary with the child's sex. Some studies have reported greater effects on flows at lower lung volumes in girls than in boys (Burchfiel et al. 1986; Tashkin et al. 1984; Yarnell and St. Leger 1979; Vedal et al. 1984). Flows at higher lung volumes seem more affected in boys (Burchfiel et al. 1986; Yarnell and St. Leger 1979; Berkey et al. 1986; Tashkin et al. 1984). Whether these sex effects represent differences in exposure, differences in susceptibility to environmental cigarette smoke, or differences in growth and development is unclear.

Tager and colleagues (1983) followed 1,156 children for 7 years to determine the effect of maternal smoking on the growth of pulmonary function in children (Figure 2). After correcting for previous level of FEV_1, age, height, personal cigarette smoking, and correlation between mother's and child's pulmonary function level, maternal smoking was associated with a reduced annual increase in FEV_1 and FEF_{25-75}, using two separate methods of analysis. If the effect of maternal smoking is maintained to 20 years of age, then a 3 to 5 percent reduction of FEV_1 and FEF_{25-75} due to maternal smoking would be projected. The validity of this projection remains to be established. Because few mothers changed their smoking habits, the

49

TABLE 3.—Pulmonary function in children exposed to involuntary smoking

Study	Subjects	Pulmonary function measured	Outcome	Comments
Schilling et al. (1977)	816 children, aged 7–17, Connecticut and South Carolina, United States	FEV_1 as percent predicted	No effect of parental smoking	No control for sibship size or correlation of sibling pulmonary function; for children who never smoked, V_{max50} significantly less in children with smoking mothers
Tager et al. (1979)	444 children, aged 5–19, East Boston, Massachusetts, United States	MMEF in standard deviation units	Significant effect of parental smoking	Controlled for sibship size and correlation of sibling pulmonary function
Weiss et al. (1980)	650 children, aged 5–9, East Boston, Massachusetts, United States	MMEF in standard deviation units	Significant effect of parental smoking	Controlled for sibship size and correlation of sibling pulmonary function
Vedal et al. (1984)	4,000 children, aged 6–13, United States	FEV_1, FVC, $\dot{V}_{max50}$, $\dot{V}_{max75}$, V_{max90}	FVC positively associated, flows negatively associated	Flows dose–response with amount smoked by mother
Lebowitz and Burrows (1976)	271 households, complete histories of parent smoking and pulmonary function of children, age >6, Tucson, Arizona, United States	FEV_1, FVC, $\dot{V}_{max50}$, $\dot{V}_{max75}$ derived from MMEF V curves, as standard deviation units	No effect of parental smoking	Suggestion: may be real differences in indoor levels of exposure compared with more northerly climates
Lebowitz et al. (1982)	229 children, Tucson, Arizona, United States	FEV_1, z score	No effect of parental smoking	Higher levels of pulmonary function for children of smoking parents than for non-smoke-exposed children

TABLE 3.—Continued

Study	Subjects	Pulmonary function measured	Outcome	Comments
Dodge (1982)	558 children, aged 8–10, Arizona, United States	FEV_1 by age change FEV_1/H^2/year	No effect of parental smoking	Potential participation rate bias; cross-sectional data not controlled for child height; annual FEV_1/H^2 at ages 8, 9, and 11 consistently greater in nonsmoking households than two-parent smoker households; statistical test not significant
Tashkin et al. (1984)	1,080 nonsmoking, nonasthmatic children, Los Angeles, United States	$\dot{V}_{max}$, $\dot{V}_{max75}$, $\dot{V}_{max25}$, FEF_{25-75}	Decreased $\dot{V}_{max}$, $\dot{V}_{max25}$ for boys, and FEF_{25-75}, $\dot{V}_{max75}$ for girls with smoking mother at least	No effect of paternal smoking
Chen and Li (1986)	571 children, aged 8–16, China	FEV_1 and MMEF	Significantly decreased FEV_1 and MMEF in children exposed to paternal cigarette smoke	Adjusted for child's own smoking, gas stoves, and parental symptoms
Hasselblad et al. (1981).	16,689 children, aged 5–17, seven geographic regions, United States	FEV_1 as percent predicted	Significant effect of maternal but not paternal smoking	Large number of children excluded for invalid pulmonary function data or missing parental smoking data
Speizer et al. (1980)	8,120 children, aged 6–10, six U.S. cities	FVC and FEV_1 as percent predicted	No effect for FEV_1 or FVC	Recent analysis demonstrated an effect for FVC and FEV_1
Lebowitz (1984)	117 families, Tucson, Arizona, United States	FVC and FEV_1	No effect of parental smoking	Also assessed, TSP and ozone rates had little effect
Ekwo et al. (1983)	1,355 children, aged 6–12, Iowa City, Iowa, United States	FEV_1, FVC	No effect of parental smoking	Data for this outcome not specifically analysed; increased bronchial responsiveness among smoke-exposed children
Spinaci et al. (1985)	2,385 schoolchildren, Turin, Italy	FEV_1	Statistically significant effect of maternal smoking	No passive smoking effect difference between boys and girls

TABLE 4.—Pulmonary function in children exposed to involuntary smoking; longitudinal studies

Study	Subjects	Pulmonary function measured	Outcome	Comments
Tager et al. (1983)	1,156 children, aged 5–10 at initial survey, East Boston, Massachusetts, United States	FEV_1, FEF_{25-75}	Significantly decreased FEV_1 and FEF_{25-75} growth rate for children of smoking mothers	7-year followup; no effect of paternal smoking; magnitude roughly 4 to 5 percent
Ware et al. (1984)	10,000 children, aged 6–11, six U.S. cities	FVC, FEV_1	FVC positively associated with smoking; FEV_1 negatively associated with smoke exposure	FEV_1 dose–response with amount smoked by mother; magnitude of effect estimate 6 percent
Berkey et al. (1986)	7,834 children, aged 6–10, six U.S. cities	FVC, FEV_1	Slightly higher FVC level, slightly lower FEV_1 level in smoke-exposed; growth of both decreased by smoke exposure	Consistent with 3 percent deficit in FEV_1 growth
Burchfiel et al. (1986)	3,482 children, aged 0–10, Tecumseh, Michigan, United States	FVC, FEV_1, $\dot{V}_{max50}$	FEV_1 level and growth decreased by maternal smoking	Dose–response in male children with number of parental smokers
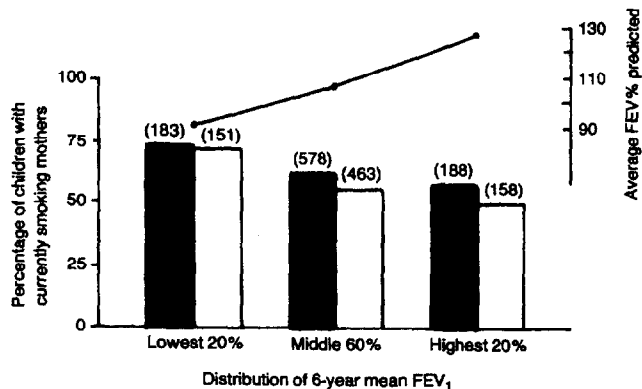
FIGURE 2.—Percentage of children with mothers who were current cigarette smokers at initial examination (black columns) and sixth examination (white columns), according to distribution of mean age, height, and sex-corrected FEV₁ over the first six examinations

NOTE: Lowest 20%, middle 60%, and highest 20% refer to children with values in the bottom one-fifth, middle three-fifths, and upper one-fifth, respectively, of the mean FEV₁ distribution; numbers in parentheses indicate number of children in each group; the three circles represent the average percent predicted values of FEV₁ for the three groups; results for male and female children were combined, because difference between sexes was not significant.

SOURCE: Tager et al. (1983).

study could not establish the ages at which children were most vulnerable to exposure to tobacco smoke.

Ware and colleagues (1984) followed 10,106 white children for two successive annual examinations as part of the Harvard Air Pollution Health Study in six U.S. cities. The forced vital capacity was significantly higher for children of mothers who were either current smokers or ex-smokers. However, children whose mothers were current smokers had a 0.6 percent lower mean FEV₁ at the first examination and 0.9 percent lower mean FEV₁ at the second examination. Maternal smoking had a greater effect than paternal smoking, although the effects of both were significant. The changes in level of FEV₁ observed were small. For exposure to a mother who smoked one pack of cigarettes per day, the FEV₁ was estimated to be decreased by less than 1 percent, or 10 to 20 mL for a child with an FEV₁ between 1.5 and 2.5 liters. Projecting the effect cumulatively to age 20 yields an approximately 3 percent deficit. This effect is comparable to that observed by Tager and colleagues (1983). These small average effects may underestimate the effects on populations of susceptible children.

53

A more extensive analysis of longitudinal data from the Harvard cohort was performed using a mathematical model to describe lung growth (Berkey et al. 1986). This analysis included 7,834 children between 6 and 10 years of age who were evaluated from two to five times over a 5-year period. The model estimated that a smoke-exposed child at age 8 would have an FEV_1 0.81 percent lower than a non-smoke-exposed child, and growth of FEV_1 would be 0.17 percent lower per year. Both effects were statistically significant. For an 8-year-old child with an FEV_1 of 1.62 liters, these results translate into a deficit of 13 mL in FEV_1 and of 3 mL in annual increase in FEV_1. The magnitude of the maternal smoking effect is consistent with a deficit in FEV_1 of 2.8 percent in naturally attained growth, if the effect is sustained throughout childhood.

Burchfiel and colleagues (1986) have conducted a longitudinal study of 3,482 children observed over a 15-year period in Tecumseh, Michigan. The mean increase in FEV_1 for nonsmoking boys between the ages of 10 and 19 years was 82.3, 76.2, and 74.5 mL per year for subjects with zero, one, and two smoking parents, respectively. Boys with one parent who smoked experienced 92.6 percent and boys with two parents who smoked experienced 90.5 percent of the growth in FEV_1 seen in male children with nonsmoking parents. Effects of parental smoking were not found in girls.

The available data demonstrate that maternal smoking reduces lung function in young children. However, the absolute magnitude of the difference in lung function is small on average. A small reduction of function, on the order of 1 to 5 percent of predicted value, would not be expected to have functional consequences. However, some children may be affected to a greater extent, and even small differences might be important for children who become active cigarette smokers as adults.

A minority of adult cigarette smokers develop chronic obstructive lung disease, and factors influencing lung growth and development during childhood might predispose to disease in adulthood (Samet et al. 1983; Speizer and Tager 1979). In Figure 3 is depicted a model of growth and decline in pulmonary function from childhood through adulthood, as measured by the FEV_1. Pulmonary function peaks in early adult life and declines steadily thereafter in both smokers (curve B) and nonsmokers (curve A). In people who develop chronic lung disease (curve C), a more rapid decline has occurred. Childhood factors could predispose to the development of disease by reducing the functional level at which decline begins or by increasing susceptibility to cigarette smoke and increasing the rate of decline. Thus, in this model, small decrements in the maximally attained level of pulmonary function may be important in identifying the susceptible smoker. However, the prerequisite longitudinal studies needed to test this hypothesis have not yet been conducted.

54
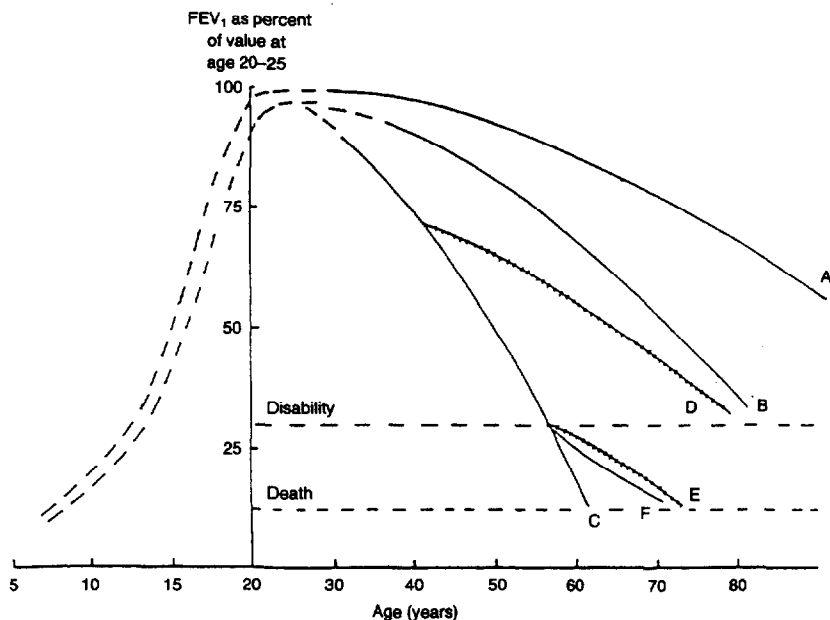
FIGURE 3.—Theoretical curves representing varying rates of change in FEV₁ by age

NOTE: Curve A, normal decline in FEV₁ (forced expiratory volume in 1 second); curve B, accelerated decline in FEV₁ with cigarette smoking; curve D, the effect of smoking cessation, also seen in disabled individuals (curve E); disability-related decline often continues as a variable rate (curves C and F).

SOURCE: Speizer and Tager (1979).

Bronchoconstriction

Nonspecific bronchial responsiveness has been considered a potential risk factor for the development of chronic obstructive lung disease in both adults and children (US DHHS 1984). This physiologic trait may be influenced by environmental exposures such as involuntary smoking by children and active smoking by adults, and by respiratory infections at all ages.

Asthma is a chronic disease characterized by bronchial hyperresponsiveness. Epidemiologic studies of children have shown no consistent relationship between the report of a doctor's diagnosis of asthma and exposure to involuntary smoking. Although one study showed an association between involuntary smoking and asthma (Gortmaker et al. 1982), others have not (Schenker et al. 1983; Horwood et al. 1985). This variability may reflect differing ages of the children studied, differing exposures, or uncontrolled bias. In several recent studies (Murray and Morrison 1986; O'Connor et al.

55

1986; Weiss et al. 1985; Martinez et al. 1985; Ekwo et al. 1983), nonspecific bronchial responsiveness was examined in relationship to involuntary smoking. The results of these studies suggest that exposure to maternal cigarette smoking is associated with increased nonspecific airways responsiveness. Some reports suggest that the increased responsiveness is present only in children known to be asthmatic (Murray and Morrison 1986; O'Connor et al. 1986), whereas others suggest that the increased responsiveness is seen in all children (Ekwo et al. 1983; Martinez et al. 1985). The pathophysiological mechanisms underlying the increased responsiveness and the long-term consequences of the increased responsiveness remain unknown. This section reviews the studies on asthma and on bronchial hyperresponsiveness.

Gortmaker and coworkers (1982) studied the relationship between parental smoking and the prevalence of asthma in children up to 17 years of age. Random community-based populations in Michigan (3,072 children) and Massachusetts (894 children) were surveyed. Parents reported on their own smoking habits and on the asthma histories of their children. Biased reporting by parents who smoked was assessed by examining the relationship between parental smoking and other conditions, and considered not to be present. Asthma prevalence declines with age, and asthmatic children are unlikely to tolerate active smoking; therefore, misclassification of actively smoking asthmatic children as nonsmokers seems unlikely. In comparison with children of nonsmokers, children whose parents smoked were more likely to have asthma (relative risks of 1.5 and 1.8 for Michigan and Massachusetts children, respectively) and severe asthma (relative risks of 2.0 and 2.4, respectively). The investigators estimated that between 18 and 23 percent of all childhood asthma and 28 and 34 percent of severe childhood asthma is attributable to exposure to maternal cigarette smoke.

Schenker and coworkers (1983) studied 4,071 children between 5 and 15 years of age in western Pennsylvania. These investigators found no relationship of parental smoking to the occurrence of asthma, after adjustment for potential confounding factors.

Horwood and coworkers (1985) conducted a cohort study of 1,056 children in New Zealand who were followed from birth to age 6 years. A family history of allergy and male sex were the only significant predictors of incident cases of asthma. Neither parental smoking nor respiratory illnesses were predictive of the occurrence of asthma in this investigation.

A recently reported cross-sectional study by Murray and Morrison (1986) suggests a mechanism by which maternal cigarette smoking might influence the severity of childhood asthma. These investigators studied 94 children, aged 7 to 17 years, with a history of asthma. The children of mothers who smoked had 47 percent more symp-

56

Mother

Nonsmoker   Smoker

PC$_{20}$ history 16
mg/mL

8

4

2

1

0.5

0.25

0.125

0.06

0.03

0

p=0.002
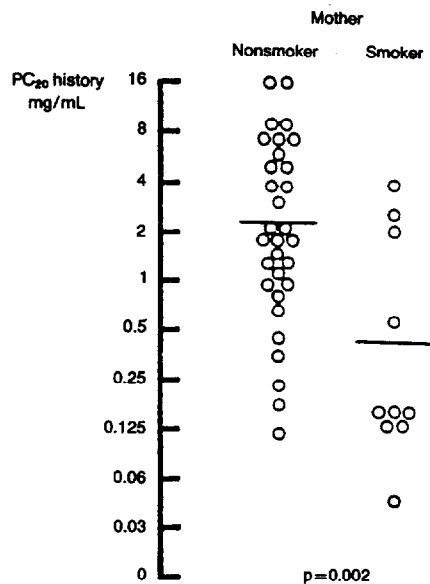
**FIGURE 4.—PC$_{20}$ in two groups of children with a history
of wheezing**

NOTE: Mothers of 32 were nonsmokers; mothers of 10 were smokers.

SOURCE: Murray and Morrison (1986).

toms, a 13 percent lower FEV$_1$, and a 23 percent lower FEF$_{25-75}$ than
the children of nonsmoking mothers. Forty-one children, who had
been able to discontinue medication and had no recent respiratory
illness, underwent a histamine challenge test. There was a fourfold
greater responsiveness to histamine among the asthmatic children of
mothers who smoked (Figure 4) compared with asthmatic children of
nonsmoking mothers. Dose–response relationships were present for
all outcome variables in this study: symptoms, pulmonary function,
and airways responsiveness. The differences between children of
smoking mothers and children of nonsmoking mothers were greatest
in the older children. The father's smoking behavior did not
influence the child's asthma severity. The sample of asthmatic
children with mothers who smoked was small (N=10), and only 41 of
96 children had histamine challenge tests. Given the heterogeneity
of asthma, the variable nature of bronchial hyperreactivity in
asthma, and the potential for biased selection, these results must be
interpreted with caution.

O'Connor and coworkers (1986) studied 286 children and young
adults, 6 to 21 years of age, drawn from a community-based sample,

and confirmed the findings of Murray and Morrison (1986). Bronchial responsiveness was measured with eucapneic hyperpnea to subfreezing air. Among the 265 subjects without asthma there was no significant relationship between maternal cigarette smoking and nonspecific bronchial responsiveness. However, in the 21 subjects with active asthma, maternal smoking was significantly associated with increased levels of bronchial responsiveness.

In a study of 1,355 children 6 to 12 years of age, significant increases in FEV and FEF_{25-75} were observed following isoproterenol administration in children whose parents smoked (Ekwo et al. 1983). Increases after isoproterenol were not observed in children of nonsmoking parents.

Weiss and coworkers (1985) evaluated 194 subjects between the ages of 12 and 16 drawn from the same population as those reported by O'Connor and coworkers (1986), with eucapneic hyperpnea to subfreezing air as a test for bronchial responsiveness and allergy skin tests as a test for atopy. Subjects defined as atopic (any skin test wheal greater than or equal to 5 mm) had twice the frequency of lower respiratory illnesses in early childhood and were twice as likely to have a mother who smoked. However, there was no relationship between maternal smoking and increased bronchial responsiveness.

Martinez and associates (1985) studied 170 9-year-old children in Italy. Nonspecific bronchial responsiveness to methacholine and allergy prick test positivity in these subjects was significantly associated with maternal cigarette smoking.

These data suggest that maternal cigarette smoking may influence the severity of asthma; a mechanism for this effect may be through alteration of nonspecific bronchial responsiveness. Further investigation is needed to determine whether exposure to environmental cigarette smoke can induce asthma in children and whether ETS exposure increases the frequency or severity of attacks of bronchoconstriction in asthmatics. The effect of involuntary smoking on increased bronchial responsiveness in asthmatics and in nonasthmatics has only recently been addressed. These initial data are provocative, but the magnitude of the effect, the target population at risk, the underlying mechanisms, and the long-term consequences have not been described. Furthermore, the complex interrelationships among respiratory illness, atopy, parental smoking, and airways responsiveness have not been clarified and require further study.

Ear, Nose, and Throat

Five studies (Said et al. 1978; Iverson et al. 1985; Kraemer et al. 1983; Black 1985; Pukander et al. 1985) show an excess of chronic

middle ear effusions and diseases in children exposed to parental smoke.

Said and colleagues (1978) questioned 3,920 children between 10 and 20 years of age about prior tonsillectomy or adenoidectomy, considered an index of frequent upper respiratory or ear infections. The investigators reported that, in general, this surgery was performed before the children were 5 years old. The prevalence of prior surgery increased with the number of currently smoking parents in the home.

Iverson and coworkers (1985) prospectively studied 337 children enrolled in all day-care institutions in a municipality over a 3-month period to evaluate the importance of involuntary smoking for middle ear effusion in children. Middle ear effusion was assessed with tympanometry, and the overall prevalence was found to be approximately 23 percent. Although various indoor environmental factors were assessed in this investigation, only parental smoking was significantly associated with middle ear effusion. The effect of parental smoking persisted with control for the number of siblings. The overall age-adjusted odds ratio was 1.6 (95 percent confidence interval 1.0–2.6). In 5- to 7-year-old children, 10 to 36 percent of all chronic middle ear effusions could thus be attributed to smoking on the basis of these results.

Kraemer and coworkers (1983) performed a case–control study of 76 children to examine the relationship of environmental tobacco smoke exposure to the occurrence of persistent middle ear effusions. Frequent ear infections, nasal congestion, environmental tobacco smoke exposure, and atopy were all more frequent in children with ear effusions. The effect of involuntary smoking was observed only if nasal congestion was present, and was greatest in children who were atopic.

Black (1985) performed a case–control study of glue ear with 150 cases and 300 controls. Parental smoking was associated with a relative risk of 1.64 (95 percent C.I. 1.03–2.61) for glue ear. In Finland, Pukander and coworkers (1985) conducted a case–control study of 264 2- to 3-year-old children with acute otitis media and 207 control children and found an association between parental smoking and this acute illness.

These studies are consistent in their demonstration of excess chronic middle ear effusions, a sign of chronic ear disease, in children exposed to parental cigarette smoke. Potential confounding factors for middle ear effusions should be examined carefully in future studies. The long-term implications of the excess middle ear problems deserve further study.

59

Adults

Acute Respiratory Illness

There are no studies of acute respiratory illness experience in adults exposed to environmental cigarette smoke.

Cough, Phlegm, and Wheezing

Few studies have addressed the relationship of chronic respiratory symptoms in nonsmoking adults with environmental tobacco smoke exposure. Schilling and colleagues (1977) found that symptoms in adult men and women were related to personal smoking habits and that the occurrence of cough, phlegm, or wheeze in nonsmokers was not related to the smoking habits of their spouses. Schenker and colleagues (1982) confirmed these results in a telephone survey of 5,000 adult women in western Pennsylvania.

Pulmonary Function

White and Froeb (1980) reported on 2,100 asymptomatic adults drawn from a population enrolled in a physical fitness program (Table 5). They reported statistically significant decreases in FEV_1 and maximum midexpiratory flow rate (MMEF) as a percent of predicted in nonsmokers exposed to tobacco smoke in the work environment for at least 20 years compared with nonsmoking workers not exposed. The magnitude of effect was comparable to that of actively smoking 1 to 10 cigarettes per day. However, the absolute magnitude of the difference in mean levels of function between the smoke-exposed group and the unexposed group was small: 160 mL (5.5 percent) for FEV_1 and 465 mL per second (13.5 percent) for MMEF. Carbon monoxide levels were measured in selected workplaces and ranged from 3.1 to 25.8 ppm. The study population was self-selected, and the exposure classification was crude and did not account for people who changed jobs. It is unclear how the ex-smokers in the population were handled in the analysis. Kentner and coworkers (1984) performed a cross-sectional investigation on 1,351 workers and found no influence of involuntary smoking on pulmonary function. In this study, involuntary smoking at home and at work was considered.

Comstock and colleagues (1981) examined 1,724 subjects drawn from two separate studies in Washington County, Maryland. Male and female nonsmokers married to smokers did not have a significantly increased risk of having an FEV_1 less than 80 percent of predicted or an FEV_1/FVC ratio less than 70 percent. Schilling and colleagues (1977) also did not find an effect of involuntary smoking in adults. Effects were not examined within strata defined by age in either of these studies.

60

TABLE 5.—Pulmonary function in adults exposed to involuntary smoking

Study	Subjects	Pulmonary function measured	Outcome	Comments
White and Froeb (1980)	2,100 adults, San Diego, California, United States	FVC, FEV_1, and MMF as percent predicted	Significant effect of office exposure to involuntary smoke	Potential selection bias; only current cigarette smoke exposure assessed; treatment of ex-smokers unclear
Comstock et al. (1981)	1,724 adults, Washington County, Maryland, United States	FEV_1 as percent predicted	No effect of wives' smoking on husband's pulmonary function	Includes adults aged 20+ Cross-sectional study
Kauffmann et al. (1983)	7,818 adults, selected subgroups, seven cities, France	FEV_1, FVC, and MMEF	All measures significant effect in wives of smoking husbands; only MMEF significant in husbands of smoking wives	Not height adjusted; dose-response to amount of husbands' smoking for MMEF in wives; no effect below age 40 Cross-sectional study
Brunekreef et al. (1985)	173 adults, subgroups of larger study, the Netherlands	Peak flow, inspiratory vital capacity (IVC), FEV_1, and MMEF	Significant effect in wives of smoking husbands for peak flow FEV_1 cross-sectionally; no effect longitudinally	Small sample size
Kentner et al. (1984)	1,851 adult office workers, Germany	FVC, FEV_1	No effect of work exposure on pulmonary function	Cross-sectional study

61

Kauffmann and colleagues (1983) suggested that the effects of exposure from a spouse who smoked may be manifest only after many years of exposure. These investigators assessed the effects of marriage to a smoker in 7,818 adults drawn from several cities in France. Among 1,985 nonsmoking women aged 25 to 59, 58 percent of whom had husbands who smoked, the level of MMEF was significantly reduced in women married to smokers compared with women married to nonsmokers; this effect did not become apparent until age 40. The reduction was small, on average.

Recently, studying another population, Kauffmann and colleagues (1986) suggested that the FEV_1/FVC ratio may be a more sensitive test for detecting differences between exposed and nonexposed subjects, particularly in those with symptoms of wheezing; however, this suggestion has not been evaluated in other populations.

Brunekreef and coworkers (1985), from the Netherlands, reported on 173 nonsmoking women who were participants in a larger longitudinal study of pulmonary function. The women were classified by whether they were or were not exposed to tobacco smoke at study onset or at followup. Cross-sectionally, significant differences in pulmonary function were observed between smoke-exposed and nonexposed women. However, the rate of decline of lung function during the followup period was not affected by tobacco smoke exposure in the home. This study had a small number of subjects and inadequate statistical power to detect effects of exposure on rate of decline that were not extremely large.

Jones and colleagues (1983) selected women with either high or low FEVs from a population-based longitudinal study in Tecumseh, Michigan. Exposure to cigarette smoke at home from husbands who smoked was not significantly different in the two groups of women.

Nonsmoking men who participated in the Multiple Risk Factor Intervention Trial had significantly lower levels of pulmonary function if their wives smoked in comparison with similar men whose wives did not smoke (Svendsen et al. 1985).

The physiologic and clinical significance of the small changes in pulmonary function found in some studies of adults remains to be determined. The small magnitude of effect implies that a previously healthy individual would not develop chronic lung disease solely on the basis of involuntary tobacco smoke exposure in adult life. Whether particular characteristics increase susceptibility, such as childhood exposures or illnesses, atopy, reduced pulmonary function from whatever cause, and increased airways responsiveness, remains unknown. These small changes may also be markers of an irritant response, possibly transient, to the irritants known to be present in environmental tobacco smoke.

Bronchoconstriction

Normal Subjects

Only limited data have been published on the acute effects of inhalation of environmental tobacco smoke on pulmonary function in normal subjects (Table 6) and none on bronchial responsiveness. The available data have been obtained in exposure chambers under carefully monitored and controlled circumstances (Pimm et al. 1978; Shephard et al. 1979; Dahms et al. 1981).

Pimm and colleagues (1978) exposed nonsmoking adults to smoke in an exposure chamber. Relatively constant levels of carbon monoxide (approximately 24 ppm) were achieved in the chamber during involuntary smoking. Peak blood carboxyhemoglobin levels were always less than 1 percent in these subjects before smoke exposure, but were significantly greater after the study exposure. Lung volumes, flow volume curves, and heart rates were measured for all subjects. Measurements were made at rest and following exercise under control and smoke-exposure conditions. Flow at 25 percent of the vital capacity was reduced at rest in men and with exercise in women. Although statistically significant, the magnitude of the change was small: a 7 percent decrease in flow in men and 14 percent in women.

Shephard and coworkers (1979) utilized a similar cross-over design in a chamber of exactly the same size as that used by Pimm and associates. Their results were similar, with a small (3 to 4 percent) decrease in FVC, FEV_1, $\dot{V}_{max50}$, and $\dot{V}_{max25}$. They concluded that these changes were of the magnitude anticipated from exposure to the smoke of less than one-half of a cigarette in 2 hours (the exposure anticipated for an involuntary smoker).

Dahms and colleagues (1981) used a slightly larger chamber and an exposure with an estimated peak carbon monoxide level of approximately 20 parts per million. They found no change in FVC, FEV_1, or FEF_{25-75} in normal subjects after 1 hour of exposure.

The active smoker manifests acute responses to the inhalation of cigarette smoke; thus, high-dose involuntary exposure to tobacco smoke may plausibly induce similar responses in nonsmokers. The magnitude of these changes is quite small, even at moderate to high exposure levels, and it is unlikely that this change in airflow, per se, results in symptoms.

Asthmatics

Dahms and colleagues (1981) exposed 10 patients with bronchial asthma and 10 normal subjects to cigarette smoke in an environmental chamber. Pulmonary function was measured at 15-minute intervals for 1 hour after smoke exposure. Blood carboxyhemoglobin levels were measured before and after the 1-hour exposure. The

63

TABLE 6.—Acute effects on pulmonary function of passive exposure to cigarette smoke; normal subjects

Study	Type of exposure	Magnitude of exposure	Effects	Comments
Pimm et al. (1978)	Chamber 14.6 m, furniture sparse, smoking machine in room	Peak [CO] ~ 24 ppm; particulates >4 mg/m^3	Men: 5% increase FVC, 11% increase RV, 4% decrease $\dot{V}_{max25}$ during exercise Women: 7% decrease $\dot{V}_{max25}$ after exercise; no effects on VC, TLC, FVC, FEV$_1$, $\dot{V}_{max50}$	Nonsmokers; average age, men 22.7, women 21.9; sham exposure as control
Shephard et al. (1979)	As above	Low exposure: peak [CO] ~ 20 ppm, particulates ~ mg/m^3; high exposure: [CO] ~ 31 ppm	Low exposure: 3% decrease FEV$_1$, 4% decrease $\dot{V}_{max50}$, 5% decrease $\dot{V}_{max25}$ with exercise; no increased effect with high exposure	Nonsmokers: average age, men 23, women 25; sham exposure as control; subject estimated inhalation ~ 1/2 cigarette/2 hours
Dahms et al. (1981)	Chamber 30 m, climate controlled	Room levels not measured; estimated at peak [CO] ~ 20 ppm	0.9% increase in FVC, 5.2% increase in FEV$_1$, 2.2% increase in FEF at 1 hour	10 nonsmokers; age range 24–53 years; not blinded; no sham exposure

carboxyhemoglobin levels in subjects with asthma increased from 0.82 to 1.20 percent. In normal subjects the increase was from 0.62 to 1.05 percent. The increases in carboxyhemoglobin in the two study groups were not significantly different. Asthmatic subjects had a decrease in forced vital capacity (FVC), FEV_1, and MMEF to a level significantly different from their preexposure values. The decreases in asthmatic subjects were present at 15 minutes, but worsened over the course of the hour to approximately 75 percent of the preexposure values. Normal subjects had no change in pulmonary function with this level of exposure. In this study, subjects were not blinded as to the exposure and were selected because of complaints about smoke sensitivity.

Shephard and colleagues (1979), in a very similar experiment, subjected 14 asthmatics to a 2-hour cigarette smoke exposure in a closed room (14.6 m^3). The carbon monoxide levels (24 ppm) were similar to those predicted in the study of Dahms and coworkers (1981). Blood carboxyhemoglobin levels were not measured. Subjects were randomized and blinded to sham (no smoke) and smoke exposure and tested on two separate occasions. Data were expressed as the percentage change from the sham exposure. Significant changes in FVC and FEV_1 were not observed between the sham and the smoke exposure periods, although 5 of 12 subjects did report wheezing or tightness in the chest on the day of smoke exposure.

Wiedemann and associates (1986) examined nonspecific bronchial responsiveness to methacholine in 9 asthmatic subjects and 14 controls and the effect of acute involuntary smoking on nonspecific bronchial responsiveness. At the time of the study, all asthmatics were stable with normal or near normal pulmonary function. The subjects underwent baseline pulmonary function and methacholine challenge testing. On a separate day they were exposed to cigarette smoke for 1 hour at 40 to 50 ppm of carbon monoxide and underwent pulmonary function and methacholine challenge testing. Pulmonary function was not influenced by exposure. Nonspecific bronchial responsiveness decreased significantly, rather than increasing, as would be anticipated following an irritant exposure.

Acute exposure in a chamber may not adequately represent exposure in the general environment. Biases in observation and the in selection of subjects and the subjects' own expectations may account for the widely divergent results. Studies of large numbers of individuals with measurement of the relevant physiologic and exposure parameters will be necessary to adequately address the effects of environmental tobacco smoke exposure on asthmatics.

Ear, Nose, and Throat

There are no studies of chronic ear, nose, and throat symptoms in adults with involuntary smoking exposure.

Lung Cancer

This section reviews the epidemiological evidence on involuntary smoking and lung cancer in nonsmokers, which has been derived from retrospective and prospective epidemiological studies. First, common methodological issues that apply to all these studies are considered. Second, for each type of study design, individual studies are reviewed for their methodological approach (Tables 7 and 8), findings associated with tobacco smoke exposure (Table 9, Figure 5), and strengths and limitations. Third, the lung cancer risk associated with involuntary smoking is examined as a low-dose exposure to cigarette smoke by combining the dose–response relationships for active smoking with the exposure data for involuntary smoking to predict the expected lung cancer risk due to involuntary smoking. This expected risk is then compared with the actual risks observed in studies of involuntary smoking. Finally, the existing epidemiological evidence is summarized and the plausibility of the association between lung cancer and involuntary smoking is evaluated on the basis of our current knowledge.

Observed Risk

General Methodological Issues

For both retrospective and prospective studies, the common methodologic concerns are disease misclassification and misclassification of the subject's personal smoking status or exposure to ETS. Disease misclassification, for example, refers to the incorrect classification of the lung as the primary site of a cancer that originated elsewhere. Disease misclassification is of greatest concern in studies in which the diagnosis of lung cancer was not histologically confirmed. Such misclassification tends to be random and to bias relative risk estimates toward unity (Copeland et al. 1977). Patients with lung cancer, or any disease associated with cigarette smoke exposure, may report exposure to ETS more frequently than controls because of bias in recall.

Misclassification of the subject's personal smoking status may occur in both retrospective and prospective studies; this misclassification refers to incorrectly classifying a subject as a nonsmoker when the subject is actually an ex-smoker or a current smoker, or to incorrectly classifying the subject as a smoker when the subject is a nonsmoker. Biochemical markers such as cotinine and nicotine, which can be used to detect unadmitted active smokers, are sensitive only to a recent exposure to tobacco smoke; thus, they are not particularly useful for identifying ex-smokers who deny their past smoking histories. Misclassification of smokers or ex-smokers as nonsmokers may produce the appearance of an involuntary smoking effect when, in fact, the true relationship is with active smoking.

66

TABLE 7.—Description of prospective studies

Factor	Studies		
	Hirayama	Garfinkel	Gillis
Source of subjects	Census population, 29 health districts, Japan	Volunteers, 25 States, United States	Health survey participants, two urban areas, Scotland
Nonsmoker population size (sex)	91,450 (F)	176,739 (F)	827 (M) 1,917 (F)
Age range	≥40	35–84	45–64
Years of enrollment	1966	1959–1960	1972–1976
Last year of followup	1981, 1983	1972	1982
Method of followup	Record linkage between risk factor records and death certificates	Monitored by ACS volunteers, death certificates from local/State health departments	Record linkage with Registrar General files
Verification of diagnosis	None	Verified method of diagnosis and histology for first 6 years' followup	Local cancer registry
Method and type of information obtained	Interview (?): smoking and drinking habits, dietary history, occupation, other health-related variables	Self-administered questionnaire: education, residence, occupational exposure, smoking and medical history	In-person interview: smoking habits, symptoms of respiratory and cardiovascular diseases
Index of passive smoking	Husband's smoking at entry: nonsmoker, ex-smoker, current smoker (cig/day)	Husband's smoking at entry: nonsmoker, current smoker, and cig/day; ex-smokers excluded	Spouse's smoking at entry: current or never smoker; ex-smokers excluded (quit ≥5 years before entry)
Number of lung cancer deaths in nonsmokers	200 (F)	153 (F)	6 (M), 8 (F)

SOURCE: Hirayama (1981a, 1983, 1984a, b), Garfinkel (1981), Gillis et al. (1984).

Misclassification of involuntary smoking exposure refers to the incorrect categorization of exposed subjects as nonexposed and of nonexposed subjects as exposed. Most studies of lung cancer to date have used the number of cigarettes smoked by spouses as a measure of exposure to involuntary smoking, and thus have disregarded duration of exposure, exposure from other sources, and factors that influence exposure, such as proximity to the smokers or size and ventilation of the room where the exposure occurred. Moreover, all

67

TABLE 8.—Description of case–control studies

Study	Country	Case Source and type	Control Source and type	Respondent and type of interview	Confirmed histology Pathological/ cytological	Adenocarcinoma	Index of passive smoke: habits of spouses and others
Trichopoulos et al. (1981, 1983)	Greece	Chest and cancer hospitals; 77 NS (F)	Orthopedic hospital; 225 NS; not matched	Self; not blinded	65%	Presumed none	Current and former spouses (amount, yr); no other
Correa et al. (1983)	New Orleans, United States	Hospitals; 30 NS (8 M, 22 F)	Same hospitals, non-tobacco-related diseases; 313 NS (180 M, 133 F); matched for age, sex, race, hospital	Self, and proxy (case, 23%; control, 11%); blinded	97%	54% among women	Current spouse (type, amount, yr); parents
Chan and Fung (1982)	Hong Kong	Four hospitals; 84 NS (F)	Orthopedic, same hospitals; 139 NS; not matched	Self; not blinded	82%	45%	Not spouse specifically; one question: at home and at work
Koo et al. (1983, 1984)	Hong Kong	Eight hospitals; 88 NS (F)	Population; 137 NS; matched for age, race, sex, socioeconomic status, residence district	Self; not blinded	97%	59%	Current and former spouses (amount, yrs, hrs); parents, other cohabitants, coworkers (amount, yrs, hrs)
Kabat and Wynder (1984)	United States	Most from one NY hospital; 134 NS; passive smoking data on only 78 NS (25 M, 53 F)	Same hospital (?); non-tobacco-related disease; 78 NS (25 M, 53 F); matched for age, sex, race, hospital, date of interview, nonsmoking status	Self; not blinded	100%	54% M 74% F of 134 NS	Current spouse (present or past smoking habits); current exposure at home and work

TABLE 8.—Continued

Study	Country	Case — Source and type	Control — Source and type	Respondent and type of interview	Confirmed histology — Pathological/ cytological	Confirmed histology — Adenocarcinoma	Index of passive smoke: habits of spouses and others
Wu et al. (1985)	Los Angeles, United States	Population-based registry; 29 NS (F)	Population; 62 NS; matched for age, race, sex, neighborhood	Self; not blinded	100%	100%	Current and former spouses (amount, yrs); parents, cohabitants (amount, yrs), coworkers (hr/day, yrs)
Garfinkel et al. (1985)	New Jersey, Ohio, United States	Four hospitals; 134 NS (F)	Same hospitals, colorectal cancer patients; 402 NS; matched for age, hospital, nonsmoking status	Self (case, 12%; control, ?) and proxy; blinded	100%	65%	Current spouse or cohabitant (total and at home: amount, yrs); other exposure, average hrs/day (at home, work, other) 5 and 25 yrs before diagnosis; childhood exposure

69

TABLE 8.—Continued

Study	Country	Case Source and type	Control Source and type	Respondent and type of interview	Confirmed histology Pathological/ cytological	Adenocarcinoma	Index of passive smoke:. habits of spouses and others
Lee et al. (1986)	United Kingdom	Hospital-based; 47 NS (15 M, 32 F)	Same hospitals; 96 NS (30 M, 66 F); matched for age, sex, marital status, hospital	Self, hospital inpatient interview; Spouse, followup interview; not specified	?	?	Current spouse (smoking habit during admission yr and maximum during marriage); other exposure at home, at work, during travel and leisure
Akiba et al. (1986)	Japan	Hiroshima and Nagasaki bomb survivors; 103 NS (19 M, 84 F)	Same cohort, noncancer or chronic respiratory disease; 380 NS (110 M, 270 F); matched for age, sex, city of residence, vital status, yr of death	Self (case, 10%; control, 12%) and proxy; not blinded	57%	?	Current spouse (amount, age start, age stop, yrs cohabited); parents
Pershagen et al. (in press)	Sweden	National census of Sweden and Swedish Twin Registry; 67 NS (F)	Two controls from each source; 347 NS; matched for year of birth, vital status at followup end for twin registry control	Self, and proxy (case, almost all; control, ≥65%); not applicable, mailed questionnaire	99%	57%	Spouse lived with longest (amount, yrs); parents

TABLE 9.—Results from selected prospective and case-control studies; lung cancer risk associated with spouses' smoking

Study	Spouses' smoking				
	Nonsmoker	Ex-smoker	1–14/day	15–19/day	20+/day
Hirayama (1984a)	1.0	1.4 (0.9, 2.2)[1]	1.4 (1.0, 2.0)	1.6 (1.0, 2.4)	1.9 (1.3, 2.71)
	Nonsmoker	<20/day		20+/day	
Garfinkel (1981)	1.0	1.3 (0.9, 1.9)		1.1 (0.8, 1.6)	
		Not exposed		Exposed	
Gillis et al. (1984)	Men / Women	1.0 / 1.0		4.3 / 1.0	
	Nonsmoker	Ex-smoker	1–20/day	21+/day	
Trichopoulos et al. (1983)	1.0	1.9 (0.9, 4.1)	1.9 (1.0, 3.7)	2.5 (1.7, 3.8)	
	Nonsmoker	1–40 pack-yr		>41 pack-yr	
Correa et al. (1983)	1.0	1.5 (0.6, 3.8)		3.1 (1.1, 8.5)	
	No	Yes			
Chan and Fung (1982)	1.0	0.8 (0.5, 3.1)			
	Nonsmoker	≤35,000 hrs[2]		>35,000 hrs	
Koo et al. (1984)		1.3 (0.8, 2.4)		1.0 (0.2, 2.7)	
	No	Yes			
Kabat and Wynder (1984)	1.0	0.9 (0.3, 2.1)			
	Nonsmoker	1–20 yrs		21+ yrs	
Wu et al. (1985)	1.0	1.4 (0.4, 4.9)		1.2 (0.4, 3.7)	
	Nonsmoker	Cigar/pipe	<10/day	10–19/day	≥20/day
Garfinkel et al. (1985)	1.0	1.2 (0.8, 1.7)	1.2 (0.8, 1.6)	1.1 (0.8, 1.5)	2.1 (1.1, 4.0)
	No	Yes			
Lee et al. (1986)	1.0	1.1 (0.5, 2.4)			
	Nonsmoker	1–19/day	20–29/day	30+/day	
Akiba et al. (1986)	1.0	1.3 (0.7, 2.3)	1.5 (0.8, 2.8)	2.1 (0.7, 2.5)	
	Nonsmoker	Low[3]		High[4]	
Pershagen et al. (in press)	1.0	1.0 (0.6, 1.8)		3.2 (1.0, 9.5)	

[1] Numbers in parentheses are the 95 percent confidence limits.

[2] Total exposure from spouses, cohabitants, coworkers.

[3] Husband smoked ≤15 cigarettes/day or 1 pack (50 g) of pipe tobacco/week or any amount during <30 years of marriage.

[4] Husband smoking >15 cigarettes/day or 1 pack of pipe tobacco/week during ≥30 years of marriage.

Pershagen

Correa

10
9
8
7
6
5
4
3
2
1

Relative risk

Chan
Kabat Lee Koo
Wu
Akiba
Garfinkel
Trichopoulos

S[1]   S   S   Low[2] High   1-20 21+   1-19 20-29 30+   1-19 20+   Low High   1-20 21+   1-40 41+

years   per day   per day   per day   pack-years

Smoking habits of spouses
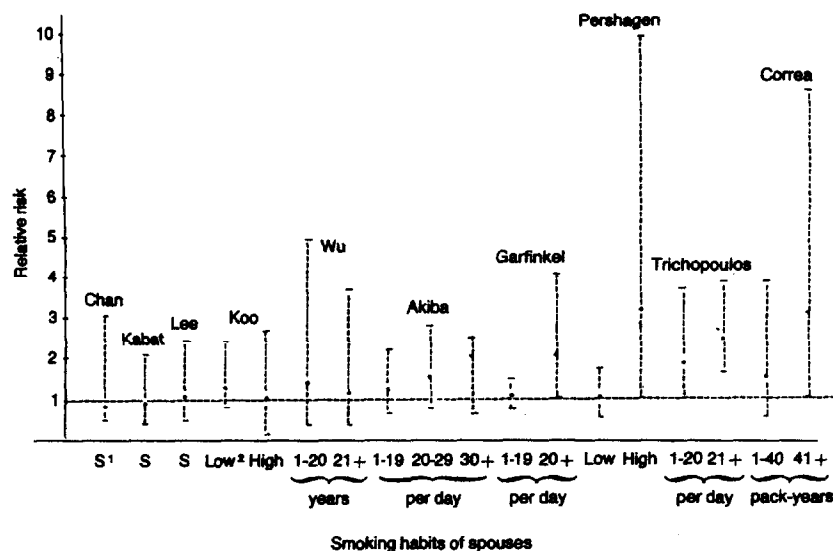
FIGURE 5.—Relative risks and 95 percent confidence intervals in case-control studies of passive smoking and lung cancer

[1] S=smoker.

[2] Low and high exposure levels are described in Table 9.

SOURCE: Chan and Fung (1982); Kabat and Wynder (1984); Lee et al. (1986); Koo et al. (1984); Wu et al. (1985); Akiba et al. (1986); Garfinkel et al. (1985); Pershagen et al. (in press); Trichopoulos et al. (1983); Correa et al. (1983).

of the published studies have based involuntary smoking exposure measures on questionnaires without validation of these data with biochemical markers or environmentally measured concentrations of tobacco smoke constituents. Misclassification of involuntary smoking exposure is likely to be random and to bias the effect measures toward the null (Copeland et al. 1977).

Misclassification of exposure to environmental tobacco smoke is inherent in epidemiological studies of involuntary smoking. Tobacco smoking has not been restricted in most indoor environments until recently, and exposure has been almost inevitable in the home, the workplace, or other locations. Studies with the biological markers nicotine and cotinine confirm that tobacco smoke exposure is widespread; detectable levels of these markers are found even in people without reported recent exposure. Thus, the exposure variables employed in epidemiological studies do not separate nonexposed subjects from exposed subjects; instead, they discriminate more exposed groups from less exposed groups. As a result, the

72

epidemiological approach is conservative in estimating the effects of involuntary smoking. A truly nonexposed but otherwise equivalent comparison population has not been identified. The extent of the resulting bias cannot be readily estimated and probably varies with the exposure under consideration, which may be one reason for the variability in risk estimates obtained by different studies.

Information bias is an added concern in case–control studies, since neither interviewer nor respondent bias can be ruled out. It is not feasible to blind interviewers to the case or control status of respondents because of the usually obvious manifestations of lung cancer and because of the setting in which some of the interviews are conducted. Moreover, blinding of interviewers and respondents to the study hypothesis is difficult because the majority of questions are concerned with exposure to tobacco smoke. The direction of the information bias may be dependent on the type of respondent. Self-respondents may be more apt to interpret their disease as related to exposure to tobacco smoke and thus overreport the exposure. However, the direction of the information bias is less clear when interviews are conducted with surrogate respondents. The ability of a surrogate to provide accurate information may depend on the relationship of the surrogate respondent to the subject, whether the surrogate lived with the subject during the time frame of the questions asked, the degree of detail requested, and the amount of time elapsed since the event in question (Gordis 1982; Pickle et al. 1983; Lerchen and Samet 1986). Surrogate respondents may minimize the reporting of their own smoking because of guilt, or may overreport about involuntary smoking exposure in an attempt to explain their relative's illness. Thus, depending on the direction of the information bias, it may dilute or strengthen the effect being measured (Sackett 1979). In general, however, the information on smoking status and on amount smoked provided by surrogates has been found to be fairly comparable to that provided by the individuals themselves (Blot and McLaughlin 1985).

Finally, participants and nonparticipants in case–control studies may be inherently different with respect to their exposure to involuntary smoking because their awareness of the hypothesis under study may motivate the decision to participate. However, participants in case–control studies are generally not informed of the hypothesis under study.

Spousal Exposure: Prospective Studies

The Japanese Cohort Study

Hirayama (1981a, 1983, 1984a) has presented data from a large cohort study that included 91,540 nonsmoking married women who were residents of 29 health districts in Japan. Subjects were 40 years

of age or older at enrollment in 1965; information was collected on smoking and drinking habits, diet (e.g., green-yellow vegetables, meat), occupation, and other health-related variables.

The initial report on involuntary smoking was based on 14 years of followup (1966–1979). The husbands' smoking histories were available for 174 of 240 lung cancer cases identified among the nonsmoking married women (Hirayama 1981a); this number increased to 200 with 2 additional years of followup (Hirayama 1983, 1984a). Results pertaining to the association of spouses' lung cancer risk with the husbands' smoking were essentially identical in the first and second reports.

On the basis of the smoking habits of the husbands at entry, the 200 nonsmoking women were classified as married to a nonsmoker, an ex-smoker, or a current smoker. The lung cancer mortality ratios standardized by husband's age were 1.00, 1.36, 1.42, 1.58, and 1.91 for women whose husbands were nonsmokers, ex-smokers, and daily smokers of 1 to 14, 15 to 19, and 20 or more cigarettes, respectively (one-sided p for trend, 0.002). Similarly significant dose–response trends were observed when the mortality ratios were standardized by age of the wives, by occupation of the husbands (agricultural, industrial, other), by age and occupation of the husbands, and by the time period of observation (1966–1977 versus 1978–1981). The risk of lung cancer among nonsmoking wives of smokers was reduced to 0.7 (two-sided p=0.05) if they ate green-yellow vegetables daily compared with 1.0 if they ate such vegetables less often than daily (Hirayama 1984b). No other characteristic of the wives (e.g., drinking habits, parity, occupation, nonvegetable dietary items) or of the husbands (e.g., drinking habits) was significantly predictive of lung cancer risk.

Nonsmoking men whose wives were smokers also showed an elevated lung cancer risk. On the basis of 67 lung cancers in nonsmoking married men, the lung cancer mortality ratios were 1.00, 2.14, and 2.31 if their wives had never smoked or had smoked 1 to 19 cigarettes or 20 or more cigarettes per day, respectively (one-sided p for trend, 0.023) (Hirayama 1984b).

This study has been critically discussed in correspondence since its initial publication. Because a detailed breakdown of the at-risk population was not presented in the initial report, the lung cancer mortality rate was thought by some to be higher in the unmarried nonsmoking women than in the nonsmoking women married to smokers (Rutsch 1981; Grundmann et al. 1981). This impression was clarified by the researcher (Hirayama 1981b,c,d) and shown to be the result of incorrect interpretation of data in the original paper. Other potential problems cited were sampling bias in the study cohort, misclassification in the diagnosis of lung cancer, misclassification of the nonsmoking status of wives, misclassification of involuntary

smoking exposure, failure to control for potential confounders, and inadequate statistical treatment of data. Each of these points of criticism is discussed below.

MacDonald (1981a,b) questioned the representativeness of the 29 health districts selected in the study cohort and suggested that industrial pollution, such as asbestos exposure from shipbuilding industries specific to the selected health districts, may have biased the results. However, the levels of exposure to this factor would have to coincide with the husbands' smoking level to explain the effect observed. Such an association seems unlikely. If the cohort were not representative, the generalizibility but not the validity of the findings would be challenged (Criqui 1979).

The accuracy of the diagnosis of primary lung cancer on the basis of death certificates and the adequacy of the data without information on the histology of the tumor were questioned (Grundmann et al. 1981; MacDonald 1981a). From a sample of 23 cases, Hirayama (1981b) reported that the distribution by histology of lung cancer in nonsmoking women whose husbands smoked was similar to that in women who smoked. Failure to discriminate in some cases between primary and metatastic lesions to the lung may be a potential problem with disease diagnosis. Although Hirayama was unable to assess the accuracy of the diagnosis listed on the death certificate, there is no reason to believe that error in recording the causes of death of wives was influenced by the smoking habits of their husbands, and any misclassification is likely to be random. Inclusion of nonlung cancer cases would tend to bias the risk ratio toward unity or no effect (Barron 1977; Greenland 1980).

The relatively high risks observed for nonsmokers whose husbands smoked led to speculation that Japanese women may report themselves as nonsmokers when they actually smoke (Lehnert 1984). However, some assurance of the reliability of the smoking data provided by the Japanese women comes from an investigation in Hiroshima and Nagasaki (Akiba et al. 1986) that found strong concordance between smoking status reported by the women themselves and that reported by their next of kin.

Classifying nonsmoking women solely on the basis of the smoking habits of their current husbands probably does not quantify their exposure with precision because it accounts for only one of the many possible sources of tobacco smoke exposure. Moreover, using the number of cigarettes smoked per day by the husbands as a measure of exposure dose assumes that the husbands' increasing daily cigarette consumption is directly related to an increasing ETS exposure of the wives (Kornegay and Kastenbaum 1981; Lee 1982b).

The analyses were further criticized for not accounting for potential confounding factors such as socioeconomic status (SES) and exposure to indoor air pollutants (e.g., from heating and cooking

sources) (Sterling 1981). However, Hirayama showed a fairly consistent relationship between involuntary smoking exposure and lung cancer across SES categories. The role of indoor air pollutants could not be addressed directly in the study, but data from one health district in the study indicated no association between heating or cooking practices and the smoking habits of the husbands (Hirayama 1981b).

The researcher's failure to specifically describe the methods for age standardization in the initial report led to speculation that the statistical methods used were incorrect (Kornegay and Kastenbaum 1981; Mantel 1981; Tsokos 1981; Lee 1981); however, the calculations were later confirmed (Harris and DuMouchel 1981; Hammond and Selikoff 1981). The choice of stratification variables used for age standardization was also criticized because the husbands' ages instead of the wives' ages and 10-year age groups instead of narrower ones were used (Tsokos 1981; MacDonald 1981b). Later publications confirmed that similar results were obtained regardless of the method of standardization (Hirayama 1984a).

The American Cancer Society Cohort Study

A second prospective study (Garfinkel 1981) that examined the effects of involuntary smoking was the American Cancer Society (ACS) study of about 1 million people living in 25 States. A self-administered questionnaire on education, residence, occupational exposure, and smoking and medical history was completed by the study subjects upon enrollment.

This report on involuntary smoking was based on 12 years of followup (1960–1972) and included 176,739 nonsmoking married women whose husbands' smoking habits were available and whose husbands were never smokers or current smokers. In the total cohort of nonsmoking women, 564 lung cancer deaths occurred, and data on the husbands' smoking habits were available for 153 (27.1 percent). Wives of ex-smokers and of cigar or pipe smokers were excluded from the analysis.

A small, statistically nonsignificant increased risk for lung cancer was found for nonsmokers married to smokers. The mortality ratios for lung cancer in nonsmoking women were 1.0, 1.27, and 1.10 when the husbands were nonsmokers, daily smokers of fewer than 20 cigarettes, and daily smokers of 20 or more cigarettes, respectively. The results were essentially unchanged after accounting for the potential confounding effects of age, race, education, residence, and husband's occupational exposure.

The ACS study, like the Japanese study, was not designed to study the long-term effects of involuntary smoking. However, the ACS study does provide an estimate of the extent of misclassification of lung cancer. On the basis of medical record verification, the death

76

certificate diagnosis of lung cancer in nonsmoking women was incorrect for 12 percent of the cases. Although confirmation of diagnosis was sought only for the first 6 years of followup, the available data suggest that some misclassification of lung cancer occurred. To the extent that passive smoking is related to lung cancer in nonsmokers, inclusion of nonlung cancers would tend to dilute a true effect.

A limitation of the ACS study is the nonavailability of smoking information on the husbands of a large proportion of the nonsmoking women who died of lung cancer. Because smoking habits are correlated with various social characteristics, this large loss of information may have created a bias in this study. The researcher stated that an index of tobacco smoke exposure based only on smoking habits of current husbands may be particularly inadequate for the United States, with its high rate of divorce and substantial proportion of women working outside the home. This speculation is supported by data from a group of 37,881 nonsmokers and ex-smokers who were members of a health plan in California. Friedman and colleagues (1983) stated that 47 percent of the nonsmoking women and 39 percent of the nonsmoking men married to smokers reported no exposure at home. Moreover, being married to a nonsmoker did not assure the absence of exposure to tobacco smoke, since 40 percent of the nonsmoking women and 49 percent of the nonsmoking men married to nonsmokers reported some exposure to tobacco smoke during the week. Thus, random misclassification could have biased the results toward unity and led to an underestimate of the effect of passive smoking.

The Scottish Study

Gillis and colleagues (1984) conducted a prospective cohort study of 16,171 Scottish men and women, aged 45 to 64 years, from two urban areas, who attended a multiphasic health screening clinic between 1972 and 1976. A questionnaire on smoking habits and symptoms of respiratory and cardiovascular diseases was completed at entry into the study.

The preliminary analysis of involuntary smoking, representing 6 to 10 years of followup, was based on the 2,744 nonsmokers among the 8,128 subjects who lived as couples and could be paired according to smoking habits. Subjects who lived alone or whose partner did not participate and ex-smokers who had stopped smoking for 5 years or more were excluded. The nonsmokers were classified as nonsmokers not exposed to environmental tobacco smoke or as nonsmokers exposed to environmental tobacco smoke, according to the smoking habits of their spouses.

A higher age-standardized lung cancer mortality rate was reported for nonsmoking men exposed to tobacco smoke (13 per 10,000) than

for nonsmoking men not exposed (4 per 10,000); however, no statistical tests were conducted because of the small number of cancers. Lung cancer rates were similar for nonsmoking women regardless of the status of their exposure to tobacco smoke (4 per 10,000). The extremely small number of observed lung cancer deaths (6 men, 8 women) limit the interpretation of the study's findings.

Spousal Exposure: Case–Control Studies

Table 8 summarizes the case–control studies that have examined the relationship between involuntary smoking exposure and lung cancer.

The Greek Study

Trichopoulos and colleagues (1981, 1983; Trichopoulos 1984) examined the effect of involuntary smoking on lung cancer risk in a case–control study of 51 Caucasian female lung cancer patients (excluding adenocarcinoma and terminal bronchiolar carcinomas) from three chest hospitals and 163 female controls from an orthopedic hospital in Athens, Greece. All subjects were interviewed in person by one physician who questioned them regarding their personal smoking habits and those of their current and former husbands. Thirty-five percent of the cases were diagnosed only on the basis of clinical or radiologic information; the remainder were cytologically (37 percent) or histologically (28 percent) confirmed.

Nonsmoking women were classified by the smoking habits of their current or former husbands. Husbands were nonsmokers if they had never smoked or had stopped smoking more than 20 years previously, ex-smokers if they stopped 5 to 20 years previously, and current smokers if they were smoking or had stopped less than 5 years before the interview. Being never married, widowed, or divorced was equated as being married to a nonsmoker or an ex-smoker, depending on the length of time in the category.

The initial report was based on 40 nonsmoking cases and 149 nonsmoking controls. The odds ratios (ORs) for women married to nonsmokers, ex-smokers, current smokers of 1 to 20 cigarettes per day, and current smokers of 21 or more cigarettes per day were 1.0, 1.9, 2.4, and 3.4, respectively (two-sided p for trend, <0.02). In a later report on 77 nonsmoking cases and 225 nonsmoking controls, the ORs were somewhat lower: 1.0, 1.9, 1.9, and 2.5, respectively (Trichopoulos et al. 1983; Trichopoulos 1984).

The findings of this study were questioned because the diagnosis of cancer was not pathologically confirmed for 35 percent of the cases (Hammond and Selikoff 1981; Lee 1982b). The inclusion of cases that were not lung cancers would tend to dilute the results toward the null because they may not be related to involuntary smoking.

Terminal bronchial (alveolar) carcinoma and adenocarcinoma of the lung were excluded from the pathologically confirmed group; this exclusion may have been premature (Hammond and Selikoff 1981; Kabat and Wynder 1984), as the causal association between personal smoking and adenocarcinoma of the lung is well established (IARC 1986). Because the controls were selected from a different hospital than were the cases, selection bias cannot be ruled out. Interviewer bias is also possible, since all subjects were interviewed by a single physician who knew the case or control status of each subject, and also knew the hypothesis under investigation.

The index of exposure to tobacco smoke used in this study included the smoking habits of former and current husbands. Since the definition of ex-smokers excluded those who had stopped smoking recently (within the last 5 years), it was unanticipated that the risks observed for women whose husbands were ex-smokers (i.e., quit 5 to 20 years previously) were as high as for those whose husbands were current smokers. Additional information on the smoking habits of these ex-smokers would be valuable.

The Louisiana Study

The case–control study by Correa and colleagues (1983) was based on 1,338 primary lung cancer cases, of which 97 percent were pathologically confirmed. Controls (N=1,393) were matched to cases by race, sex, and age ($\pm$5 years) and were patients at the same hospitals as cases but without a diagnosis related to tobacco smoking.

Standardized interviews were conducted with the subjects (76 percent of cases, 89 percent of controls) or their next of kin. Questions on occupation, residency, personal smoking and drinking habits, and smoking habits (including type of tobacco smoked and amount and duration of smoking) of the current spouse and parents were asked.

Thirty nonsmoking ever-married lung cancer (excluding bronchioalveolar cell) patients (8 men, 22 women) and 313 ever-married nonsmoking controls (180 men, 133 women) were classified according to their spouse's total lifetime pack-years and current daily amount smoked at the time of interview. After adjusting for sex, ORs of 1.00, 1.48, and 3.11 were observed when spouses had smoked none, 1 to 40 pack-years, and 41 or more pack-years, respectively (two-sided $p < 0.05$). The results based on current daily number of cigarettes smoked by spouses were similar.

The study is limited by the small number of nonsmoking cases, but the consistency of the results for men and women strengthens the findings. Misclassification of involuntary smoking is possible because only smoking habits of the current husband were assessed, ignoring the effect of divorce, remarriage, and exposure from coworkers. Exposure from parents during childhood was determined, but case

numbers were too small for a meaningful analysis of this factor among nonsmokers.

The Hong Kong Studies

The high rates of lung cancer, particularly adenocarcinoma of the lung, among women of Chinese descent in Hong Kong are unexpected in the face of their low rates of tobacco smoking. The role of involuntary smoking was investigated in two studies conducted in Hong Kong (Chan et al. 1979; Chan and Fung 1982; Koo et al. 1983, 1984).

Chan and colleagues (1979) examined the role of involuntary smoking among 84 female lung cancer patients and 139 orthopedic control patients, none of whom had ever smoked. Of the 84 nonsmoking cases, 69 (82 percent) were pathologically confirmed, and 38 of these 69 cases were adenocarcinoma of the lung. The controls were from the same hospitals as the cases, but were not individually matched to the cases on any characteristics.

Cases and controls were questioned regarding their residence, education, occupation, cooking practices, and personal smoking habit. One question on exposure to others' tobacco smoke was included: "Are you exposed to the tobacco smoke of others at home or at work?" The researchers reported that the controls lived with smoking husbands more frequently (47.5 percent) than the cases (40.5 percent) (OR 0.77), but did not explain how this question was used to classify the habits of the spouse alone. The method used to classify currently unmarried respondents (i.e., never married, widowed, divorced) with regard to exposure to their spouses' smoking was not described, and it is not known if the nonsmoking cases and controls were comparable in terms of current marital and employment status. Thus, insufficient information on the measure used to assess ETS exposure, and on the comparability of the nonsmoking cases and controls, limits interpretation of this study's results.

The study by Koo and colleagues (1983, 1984) involved 200 Chinese female lung cancer patients who were identified from eight hospitals in Hong Kong; almost all cases were pathologically confirmed (97 percent). Among these women, 88 had never smoked, of whom 52 (59 percent) had adenocarcinomas of the lung. An equal number of "healthy" population controls, individually matched to cases by age (±5 years), socioeconomic status, and district of residence, were interviewed. Among the controls, 137 had never smoked.

Using a semistructured questionnaire, taped interviews were obtained and information on residence, occupation, family and medical history, personal smoking habits, and smoking habits of all cohabitants and coworkers was elicited. ETS exposure was quantified in hours and years according to who (i.e., husband, parents, in-laws, children, others) smoked in the subject's presence and where

80

(i.e., at home, at work) the exposure occurred. The analysis was based on a cumulative smoke exposure index (in total hours and total years) specific to place of exposure.

The investigators concluded that there was no association between involuntary smoking and lung cancer in nonsmoking Chinese women, regardless of the index of smoke exposure used. A small, but statistically nonsignificant, increased risk (RR 1.24) was associated with any exposure to tobacco smoke. There were no significant differences between the cases and the controls in total hours or total years of exposure. The results remained unchanged when exposure hours were categorized into three levels of exposure. Odds ratios of 1.00, 1.28, and 1.02 were associated with no, low ($\leq 35,000$ hours), and high ($>35,000$ hours) exposure levels, respectively. There was no apparent trend of lung cancer risk with the age when exposure to tobacco smoke began. The ORs for never exposed and first exposed at ages 0 to 19, 20 to 39, and 40 or older were 1.00, 0.96, 1.53, and 0.91, respectively (Koo et al. 1984). Analysis by cell type suggested that the effects of involuntary smoking may be more pronounced for Kreyberg I tumors (squamous, small-cell, and large-cell carcinomas) (OR 1.47, 95 percent C.I. 0.64, 3.36) than for adenocarcinoma (OR 1.11, 95 percent C.I. 0.49, 2.50) (Koo et al. 1985), but these numbers were small.

The design of this study addressed the criticisms of other studies that an index of involuntary smoking exposure based only on spouses' smoking habits is inadequate, and broadened the exposure assessment to include all locations of tobacco smoke exposure. However, the cumulative exposure index created in this study may have limited validity. Unlike personal smoking, where there is essentially one source (personal smoking), one dose (usual or maximum amount smoked), and one duration of exposure (age at start and age at stop), ETS exposure derives from diverse sources at different doses and durations of exposure. The accuracy of the information on exposure to ETS will depend on the amount of detail requested, the age of the respondent, the temporal course of the exposure, and the source of the exposure. Weighing each type of exposure equally in a cumulative index (in total hours) may be incorrect because it assumes that all sources of exposure should be quantified in the same way and that each source of tobacco smoke contributes equally, disregarding intimacy of contact and proximity to smokers and conditions of exposure (e.g., room size, ventilatory factors). Thus, random misclassification of the exposure variable by inclusion of data from less relevant exposures than spousal smoking may obscure an association of involuntary smoking exposure with lung cancer risk. In this study, interviewer and respondent bias should also be considered because a structured questionnaire was not used.

All of the cases of primary lung cancer in nonsmokers were selected (Kabat and Wynder 1984) from an ongoing case–control study of tobacco-related cancer conducted in five U.S. cities between 1971 and 1980 (Wynder and Stellman 1977). For each case, one control was individually matched by age (±5 years), sex, race, hospital, date of interview (±2 years), and nonsmoking status. Controls were selected from a large pool of hospitalized patients who were interviewed over the same time period as the cases and who had diseases not related to tobacco smoking. Information on demographic factors, residence, height and weight, drinking habits, previous diseases, and occupational exposure were obtained. Questions on tobacco smoke exposure at work, at home, and from current spouse were added in 1978 and revised in 1979. Information on ETS exposure was available for 25 of 37 nonsmoking male cases, 53 of 97 nonsmoking female cases, and their respective matched controls.

A higher percentage of female controls than of female cases reported exposure to ETS at home (32 percent), at work (59 percent), and from spouses (60 percent). The percentages of female cases who reported exposure at home, at work, and from spouses were 30, 49, and 54 percent, respectively. None of the case–control differences in women were statistically significant. Male cases reported more frequent exposure at work (OR 3.27, p=0.045) and at home (OR 1.26), but no difference in the smoking status of their spouses (OR 1.00).

The process for selecting the nonsmoking controls from the larger pool of controls in the ongoing study and for selecting the non-smoking cases and controls who were questioned with regard to ETS exposure was not described adequately. It is not clear whether the 25 of 37 male and 53 of 97 female nonsmoking cases and controls who provided information on involuntary smoking were all interviewed during or after 1978 when the questions on involuntary smoking were introduced. The proportion seemed high, since it represented 68 percent of male and 55 percent of female nonsmoking cases interviewed during the 10 years of data collection. The study was not designed to specifically address the effect of involuntary smoking, and a variable subset of questions on involuntary smoking was asked, depending on when the subjects were interviewed. Misclassification of the exposure is possible because it is not clear whether the cases and controls answered the same set of questions and whether a comparable amount of information was obtained. The researchers acknowledged the limitations of this study and presented its results as preliminary findings.

The Los Angeles County Study

In the case–control study by Wu and colleagues (1985), 220 white female lung cancer patients (149 with adenocarcinoma and 71 with squamous cell carcinoma) and 220 population controls were individually matched on sex, race, age (±5 years), and neighborhood of residence. Cases were identified from the population-based tumor registry of Los Angeles County. All cases were histologically confirmed; the histological type was based on the pathology report from the hospital of diagnosis.

Using a structured questionnaire, cases and controls were directly interviewed by telephone and were asked about their own personal smoking habits and the smoking habits (amount and years of smoking) of current and former husbands, parents, and other household members during childhood and adult life. Exposure to tobacco smoke at work (in hours per day) was obtained for each job of at least 6 months' duration. Information on medical and reproductive history, heating and cooking sources, and dietary intake of vitamin A were obtained.

Of 149 patients with adenocarcinoma of the lung, 29 had never smoked, nor had 2 of 71 patients with squamous cell carcinoma. The analysis of involuntary smoking was based on the 29 nonsmokers among the adenocarcinoma cases and 62 nonsmokers among the controls.

A subject was classified as married to a smoker if any of her husbands had ever smoked. Similarly, a subject was considered exposed at work if she was exposed to tobacco smoke for at least 1 hour per day at any of her jobs. There were small, but nonsignificantly increased risks associated with ETS exposure from spouse or spouses (OR 1.2; 95 percent C.I. 0.2, 1.7), and from coworkers (OR 1.3; 95 percent C.I. 0.5, 3.3). Increased risk was not associated with smoke exposure from either parent (OR 0.6; 95 percent C.I. 0.2, 1.7). Exposure to tobacco smoke from spouses and from coworkers was combined in an index representing smoke exposure during adult life. There was an increasing trend in risk with increasing years of exposure. The ORs were 1.0, 1.2, and 2.0 for 0, 1 to 30, and 31 or more years of involuntary smoking exposure during adult life, respectively, but the results were not statistically significant. Because the exposures may have occurred concurrently, the years of exposure represented units of exposure rather than calendar years of exposure.

This study is limited by the small number of nonsmoking cases and controls. Unlike the two case–control studies that excluded adenocarcinoma or bronchioalveolar cell carcinoma (Trichopoulos et al. 1981; Correa et al. 1983), cases in this analysis were of these cell types (17 adenocarcinoma, 12 bronchioalveolar); this case mix may explain the weak association observed.

The Four Hospitals Study

A case–control study by Garfinkel and colleagues (1985) included 134 nonsmoking female lung cancer cases selected from three hospitals in New Jersey and one in Ohio over an 11-year period, 1971–1981. Medical records served as the initial source of information on smoking status of the subject, and the nonsmoking status of each case and control was verified at interview. Three controls, colorectal cancer patients matched to cases by age (±5 years) and hospital, were interviewed for each case, giving a total of 402 controls. All diagnoses of cases and controls were pathologically confirmed. Interviewers, blinded to the diagnosis of the subjects and to the study hypothesis, administered a standard questionnaire to subjects or their next of kin. Information on the smoking habits of current spouse (total and amount smoked at home), tobacco smoke from other sources (in hours per day at home, at work, and in other settings), and exposure to tobacco smoke during childhood were obtained.

Subjects were classified according to the smoking habits of current husbands. Smoking habits of a cohabitant in the same household was used for single women or those who no longer lived with their spouses. Of the cases, 57 percent were classified according to the smoking habits of husbands; the corresponding percentage in controls was not provided. Nonsmoking women living with a smoker showed an elevated risk for lung cancer (OR 1.31). The ORs for lung cancer in nonsmoking women were 1.00, 1.15, 1.08, and 2.11 when the husbands were nonsmokers, daily smokers of less than 10, 10 to 19, and 20 or more cigarettes at home, respectively (one-sided p for trend, <0.025). Similarly, a significant positive linear trend (one-sided $p < 0.025$) was shown when the husbands' total amount smoked was categorized into four levels. However, there was no apparent dose-related trend by years of exposure to the husbands' smoking (0, <20, 20–29, 30–39, 40+ years).

There was no apparent association between lung cancer and tobacco smoke exposure from other sources. Cases and controls did not differ in their reported exposure to tobacco smoke during childhood or in their average hours of exposure per day to other's tobacco smoke during the last 5 years and 25 years before diagnosis. The results remained unchanged when exposures at home, at work, and in other settings were examined separately. The odds ratios were highest for exposure in other settings, but they were based on a small number of positive responses. There was no consistent pattern by histologic type. Squamous cell carcinoma showed the strongest relationship with involuntary smoking, based on the husbands' smoking habits at home (RR 5.0, 95 percent C.I. 1.4, 20.1), but failed to show any relationship when involuntary smoking exposure was classified by hours of daily exposure.

This case–control study has the largest number of nonsmoking lung cancer cases to date and provides estimates of the misclassification of disease and of the smoking status of the subjects. Among the published studies on involuntary smoking, this is the only one involving independent verification of the diagnoses of all cases. This verification showed that 13 percent of the cases classified as lung cancer were not primary cancers of the lung. This study showed that 40 percent of the women with lung cancer who had been classified as nonsmokers (or smoking not stated) on hospital records had actually smoked, compared with 9 percent of the controls. The inclusion of lung cancer patients who had actually smoked would have substantially increased the odds ratios with involuntary smoking, because 81 percent of the potentially misclassified cases had husbands who smoked compared with 68 percent of the "true" nonsmoking patients with lung cancer. It should be noted that none of the other studies on involuntary smoking and lung cancer based classification of smoking status solely on data from medical records. The measure of involuntary smoking based on smoking habits of husbands attempted to differentiate between current total smoking habits and current smoking habits at home. The interview also included ETS exposure not only at home but at work and in other settings.

The exposure information presented in this study is potentially limited by its extensive reliance on surrogate interviews. Owing to the need to assemble sufficient nonsmoking cases, diagnoses as early as 1971 were included, so proxies were interviewed for a high percentage of the deceased cases. Among the cases, 12 percent of the interviews were conducted with the subject, 25 percent with the husband, 36 percent with offspring, and 27 percent with an informant who had known the subject for at least 25 years. The corresponding distribution of informants in the control series was not presented. Although the ORs did not vary consistently by respondent group, the OR for smoke exposure based on the husbands' smoking tended to be lower when husbands were the respondents. Presumably, the husbands reported their own smoking habits, and it cannot be determined whether bias resulted. The information provided by surrogates may be particularly inaccurate for exposures outside the home. Systematic bias between personal and surrogate interviews and systematic bias by informant status must also be considered. Given that the topic of involuntary smoking is potentially sensitive for the family of a lung cancer patient, it is possible that some surrogates may not have provided accurate histories, particularly with regard to their own smoking habits. Surrogate respondents for cases might have been more likely to underreport exposure than those for controls; such differential reporting would have led to an underestimation of the true effect. The multiple regression analysis performed in this study did take

respondent status into consideration, and it was determined that this factor could not account for the relationship with husband's smoking status (Garfinkel et al. 1985). It is not clear if the colorectal cancer controls were diagnosed in the same years as the lung cancer cases. Because the response patterns of relatives who are interviewed after the recent death of a subject may differ from responses obtained long after the subject has died, another source of bias may have been introduced.

A United Kingdom Study

In an ongoing hospital-based case–control study of lung cancer, chronic bronchitis, ischemic heart disease, and stroke, Lee and colleagues (1986) examined the role of involuntary smoking in a group of inpatients interviewed after 1979, when, to cover involuntary smoking, the questionnaire was extended to married patients. An attempt was also made to interview the spouses of the married nonsmoking lung cancer patients and the spouses of the comparison group.

The interview on involuntary smoking administered to hospital inpatients included questions on the smoking habits of their first spouse and on ETS exposure at home, at work, during travel, and during leisure, based on a subjective four-point scale. Spouses of nonsmokers were asked about their own smoking habits at the time of interview, during the year of admission of the subject, and during the course of their marriage.

A total of 56 lung cancer cases among married lifelong nonsmokers was identified; 2 controls were selected for each case and individually matched on nonsmoking status, sex, marital status, age, and hospital. Among the 56 cases and 112 controls, information on spouses' smoking habits was available for 29 (52 percent) cases and 59 (56 percent) controls from an interview conducted while the patient was still in the hospital. Interviews with spouses were obtained for 34 (61 percent) of the cases and 80 (71 percent) of the controls. Using both of these sources of information, the smoking habits of spouses were available for 47 (84 percent) of the cases and 96 (86 percent) of the controls. Nine risk estimates were presented for spouses' smoking, for each of the three sources of information (subject, spouse, and both), for men and women separately and for both sexes combined. The researchers concluded that spousal smoking was not associated with lung cancer, because risks were not consistently elevated. When their spouses reported about their own smoking, a RR of 1.60 (95 percent C.I. 0.44, 5.78) was found for lung cancer in the women. In contrast, a RR of 0.75 (95 percent C.I. 0.24, 2.40) was found when the female subjects reported about the smoking habits of their spouses. On the other hand, a RR of 1.01 (95 percent C.I. 0.23, 4.41) was found for male lung cancer patients when

their spouses reported about their own smoking, whereas the risk was 1.53 (95 percent C.I. 0.37, 6.34) when the male patients evaluated their spouses' smoking habits. As might be expected, the combined risk in relation to spouses' smoking for both sexes and both sources of information was near unity, at 1.11 (95 percent C.I. 0.59, 2.39). Using a second group of controls, presumably all of the nonsmokers who had responded to the hospital inpatient interview on involuntary smoking, the researchers reported no significant case and control differences in exposure to ETS at home, at work, during travel or leisure, from spouses, or for all sources combined.

This study has several limitations that must be considered in interpreting its results. Although the study attempted to verify involuntary smoking from spouses by using two sources of information, dual reports were obtained for only 16 (29 percent) of the cases and 43 (38 percent) of the controls. The questions on involuntary smoking included exposure from other sources, but they were based on a subjective scale, and different groups of controls were used for the analyses. Information was not presented on the accuracy of the diagnosis of lung cancer or on the histological types included in the study. Moreover, the investigators did not verify the smoking status of the subjects during the interviews with spouses.

The study's inconsistent findings by source of information and by sex may reflect the absence of an association between involuntary smoking and lung cancer in this population, or may reflect methodological problems in the design or conduct of the study. The main study was not originally designed to investigate the effects of involuntary smoking. However, because of interest in this issue, the investigators decided to "increase the number of interviews of married lung cancer cases and controls." The representativeness of the cases and the controls cannot be determined because there may have been differential selection factors in enrolling nonsmoking lung cancer cases and controls into the study; thus, selection bias cannot be ruled out. The method for selecting the 112 nonsmoking controls was not adequately described in the report; it is not clear whether they were selected from the pool of all controls for lung cancer or from the pool of controls for the four diseases under study. There is also an apparent discrepancy in the number of nonsmoking cases cited in the text and presented in the results. The report cited 44 never smokers among a total of 792 lung cancer patients who completed the involuntary smoking questionnaires when they were in the hospital. However, the analysis for an involuntary smoking effect based on interviews with subjects in the hospital showed only 29 lung cancer patients. This discrepancy was not explained.

The risks in relation to smoking by spouses varied with the source of information. The risk estimates tended to be higher when the respondents were men, either reporting about their own smoking

87

habits or the smoking habits of their spouses. This pattern could result if the male respondents overestimated exposure to environmental tobacco smoke or if the female respondents underestimated exposure. An analysis of the patients (16 cases and 43 controls) for whom data were provided by the spouses and by the subjects themselves showed a 97 percent concordance for spouses' smoking during the year of the interview and 85 percent concordance for spouses' smoking some time during the marriage. Lack of specificity in the question asked regarding spouses' smoking any time during the marriage may partly explain the discrepancy in response. To the extent that there is no consistent pattern in the direction of this discrepancy, it can be assumed that a spouse was a smoker sometime during the marriage if either respondent answered positively. On the basis of this assumption, RRs of 1.47 (spouses of 4 of 7 cases and 7 of 18 male controls smoked) and 1.39 (spouses of 8 of 9 female cases and 16 of 25 female controls) were found for the men and the women, respectively, in relation to their spouses' smoking. The risk estimates were not statistically significant, but the number of subjects was small.

The Japanese Case–Control Study

The study by Akiba and colleagues (1986) included 428 (264 men, 164 women) incident primary lung cancer cases diagnosed between 1971 and 1980 in a cohort of 110,000 Hiroshima and Nagasaki atomic bomb survivors. Controls were selected among cohort members who did not have cancer. For deceased cases, corresponding controls were selected from among cohort members who died of causes other than cancer or chronic respiratory disease. The controls were individually matched to cases on a number of factors, including age, sex, birth year (± 2 years), city of residence, and vital status; a variable number of controls was interviewed, depending on the place of residence. Of the lung cancers, 29 percent were pathologically confirmed, 43 percent were radiologically or clinically diagnosed, and the remainder were found at autopsy.

Subjects or their next of kin were interviewed regarding the subjects' personal smoking, smoking habits of current spouses and parents, and occupation. Less than 10 percent of the interviews with the men and about 20 percent of the interviews with the women were conducted with the subjects themselves. The distributions of the next of kin interviewed were similar for the cases and the controls.

Among the cases, 103 (19 men, 84 women) had never smoked, compared with 380 controls (110 men, 270 women). An elevated lung cancer risk associated with smoking habits of spouses was observed for men and women. An OR of 1.8 (95 percent C.I. 0.5, 5.6) was found for nonsmoking men married to-wives who smoked and an OR of 1.5

(95 percent C.I. 1.0, 2.5) for nonsmoking women married to husbands who smoked. Lung cancer risk increased with the amount smoked per day by the husband, with an OR of 2.1 for women whose husbands smoked 30 or more cigarettes per day. The OR was higher (1.8) among women who had been exposed within the past 10 years compared with those who had been exposed before that time (OR 1.3). However, an increasing duration of exposure to husbands' smoking was not associated with a monotonic trend of increasing risk. The relation between lung cancer and husbands' smoking was observed regardless of the occupation of wives (housewife, white-collar, blue-collar), but the highest odds ratio was for women who worked in blue-collar jobs and whose husbands were heavy smokers (OR 3.2).

Despite a high proportion of proxy interviews, the distribution of informant type was comparable for cases and controls; this comparability minimizes the possibility of recall bias. The high concordance between the subjects' reported smoking status in a previous survey and the information from the next of kin is reassuring. Although a high proportion of cases had no histological confirmation, an increased risk was observed regardless of the method of diagnosis. This study also provided an opportunity to test for potential confounding factors, including radiation exposure and occupation, but none were identified.

The Swedish Study

The study by Pershagen and associates (in press) included 67 incidents of primary lung cancer cases from a cohort of 27,409 nonsmoking Swedish women who were participants in a national census survey or in a twin registry. Two controls were selected from each source and were matched to cases on year of birth, and on vital status if they were selected from the twin registry.

Subjects or their next of kin (excluding husbands) were mailed a questionnaire that assessed their exposure to tobacco smoke from parents and the husband with whom the subject had lived the longest time. Information on residential and occupational history was also obtained.

Elevated lung cancer risk associated with the smoking habits of spouses was observed. For all lung cancers, ORs of 1.0, 1.0, and 3.2 were observed for women who had no, low (≤ 15 cigarettes/day or <1 pack of pipe tobacco/week or <30 years of marriage), and high exposure to their husbands' smoking, respectively. The increased risk was found primarily for squamous and small cell carcinomas (OR 3.3); consistent effects could not be detected for other histologic types. On the basis of the approximately 75 percent of respondents who provided information on parental smoking, there was no effect

of parental smoking on risk for all lung cancers, after controlling for the husbands' smoking.

The study is similar in design to the Japanese case–control study (Akiba et al. 1986), except that the Swedish investigators obtained histologic confirmation for all of the cases under study. Moreover, this study excluded husbands as informants, so a potential bias associated with husbands' reporting their own smoking habits could be eliminated. The investigators contended that the finding of an association only for squamous cell and small cell carcinomas argues against a spurious finding because it is unlikely that the next-of-kin informers would have been aware of the histologic types diagnosed in the cases.

The German Study

The last in this description of studies to date based on the case–control design is a German study (Knoth et al. 1983), interpreted by the investigators as showing a role for involuntary smoking in the etiology of lung cancer. Of 39 nonsmoking women with lung cancer, 24 (62 percent) had lived with smokers. Although a comparison group was not interviewed, the investigators surmised that this frequency of smokers in the household was about three times higher than expected from census-based smoking statistics for men in the age group 50 to 69. The limitations of this study are evident; the researchers assumed that smoking prevalences for men were indicative of smoking prevalences for members of the cases' households and a specific control series was not enrolled.

Other Sources of Tobacco Smoke Exposure

Parental Smoking

Recently evaluated as a risk factor for lung cancer, parental smoking is of interest because of the large number of exposed children, the age at which it begins, and its duration. Results of this association are variable, demonstrating no association, association with just mothers' smoking, or association with both mothers' and fathers' smoking. Correa and colleagues (1983) reported an association between lung cancer risk and the mothers' smoking in the men, which persisted after adjusting for personal smoking habits (OR 1.5, $p < 0.01$). This association was not observed in the women, and increased risk was not related to fathers' smoking in either the men or the women. A positive association between the mother's smoking and lung cancer risk was reported in a study of female lung cancer, but the result was not statistically significant after adjusting for personal smoking habits (OR 1.7, 95 percent C.I. 0.8, 3.5) (Wu et al. 1985). Another study suggested that the father's smoking (OR 2.5) and the mother's smoking (OR 1.8) were each related to increased

lung cancer risk after adjusting for age and individual smoking habits (Sandler, Wilcox, Everson 1985b). These results were based on small numbers, however, particularly for the mother's smoking (in 2 of 15 cases, the mother smoked). Significant associations with maternal or paternal smoking were not found in two other studies (Akiba et al. 1986; Pershagen et al. in press); however, information was lacking for about one-third of the subjects. Since smoking habits of children are highly correlated with smoking habits of parents, it is difficult, even after adjusting for personal smoking habits, to be certain that an independent effect of parental smoking has been observed.

None of the studies with data on parental smoking had sufficient numbers to examine the effects of parental smoking on nonsmokers. In Louisiana, one nonsmoking case had a mother who smoked (Correa et al. 1983). In Hong Kong, 6 percent (5/88) of the nonsmoking cases reported that their parents smoked compared with 2 percent (3/137) of the nonsmoking controls (Koo et al. 1984). In Los Angeles, the frequencies of smoking by mothers and fathers were lower for nonsmoking cases (4 percent mothers, 28 percent fathers) than for nonsmoking controls (11 percent mothers, 35 percent fathers) (Wu et al. 1985). Exposure to tobacco products during childhood was not significantly different between cases and controls (OR 0.91, 95 percent C.I. 0.74, 1.12) in another study (Garfinkel et al. 1985).

It is difficult to obtain accurate information regarding remote childhood events, so data on parental smoking tend to be crude or unavailable. Information on maternal smoking during pregnancy would not be available unless the parents could be interviewed. Because lung cancer occurs most often among older persons, an interview with a parent will generally be impossible. Moreover, information on parental smoking will most likely be unavailable or meaningless if surrogate interviews are conducted.

Coworker's Smoking

The workplace, an important source of tobacco smoke exposure, was not considered in the early studies on involuntary smoking. Later case–control studies provided some information on tobacco exposure at work, but the data were limited and inconclusive. Kabat and Wynder (1984) reported a statistically significant positive association between tobacco smoke exposure at work for men but not for women. In comparison with controls, patients with cancer in Hong Kong reported more hours and years of exposure at the workplace, but only two cases and four controls had exposure to tobacco smoke at work (Koo et al. 1984). Data in the Los Angeles study suggested that the workplace may be an important source of exposure to tobacco smoke. A small increased risk was observed for

any exposure at work, and an index combining exposure from coworkers and spouse or spouses indicated a trend of increasing risk with increasing exposure (Wu et al. 1985). Garfinkel and colleagues (1985) found no differences between cases and controls in their exposure to tobacco smoke at work during either the 5 years or the 25 years before diagnosis, and a similar lack of an association was also reported by Lee and colleagues (1986).

Dose-Response Relationship

An important factor in the appraisal of the relationship between involuntary smoking and lung cancer is the assessment of dose–response relationships. However, this analysis hinges on the definition of exposure. Data on active smoking and lung cancer suggest that exposure measures considering amount, duration, and recency of exposure should be employed in examining dose–response relationships in active smokers (Doll and Peto 1978; Pathak et al. 1986). Misclassification of exposure to ETS may be expected when exposure categorization is based on the amount or the duration of smoking by the current spouse or cohabitant, as current exposure from one source may not adequately measure past exposure or cumulative exposure. Moreover, these exposure variables may not be indicative of the exposure dose to the respiratory tract because dose determinants such as ventilation rates, breathing pattern, and deposition factors are unaccounted for.

Research is now being directed toward the integration of information from questionnaire responses, biochemical studies, and environmental sampling to determine the most accurate measures of exposure to the respiratory tract. However, exposure assessments for epidemiological studies of lung cancer and involuntary smoking will remain limited by the inaccurate recall of exposures that occurred as much as 40 to 50 years earlier. Nevertheless, research on exposure should resolve several points of uncertainty. The comparability between exposure dose measured by amount smoked and by hours or years of smoking should be assessed. The relative importance of sources of ETS should also be clarified, so there will be some agreement on whether cumulative dose should differentiate between sources of exposure.

In the absence of data showing a particular exposure measure to be optimal, an index of involuntary smoking based on the amount smoked by spouses shows the most consistent dose–response relationship with lung cancer risk (Hirayama 1981a; Trichopoulos et al. 1981; Correa et al. 1983; Garfinkel et al. 1985; Akiba et al. 1986). Other indices of involuntary smoking exposure have not been as well studied and have not shown a consistent dose–response relationship with lung cancer risk. These exposure variables included total years of exposure to spouses' smoking, average daily hours of exposure

92

from all sources, and cumulative lifetime hours and years of exposure.

Among the studies that have found a dose–response relationship with amount smoked by a spouse, three have also examined the relationship by duration of spouse's smoking (Correa et al. 1983; Garfinkel et al. 1985; Akiba et al. 1986), but only one study showed similarly increased risk using a dose and duration variable (Correa et al. 1983). In the study by Garfinkel and coworkers (1985), only years of smoking by the current husband or cohabitant was asked; therefore, differences in the duration of living with current husband or cohabitant may account for the less consistent dose–response relationship. In their Japanese case–control study, Akiba and colleagues (1986) suggest that intensity (amount smoked per day and recency of exposure) may be the key index of ETS in studies of lung cancer risk.

Two studies have assessed total involuntary smoking exposure to ETS. The method used by Koo and coworkers (1984) relied on respondents to describe the exposures from each source separately, and a summary measure of exposure was derived by the investigators. The method used by Garfinkel and coworkers (1985) relied on the respondents to average their exposures from all sources for specific time periods. The method of Koo and coworkers (1984) may not have adequately considered intensity of exposure; therefore, an association may have been obscured by combining low and high intensity exposures as if they were equally important. In the study by Garfinkel and coworkers (1985), a high percentage of case interviews and, presumably, control interviews was conducted with surrogates. Although information provided by surrogates regarding demographic variables is generally valid, as are responses on cigarette smoking status (current, prior, never), more detailed information on the cigarette smoking of a deceased spouse has more limited validity (Lerchen and Samet 1986). Surrogate interviews may provide adequate information about tobacco smoke exposure at home, but may be inaccurate for describing gradients of total tobacco smoke exposure from all sources.

Expected Lung Cancer Risk

An extensive data base describes the relationship between active smoking and lung cancer (US DHEW 1979, US DHHS 1982; IARC 1986). This information has been utilized to construct mathematical models to describe the relationship of dose, duration, initiation, and cessation of active smoking for risk of lung cancer. For several reasons, comparable models have not yet been developed for involuntary smoking and lung cancer. First, research on involuntary smoking and lung cancer is recent. Second, involuntary smoking is not as readily quantified as active smoking; tobacco smoke is

ubiquitous in the environment and present in variable but generally low concentrations in comparison with MS, and inhaled dose varies with ventilation and other physiological factors (Hiller 1984; Hoegg 1972; Hoffmann et al. 1984; Schmeltz et al. 1975; Stöber 1984; US DHHS 1984).

Nevertheless, theoretical models, originally developed to describe the relationship of active smoking and lung cancer, have been used to predict lung cancer risk from involuntary smoking. Using Doll and Peto's (1978) model [(0.273×10^{-12}) (cigarette/day + 6)^2 (age 22.5)$^{4.5}$] for active smoking and lung cancer, Vutuc (1984) calculated expected lung cancer risks for various exposure levels, ranging from 0.1 to 5.0 cigarettes per day. For exposure levels of 0.1, 1.0, 2.0, and 5.0 cigarettes per day, the corresponding risk estimates were 1.03, 1.38, 1.78, and 3.36, respectively. These low-dose active smoking risk estimates are comparisons of active smokers with all nonsmokers (those with high ETS exposure and those with low ETS exposure). The risk estimates in involuntary smoking studies are a comparison of nonsmokers with higher levels of involuntary smoking exposure with nonsmokers who have lower levels of involuntary smoking exposure. As a result, the numerical values of the risk estimates in active smoking studies are not directly comparable to those in the involuntary smoking studies.

The appropriateness of extrapolating from the active smoking model hinges on the actual exposure of a nonsmoker. Estimates of exposure have been derived from various sources. Experimental conditions have been used to quantify the involuntary smoker's exposure to ETS. Hugod and colleagues (1978) reported that under conditions heavily polluted with sidestream smoke (to maintain a carbon monoxide concentration of 20 ppm), the particulates of tobacco smoke inhaled by involuntary smokers was small, the equivalent of one-half to one cigarette per day. Exposures may also be estimated from biochemical measurements. Studies comparing cotinine levels in nonsmokers and smokers show cotinine levels in nonsmokers that correspond to about one-sixth to one-third of a cigarette per day (Jarvis et al. 1984; Wald et al. 1984). Higher cotinine levels in nonsmokers, comparable to about two cigarettes per day, have been reported (Matsukura et al. 1984, 1985), but the results were questioned (Adlkofer et al. 1985; Pittenger 1985) and await confirmation.

The epidemiologic evidence on the lung cancer risk associated with marriage of a nonsmoker to a smoker has been criticized as implausible on the basis of predictions from Doll and Peto's model (Lee 1982a,b; Vutuc 1984). It has been argued that relative risks of 2 or 3 from involuntary smoking correspond to active smoking of two to five cigarettes per day and that this equivalent level of active smoking is too large to be realistic. This argument fails to consider

94

the difference in the comparison groups used to generate the risk estimates in studies of active smoking and involuntary smoking. The risk estimates for studies of active smoking use as a comparison group all nonsmokers, which includes those with and without high levels of exposure to ETS. Studies of involuntary smoking use risk estimates that are derived by comparing nonsmokers with higher levels of exposure to ETS with nonsmokers with lower levels of exposure to ETS. Because the risk estimates in active and involuntary smoking studies use different comparison groups, the numerical values are not directly comparable.

In order to make them comparable, the risk estimates in involuntary smoking and active smoking studies would have to be calculated using the same reference group. If the reference population used is all nonsmokers, then the risk estimates for nonsmokers married to nonsmokers are reduced to below 1 (i.e., their lung cancer risk would be lower than the risk for all nonsmokers as a group). The risk estimates for nonsmokers married to smokers would be above 1 (i.e., would be greater than the risk for all nonsmokers as a group), but the numerical value of the risk estimate would be reduced from th value obtained by comparison with nonexposed nonsmokers.

If the data from the Japanese cohort study (Hirayama 1981a) ar recalculated to use all nonsmokers as the reference population, the risk estimate for lung cancer in nonsmoking wives of nonsmoking husbands would be 0.63 and the risk estimate for nonsmoking women married to smokers (current or former) would be 1.12. The value of 1.12 compares the risk for nonsmoking wives of smoking husbands with the risk for all nonsmokers in the studies of active smoking. This magnitude of risk is within the range of risk that would be predicted using the Doll and Peto (1978) model for calculating active smoking risk for smokers of 0.1 (risk estimate 1.03) and 1 (risk estimate 1.38) cigarette per day. The evidence for exposure to environmental tobacco smoke based on biologic markers of tobacco smoke exposure indicate that involuntary smoking exposure results in levels of biologic markers (e.g., cotinine) that are similar to levels expected in smokers of 0.1 to 1 cigarette per day. Thus, estimates derived using similar comparison groups suggest that the lung cancer mortality experience due to involuntary smoking is similar to that which would have been expected from an extension of the dose–response data for active smoking to involuntary smoking exposures.

An alternative method of estimating expected lung cancer rates has been proposed by Repace and Lowrey (1985). They compared the age-standardized lung cancer mortality rates of Seventh-Day Adventists (SDAs) who had never smoked with a demographically comparable group of nonsmoking non-SDAs and attributed the difference in lung cancer deaths solely to involuntary smoking. This

analysis was based on the following assumptions: (1) that SDAs had no exposure to passive smoking, whereas all of the non-SDAs were exposed, (2) that men and women had equal lung cancer death rates, and (3) that there were no other differences between the two groups.

Summary

Previous Reports of the Surgeon General have reviewed the data establishing active cigarette smoking as the major cause of lung cancer. The absence of a threshold for respiratory carcinogenesis in active smoking, the presence of the same carcinogens in mainstream smoke and sidestream smoke, the demonstrated uptake of tobacco smoke constituents by involuntary smokers, and the demonstration of an increased lung cancer risk in some populations with exposures to ETS leads to the conclusion that involuntary smoking is a cause of lung cancer.

The quantification of the risk associated with involuntary smoking for the U.S. population is dependent on a number of factors for which only a limited amount of data are currently available. The first of these factors is the absolute magnitude of the lung cancer risk associated with involuntary smoking. As was previously described, the studies that have been performed to assess the lung cancer risk of involuntary smoking do not contain a zero-exposure group. Some exposure to tobacco smoke is essentially a universal experience; therefore, studies of involuntary smoking compare a low-exposure group with a high-exposure group. The magnitude of the risk estimate obtained is a function of the increase in risk produced by the difference in tobacco smoke exposure between the two groups examined, rather than an absolute measure of the risk of exposure in comparison with no exposure. The magnitude of the difference in tobacco smoke exposure between groups identified by spousal smoking habits may vary from study to study; this variation may partially explain the differences in risk estimates among the studies. The extrapolation of the risk estimate data to the U.S. population would therefore require a better understanding of the magnitude of the exposure to environmental tobacco smoke that occurs in the populations examined in the studies of involuntary smoking and lung cancer. Of particular interest is the magnitude of the difference in exposure between the high-exposure group and the low-exposure group.

A second set of data that would be needed to estimate the risk for the U.S. population is the dose and distribution of exposure to ETS in the population. The studies that have been performed have attempted to identify groups with different exposures, but little is known about the magnitude of the exposures that occur in different segments of the U.S. population or about the variability of exposure with time of day or season of the year. The changing norms about

smoking in public and the changing prevalence of active smoking during this century suggest that ETS exposure may have varied substantially over this century. A better understanding of the exposures that are actually occurring in the United States, and of past exposures, would be needed to accurately assess the risk for the U.S. population.

The epidemiological evidence that involuntary smoking can significantly increase the risk of lung cancer in nonsmokers is compelling when considered as an examination of low-dose exposure to a known carcinogen (i.e., tobacco smoke). Eleven of the thirteen epidemiological studies to date show a modest (10 to 300 percent) elevation of the risk of lung cancer among nonsmokers exposed to involuntary smoking; in six studies positive associations were statistically significant. The studies showing no or nonsignificantly positive findings were generally the weakest in terms of sample size (Gillis et al. 1984; Chan and Fung 1982; Koo et al. 1984; Kabat and Wynder 1984; Wu et al. 1985; Lee et al. 1986), study design (Kabat and Wynder 1984; Lee et al. 1986), or quality of data (Chan and Fung 1982).

In Table 10 are shown the sources and types of bias, and in Table 11, the statistical power, of the various case–control studies (Schlesselman 1982). On the basis of the observed relative risks reported in the studies, the respective exposure fraction in the control populations, and an $\alpha = 0.05$ for a two-sided significance test, only the studies by Trichopoulos and colleagues (1983) and Correa and colleagues (1983) have a probability of above 80 percent of finding a statistically significant result, whereas the majority of the case–control studies show a study power of about 0.10 to 0.20. The power of the study, as expected, improves when a one-sided significance test is considered. Among the studies in which information on involuntary smoking was available to conduct a trend test for dose, the power for detecting the observed trend was above 50 percent for five of the studies. However, the power for a two-sided test and a one-sided test, based on observed relative risk, and the power for a one-sided trend test, based on observed results, are difficult to interpret because the power is a function both of design aspects (sample size, case–control ratio, exposure prevalence) and of the observed relative risk. To focus on comparisons of the design differences between studies, the power estimates for a fixed relative risk of 2 show that five of the studies would have a power of 0.75 or greater to detect a statistically significant result. Thus, it is not surprising that some studies failed to achieve statistical significance, but the lack of statistical significance in all studies should not invalidate the positive significant associations for involuntary smoking that have been observed.

TABLE 10.—Sources and types of bias in case–control studies

Study	Author's conclusion	Misclassification of lung cancer	Misclassification of passive smoke exposure	Interviewer bias	Respondent bias
Trichopoulos et al. (1983)	Positive	+ ($\downarrow$)	+ ($\downarrow$)	+ ($\uparrow$)	—
Correa et al. (1983)	Positive	—	+ ($\downarrow$)	—	—
Chan and Fung (1982)	Negative	—	+ ($\downarrow$ or $\uparrow$)	?	?
Koo et al. (1984)	Negative	—	+ ($\downarrow$ or $\uparrow$)	?	?
Kabat and Wynder (1984)	Negative	—	+ ($\downarrow$ or $\uparrow$)	?	?
Wu et al. (1985)	Weak positive		—	+ ($\uparrow$)	—
Garfinkel et al. (1985)	Positive	—	+ ($\downarrow$ or $\uparrow$)	—	+ ($\downarrow$ or $\uparrow$)
Akiba et al. (1986)	Positive	+ ($\downarrow$)	+ ($\downarrow$)	?	+ ($\downarrow$ or $\uparrow$)
Pershagen et al. (in press)	Positive	—	+ ($\downarrow$ or $\uparrow$)	—	—

NOTE: Probability of misclassification: + = likely; — = not likely; ? = cannot be determined. Effect on observed risk: $\uparrow$ = overestimated risk as result of bias; $\downarrow$ = underestimated risk as result of bias.

Six epidemiological studies found statistically significant increased risks associated with spouse's smoking; all demonstrated a dose–response relationship, and several suggested a stronger association with squamous cell and small cell carcinoma than with other cell types. Three of these studies (Hirayama 1984a; Correa et al. 1983; Akiba et al. 1986) included nonsmoking male lung cancer patients, and the complementary findings in nonsmoking husbands married to smoking wives strengthen the evidence on involuntary smoking. The four studies with significant positive findings published since 1981 (Correa et al. 1983; Garfinkel et al. 1985; Akiba et al. 1986; Pershagen et al., in press) not only corroborated the findings of Hirayama (1981a) and Trichopoulos and colleagues (1981), but answered the many criticisms directed at these two studies.

98

TABLE 11.—Study power for case-control study based on an unmatched analysis

Study	Number of cases	Control: case ratio	Proportion of controls' spouses who smoked	Observed relative risk for ever vs. never exposed to spouses' smoking	Power for two-sided test based on observed RR	Power for one-sided test based on observed RR	Power for one-sided trend test based on observed results[1]	Power for one-sided test based on RR=2 for ever vs. never exposed
Trichopoulos et al. (1983)	77	2.92	0.52	2.11	0.79	0.87	0.88	0.88
Correa et al. (1983)	30	10.43	0.28	2.97	0.83	0.88	0.97	0.55
Chan and Fung (1982)	84	1.66	0.48	0.75	0.17	0.26	NA[2]	0.80
Koo et al. (1984)	88	1.56	0.71[3]	1.23	0.10	0.17	0.10	0.64
Kabat and Wynder[4] (1984)	36	1.03	0.54	0.85	0.05	0.10	NA[2]	0.39
Wu et al.[5] (1985)	28	1.96	0.60	1.41	0.10	0.17	0.16	0.37
Garfinkel et al. (1985)	134	3.00	0.61	1.23	0.24	0.36	0.71	0.94
Lee et al. (1986)	47	2.04	0.62	1.11	0.04	0.08	NA[2]	0.52
Akiba et al.[6] (1986)	84	2.96	0.67	1.47	0.26	0.38	0.53	0.75

TABLE 11.—Continued

Study	Number of cases	Control: case ratio	Proportion of controls' spouses who smoked	Observed relative risk for ever vs. never exposed to spouses' smoking	Power for two-sided test based on observed RR	Power for one-sided test based on observed RR	Power for one-sided trend test based on observed results[1]	Power for one-sided test based on RR=2 for ever vs. never exposed
Pershagen et al. (in press)	67	5.18	0.44	1.23	0.12	0.19	0.46[7]	0.83
Pooled[8]	676	2.96	0.52	1.53	0.99	1.00	NA	1.00
Pooled[9]	509	3.40	0.52	1.88	1.00	1.00	1.00	1.00

[1] Based on three levels of passive smoke exposure as defined in respective studies.

[2] Data not available for trend test.

[3] Includes spouses, cohabitants, and coworkers who smoked.

[4] Based on nonsmoking cases and controls with information on spouses' smoking.

[5] Based on cases and controls who were ever married.

[6] Based on female cases and controls with information on husbands' smoking (number of cigarettes smoked per day).

[7] Estimate based on 26 cases and 151 controls in the low exposure category, 7 cases and 12 controls in the high exposure category.

[8] Based on combined results of the 10 case-control studies.

[9] Based on combined results of the seven case-control studies with data available for trend test.

The most serious criticism is the misclassification of the active smoking status of the subjects, which can produce an apparent increased risk with involuntary smoking. Moreover, it is likely to result in differential misclassification because spouses tend to have similar smoking habits (Burch 1981; Sutton 1981; Higgins et al. 1967). Speculation that the positive results reported in Japan and Greece were due to cultural bias against the admission of smoking by women in these more traditional societies may be discounted because positive significant findings have now been observed in the United States (Correa et al. 1983; Garfinkel et al. 1985) and in Sweden (Pershagen et al., in press), where no comparable social stigma exists. Moreover, in the studies by Garfinkel and coworkers (1985) and Pershagen and coworkers (in press), the personal smoking status of each subject was validated and verified at interview, usually by next of kin, who presumably would have no reason to misrepresent the true smoking status of the subject.

Misclassification of the lung as the primary site and the lack of pathological confirmation are repeated concerns, but it must be stressed that this bias would tend to dilute a true effect. Correa (1983), Garfinkel (1985), and Pershagen (in press) and their respective colleagues addressed this issue by including only pathologically confirmed lung cancers and considering histological cell type in their analyses. In the study by Garfinkel and associates (1985), after an independent pathological review was conducted, a significant association of excess risk with involuntary smoking remained. Misclassification of exposure to ETS cannot be dismissed, since an index based solely on the smoking habits of a current spouse may not be indicative of past exposure, cumulative exposure, or the relevant dose to the respiratory tract.

The magnitude of risk associated with involuntary smoking exposure is uncertain. Relative risks ranging from 2 to 3 were generally reported for the highest level of exposure based on the spouses' smoking habits, but since sample sizes in most studies are not large, the point estimates of effect are unstable, and confidence limits are broad and generally overlap from one study to another. An index of involuntary smoking based on the smoking habits of the spouse is a simplistic and convenient measure. There is no reason to believe, however, that the excess risk associated with involuntary smoking is restricted to exposure from spouses. Nonsmokers married to smokers are likely to be more tolerant of ETS exposure and to experience more exposure to environmental tobacco smoke (Wald and Ritchie 1984). Higher risk estimates for involuntary smoking have been obtained in studies restricted to squamous cell and small cell carcinomas of the lung.

Although involuntary smoking can be established as a cause of lung cancer, important questions related to this exposure require

further research. More accurate estimates for the assessment of exposure in the home, workplace, and other environments are needed. Studies of sufficiently large populations should also be performed. New data from such studies should yield more certain risk estimates and describe the magnitude of the lung cancer risk in nonsmokers.

Other Cancers

Several recent studies provide data on the relationship of ETS exposure to cancer at sites other than the lung. Two published reports address the risk of other cancers in adults from exposure to tobacco smoke from spouses. Using the same Japanese cohort described previously, Hirayama (1984a) reported excess mortality for cancers of the paranasal sinus (N=28) and brain (N=34) among nonsmoking women who were married to smokers. The standardized mortality ratios (SMRs) for nasal sinus cancer were 1.00, 1.67, 2.02, and 2.55 for women whose husbands never smoked, or had smoked 10 to 14, 15 to 19, or 20 or more cigarettes per day, respectively (one-sided p for trend, 0.03). The corresponding SMRs for brain tumors were 1.00, 3.03, 6.25, and 4.32, respectively (one-sided p for trend, 0.004). The total number of deaths due to nasal cancer and brain tumors was small, and the numerators in the risk calculations were unstable, based on five nasal cancers and three brain cancers in women whose husbands were nonsmokers. In one study (Brinton et al. 1984), active tobacco smoking was associated with an increased risk of sinus cancer, particularly squamous cell tumors. Sidestream smoke has also been suggested to be of etiological importance in brain tumors in children (Preston-Martin et al. 1982).

In a case–control study of adult cancers in relation to childhood and adult exposure to involuntary smoking, Sandler and coworkers (1985a, 1986) reported an overall cancer risk of 1.6 (95 percent C.I. 1.2, 2.1) associated with exposure to spouses' smoking, which was more marked in nonsmokers than smokers. Significant increases were observed for cancer of the breast (OR 1.8), cervix (OR 1.8), and endocrine organs (OR 3.2). This study has been criticized in its choice of controls and in the exclusion of certain cancers by the design of the study. The biological plausibility of the study's findings was also questioned because the highest risk estimates were observed for cancers that have not been consistently related to active smoking and because higher risks were observed for nonsmokers than for smokers. Failure to control for potential confounding factors and known risk factors for the individual cancer sites under study may have produced artifactual results (Friedman 1986; Mantel 1986; Burch 1986). In a subsequent analysis of the same study population, Sandler, Wilcox, and Everson (1985a,b) reported increasing cancer

102

risks with increasing exposure to involuntary smoking as measured by the number of smokers in the household and by the time periods of exposure. The biologic plausibility of these findings was also questioned (Burch 1985; Higgins 1985; Lee 1985).

The effect of parental smoking on the development of cancers both during childhood and in adult life is also of interest. The relationship of parental smoking to overall cancer risk in children or in adults has been assessed in three studies. A prospective survey (Neutel and Buck 1971) of about 90,000 infants in Canada and the United Kingdom followed for a maximum of 10 years found an overall cancer risk of 1.3 (95 percent C.I. 0.8, 2.2) associated with maternal smoking during pregnancy. No dose–response relationship was observed, but there were few heavy smokers (>1 pack/day) in this study. A Swedish case–control study (Stjernfeldt et al. 1986) of all cancers found a risk of 1.4 (95 percent C.I. 1.0, 1.9) for maternal smoking during pregnancy. A dose–response relationship was demonstrated; the risk was highest in the most exposed group, those smoking 10 or more cigarettes per day (RR 1.6, $p < 0.01$). On the basis of the smoking habits of the parents of subjects up to 10 years of age, Sandler, Everson, Wilcox, and Browder (1985) reported no significant difference between all cancer cases and controls with respect to the mother's smoking (RR 1.1, 95 percent C.I. 0.7, 1.6), but the father's smoking was related to an overall increased risk (RR 1.5, 95 percent C.I. 1.1, 2.0). In these three studies, analysis by specific cancer site revealed an increased risk of leukemia associated with parental smoking.

Neutel and Buck (1971) found an almost twofold increased risk of leukemia in children of mothers who smoked during pregnancy, but the association was not statistically significant. Stjernfeldt and colleagues (1986) reported a significant positive association between maternal smoking and acute lymphoblastic leukemia. The relative risks were 1.0, 1.3, and 2.1 (p for trend, < 0.01) for mothers who smoked 0, 1 to 9, and 10 or more cigarettes per day, respectively. Similar significant positive associations with maternal smoking were not observed for other cancer sites, but the risk assessments were based on a small number of cases. This study suggests that the relationship between maternal smoking and leukemia was strongest for smoking during the 5-year period before pregnancy, intermediate for smoking during pregnancy, and lowest for smoking after pregnancy. In the study by Sandler, Everson, Wilcox, and Browder (1985), the mother's smoking and the father's smoking were separately and jointly associated with an increased risk for leukemia and lymphoma. The relative risk was 1.7 when one parent smoked and 4.6 when both parents smoked (p for trend, < 0.001). The increased risk with parental smoking was observed regardless of the personal smoking status of the subject. No other cancer site was associated

103

with the mother's smoking, although the father's smoking was associated with increased risks for other cancer sites, including the brain and the cervix. Two studies of leukemia in children found no relationship with parental smoking (Manning and Carroll 1957; Van Steensel-Moll et al. 1985). In the study by Manning and Carroll (1957), the mothers' general smoking habits were assessed, whereas Van Steensel-Moll and colleagues (1985) obtained information on the smoking habits of both parents in the year before the pregnancy. Stewart and colleagues (1958) reported a statistically significant risk of 1.1 (p=0.04) for leukemia in association with the mothers' smoking, but cautioned that the smoking information on the mothers pertained to their habits at the time of interview, which took place after the deaths of the patients and may have been affected by bereavement.

The effect of parental smoking habits has been examined in epidemiological studies of brain tumors, rhabdomyosarcoma, and testicular cancer in children. Gold and colleagues (1979) reported an association between maternal smoking prior to and during pregnancy and brain tumors in children. A relative risk of 5.0 (p=0.22) was found, but the result was based on a small number of patients and was not statistically significant. No relationship between maternal smoking during pregnancy (RR 1.1, one-sided p=0.42) and brain tumors in children was found in another study (Preston-Martin et al. 1982), but a significantly increased risk (RR 1.5, one-sided p=0.03) associated with mothers living with a smoker (usually the child's father) during pregnancy was observed. A significantly increased risk with the father's smoking, but not the mother's smoking was also reported in a study of rhabdomyosarcoma (Grufferman et al. 1982). The father's smoking conferred a significant increase in risk (RR 3.9, 95 percent C.I. 1.3, 9.6), but the mother's smoking during and after the pregnancy was not significantly different between cases and controls (RR 0.8, 95 percent C.I. 0.3, 2.0). A history of maternal smoking during pregnancy did not differ for testicular cancer cases and controls (RR 1.0, p=0.57) in one study (Henderson et al. 1979).

There are at present insufficient data to adequately evaluate the role of involuntary smoking in adult cancers other than primary carcinoma of the lung. In addition, active smokers necessarily receive greater exposure to ETS than nonsmokers. Thus, effects would not be anticipated in involuntary smokers that do not occur in active smokers (IARC 1986), and the biological plausibility of associations between ETS exposure and cancer of sites not associated with active smoking must be questioned. The findings of Hirayama (1984a) and Sandler, Everson, and Wilcox (1985) need confirmation in studies that take into account the potential confounding factors and the known risk factors for these individual sites. The evidence

104

for parental smoking and childhood cancer is also not clear, and evaluation of this association is made difficult by the various definitions of exposure that have been used, including maternal and paternal smoking before, during, and after the pregnancy. Mothers and fathers who smoke during a pregnancy generally smoked before the conception and continue to smoke after the pregnancy. Thus, an effect of involuntary smoking after birth cannot readily be distinguished from genetic or transplacentally mediated effects.

Cardiovascular Diseases

A causal association between active cigarette smoking and cardiovascular disease is well established (US DHHS 1983). The relationship between cardiovascular disease and involuntary smoking has been examined in one case–control study and three prospective studies. In the case–control study by Lee and colleagues (1986), described previously, ischemic heart disease cases and controls did not show a statistically significant difference in their exposure to involuntary smoking, based on the smoking habits of spouses or on an index accounting for exposure at home, at work, and during travel and leisure. In the Japanese cohort study, Hirayama (1984b, 1985) reported an elevated risk for ischemic heart disease (N=494) in nonsmoking women married to smokers. The standardized mortality ratios when the husbands were nonsmokers, ex-smokers or smokers of 19 or more cigarettes per day, and smokers of 20 or more cigarettes per day were 1.0, 1.10, and 1.31, respectively (one-sided p for trend, 0.019).

In the Scottish followup study (Gillis et al. 1984), nonsmokers not exposed to tobacco smoke were compared with nonsmokers exposed to tobacco smoke with respect to the prevalence of cardiovascular symptoms at entry and mortality due to coronary heart disease. There was no consistent pattern of differences in coronary heart disease or symptoms between nonsmoking men exposed to tobacco smoke and their nonexposed counterparts. Nonsmoking women exposed to tobacco smoke exhibited a higher prevalence of angina and major ECG abnormality at entry, and also a higher mortality rate for all coronary diseases. However, rates of myocardial infarction mortality were higher for exposed nonsmoking men and women compared with the nonexposed nonsmokers. The rates were 31 and 4 per 10,000, respectively, for the nonexposed nonsmoking men and women, and 45 and 12 per 10,000, respectively, for the exposed nonsmoking men and women. None of the differences were tested for statistical significance.

In the Japanese and the Scottish studies, other known risk factors for cardiovascular diseases, i.e., systolic blood pressure, plasma cholesterol, were not accounted for in the analysis.

105

In a study of heart disease, Garland and coworkers (1985) enrolled 82 percent of adults aged 50 to 79 between 1972 and 1974 in a predominantly white, upper-middle-class community in San Diego, California. Blood pressure and plasma cholesterol were measured at entry, and all participants responded to a standard interview that asked about smoking habits, history of heart disease, and other health-related variables. Excluding women who had a previous history of heart disease or stroke or who had ever smoked, 695 currently married nonsmoking women were classified by their husbands' self-reported smoking status at enrollment. After 10 years of followup, there were 19 deaths due to ischemic heart disease; the age-standardized mortality rates for nonsmoking wives whose husbands were nonsmokers, ex-smokers, and current smokers were 1.2, 3.6, and 2.7, respectively (one-sided p for trend, ≤ 0.10). After adjustment for age, systolic blood pressure, total plasma cholesterol, obesity index, and years of marriage, the relative risk for death due to ischemic heart disease for women married to current or former smokers at entry compared with women married to never smokers was 2.7 (one-sided p ≤ 0.10).

The study's findings are not convincing from the point of view of sample stability. The total number of deaths due to ischemic heart disease was small, and the denominator in the relative risk calculation is unstable, based on the deaths of two women whose husbands had never smoked. Moreover, it is well established that the risk of coronary heart disease is substantially lower among those who have stopped smoking (US DHHS 1983), although the amount of time required for this change after cessation of smoking is not clear (Kannel 1981). In this study, 15 of 19 deaths occurred in nonsmoking women married to husbands who had stopped smoking at entry, and the age-standardized rate for ischemic heart disease was highest in this group. The high proportion of deaths in nonsmoking women married to men who became ex-smokers implies that the excess resulted from a sustained effect of involuntary smoking. More detailed characterizations of exposure to ETS and specific types of cardiovascular disease associated with this exposure are needed before an effect of involuntary smoking on the etiology of cardiovascular disease can be established.

One study (Aronow 1978a,b) suggested that involuntary smoking aggravates angina pectoris. This study was criticized because the end point, angina, was based on subjective evaluation, and because other factors such as stress were not controlled for (Coodley 1978; Robinson 1978; Waite 1978; Wakehan 1978). More important, the validity of Aronow's work has been questioned (Budiansky 1983).

106

Conclusions

1. Involuntary smoking can cause lung cancer in nonsmokers.
2. Although a substantial number of the lung cancers that occur in nonsmokers can be attributed to involuntary smoking, more data on the dose and distribution of ETS exposure in the population are needed in order to accurately estimate the magnitude of risk in the U.S. population.
3. The children of parents who smoke have an increased frequency of hospitalization for bronchitis and pneumonia during the first year of life when compared with the children of nonsmokers.
4. The children of parents who smoke have an increased frequency of a variety of acute respiratory illnesses and infections, including chest illnesses before 2 years of age and physician-diagnosed bronchitis, tracheitis, and laryngitis, when compared with the children of nonsmokers.
5. Chronic cough and phlegm are more frequent in children whose parents smoke compared with children of nonsmokers. The implications of chronic respiratory symptoms for respiratory health as an adult are unknown and deserve further study.
6. The children of parents who smoke have small differences in tests of pulmonary function when compared with the children of nonsmokers. Although this decrement is insufficient to cause symptoms, the possibility that it may increase susceptibility to chronic obstructive pulmonary disease with exposure to other agents in adult life, e.g., active smoking or occupational exposures, needs investigation.
7. Healthy adults exposed to environmental tobacco smoke may have small changes on pulmonary function testing, but are unlikely to experience clinically significant deficits in pulmonary function as a result of exposure to environmental tobacco smoke alone.
8. A number of studies report that chronic middle ear effusions are more common in young children whose parents smoke than in children of nonsmoking parents.
9. Validated questionnaires are needed for the assessment of recent and remote exposure to environmental tobacco smoke in the home, workplace, and other environments.
10. The associations between cancers, other than cancer of the lung, and involuntary smoking require further investigation before a determination can be made about the relationship of involuntary smoking to these cancers.
11. Further studies on the relationship between involuntary smoking and cardiovascular disease are needed in order to

determine whether involuntary smoking increases the risk of cardiovascular disease.

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112

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114

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118

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CHAPTER 3

**ENVIRONMENTAL TOBACCO
SMOKE CHEMISTRY
AND
EXPOSURE OF NONSMOKERS**

CONTENTS

Introduction

The physicochemical nature of environmental tobacco smoke (ETS) is governed by the type and form of the tobacco product or products burned, by the prevailing environmental conditions, and by secondary reactions. Mainstream smoke (MS) is the complex mixture that exits from the mouthpiece of a burning cigarette, cigar, or pipe when a puff is inhaled by the smoker. Sidestream smoke (SS) is formed between puff-drawings and is freely emitted into the air surrounding a smoldering tobacco product. Sidestream smoke represents the major source for ETS. The exhaled portions of MS and the vapor phase components that diffuse through the wrapper into the surrounding air constitute minor contributors to ETS.

In the scientific literature, the terms "passive smoking," "involuntary smoking," and "inhalation of ETS" are frequently used interchangeably (US DHEW 1979; US DHHS 1982, 1984).

Laboratory Smoking

Data on the composition of MS and SS originate from laboratory studies. For such studies, cigarettes, cigars, or pipes are smoked by machines under standardized reproducible conditions. It is a major goal of these measurements to compare the yields of the specific components in the MS or SS or both of a variety of experimental or commercial tobacco products and to simulate, though not to reproduce, human smoking habits. The most widely used standard conditions for machine smoking cigarettes and little cigars (≤ 1.5 g) are one 35 mL puff of 2-second duration drawn once a minute to a butt length of 23 mm, or the length of the filter tip plus the overwrap plus 3 mm (Brunnemann et al. 1976). The annual reports of the U.S. Federal Trade Commission on the tar, nicotine, and carbon monoxide content of the smoke of U.S. commercial cigarettes are based on these laboratory smoking conditions. For cigars, the standard smoking conditions are a 20 mL puff of 1.5-second duration taken once every 40 seconds, and a butt length of 33 mm (International Committee for Cigar Smoke Study 1974). The most frequently used pipe-smoking conditions call for the bowl to be filled with 1 g of tobacco and a 50 mL puff of 1-second duration to be taken every 12 seconds (Miller 1964).

A number of devices for collecting sidestream smoke have been developed (Dube and Green 1982). The most widely used device is a collection apparatus made of glass and cooled by water circulating through an outer jacket. The air entering the chamber through a distributor has a flow rate of 25 mL per second (1.5 L/min) (Brunnemann and Hoffmann 1974). Under these conditions, the yields of mainstream smoke components from a cigarette approximate those obtained from the same cigarette when it is being smoked

125

in the open air. However, the velocity of the airstream through the chamber has considerable influence on the yields of individual compounds in SS (Klus and Kuhn 1982).

To collect the particulate phase of MS and SS, the smoke aerosols are passed through a glass fiber filter (a Cambridge filter with a diameter of 45 mm) that traps more than 99 percent of all particles with a diameter of at least 0.1 μm (Wartman et al. 1959). The portion of the smoke that passes through the glass fiber filter is arbitrarily designated as vapor phase, although it is realized that this separation does not fully reflect the actual physicochemical conditions prevailing in MS and SS. For the analysis of individual components or a group of components, specific trapping devices and methods have been developed (Dube and Green 1982).

Human Smoking

The standardized machine-smoking conditions used in the tobacco laboratory were set up to simulate the parameters of human smoking as practiced 30 years ago. The examination of current smoking practices suggests that machine-smoking conditions no longer reflect current practices. Human smoking patterns depend on a number of factors, one of which is the delivery of nicotine. Dosimetry of smoke constituents has shown that low nicotine delivery (<0.6 to 1.0 mg/cigarette) generally induces the smoker to draw larger puff volumes (up to 55 mL per puff), to puff more frequently (three to five times a minute), and to inhale more deeply (Herning et al. 1981). Furthermore, many smokers of cigarettes with perforated filter tips tend to obstruct the holes in these tips by pressing their lips around them; thus, they inhale more smoke than would be expected according to the machine-smoking data (Kozlowski et al. 1980). Smokers of cigarettes with a longitudinal air channel in the filter tip compress the tip in a similar manner so that the mainstream smoke delivery is increased over that measured with the laboratory methodology (Hoffmann et al. 1983).

These deviations from machine-smoking patterns cause a greater amount of tobacco to be consumed during MS generation. Consequently, the quantity of tobacco burned between puffs is diminished, and lower amounts of combustion products are released as SS. Because of the proximity to the burning tobacco product, the active smoker usually inhales more of the SS and ETS than a nonsmoker.

It is not known to what extent the different constituents of inhaled ETS aerosols can be retained in the respiratory tract of nonsmokers. Studies with MS have shown that more than 90 percent of the volatile, hydrophilic components are retained by the smoker (Dalhamn et al. 1968a) and that less than 50 percent of the volatile, hydrophobic MS components are retained by the smoker (Dalhamn et al. 1968b). On the basis of these data, it may be assumed that the

126

passive smoker retains a high percentage of the vapor phase components of ETS and significantly less of its hydrophobic volatiles.

Sidestream Smoke

Formation and Physicochemical Nature

When nonfilter cigarettes are being smoked under standardized conditions, approximately 45 percent of the tobacco column is consumed during the generation of MS (puff-drawing), whereas the remainder is burned between puffs and under conditions of a strongly reducing atmosphere. In addition, MS and SS is generated at distinctly higher temperatures than SS (Wynder and Hoffmann 1967). Thus, undiluted SS contains more tobacco-derived combustion products than does MS, and contains especially greater quantities of those combustion products that are formed by nitrosation or amination. Consequently, the composition of SS differs from that of MS.

The SS of a smoldering cigarette enters the surrounding atmosphere about 3 mm in front of the paper burn line, at about 350° C (Baker 1984). In Table 1, the MS and the SS from nonfilter cigarettes are compared. Under standardized conditions, the formation of the MS of a nonfilter cigarette (80 mm, 1,230 mg) is completed during 10 puffs, requires 20 seconds, and consumes 347 mg of tobacco. The formation of SS from the same cigarette during smoldering requires 550 seconds and consumes 411 mg of tobacco (Neurath and Horstmann 1963).

The pH of the MS of a blended U.S. cigarette ranges from 6.0 to 6.2 and the pH of SS, from 6.7 to 7.5. Above pH 6, the proportion of unprotonated nicotine in undiluted smoke rises; at pH 7.9, about 50 percent is unprotonated. Therefore, SS contains more free nicotine in the vapor phase than MS. The reported measurements of the pH of cigars were 6.5 to 8.5 for MS and 7.5 to 8.7 for SS; measurements for the pH of SS from pipes have not been published (Brunnemann and Hoffmann 1974).

Chemical Analysis

In order to establish reproducible chemical-analytical data, cigarette SS is generated in a special chamber. This assures that the cigarettes burn evenly during puff intervals when an airstream at a velocity of 25 mL per second is drawn through the chamber. At this flow rate in the chamber, MS generation is quantitatively similar to that measured without the SS chamber (Neurath and Ehmke 1964; Brunnemann and Hoffmann 1974; Dube and Green 1982). Throughout this chapter the data refer primarily to MS, SS, and ETS deriving from cigarettes and not from cigars or pipes, because

TABLE 1.—Comparison of mainstream smoke (MS) and sidestream smoke (SS) of a nonfilter cigarette: Some physicochemical data

Study	Parameters	MS	SS
Neurath and Horstmann (1963)	Duration of smoke production (sec)	20	550
	Tobacco burned (mg)	347	411
ynder and Hoffmann 967)	Peak temperature during formation (°C)	≈900	≈600
Brunnemann and Hoffmann (1974)	pH of total aerosol	6.0–6.2	6.7–7.5
Scassellati-Sforzolini and Savino (1968)	Number of particles per cigarette [1]	10.5×10^{12}	3.5×10^{12}
Carter and Hasegawa (1975); Hiller et al. (1982)	Particle sizes (nm) [1]	0.1–1.0	0.01–0.8
	Particle mean diameter (nm) [1]	0.4	0.32
Wynder and Hoffmann (1967); Keith and Derrick (1960); Baker (1984); Hoffmann, Brunnemann et al. (1984)	Smoke dilution (vol %) [2]		
	Carbon monoxide	3–5	2–3
	Carbon dioxide	8–11	4–6
	Oxygen	12–16	1.5–2
	Hydrogen	3–15	0.8–1.0

NOTE: Data obtained under standard laboratory smoking conditions of 1 puff per minute of 2-second duration and 35 mL volume.

[1] Fresh and undiluted mainstream smoke and sidestream smoke.

[2] Four mm distant from the burning cone (gas temperature, 350° C).

cigarette smoke is the major source of ETS in public places. Few data are available on the SS and ETS from cigars and pipes.

About 300 to 400 of the several thousand individual compounds identified in tobacco smoke have been quantitatively determined in both mainstream and sidestream smoke. A listing of selected agents in the MS of nonfilter cigarettes with their reported range of concentration and their relative ratio of distribution in SS compared with MS is presented in Table 2. Values greater than 1.0 reflect the greater release of a given compound into SS than into MS. The grouping of the compounds in Table 2 into vapor phase components and particulate phase constituents refers to the makeup of MS, but does not represent the physicochemical distribution of these compounds in SS. Some of the volatile compounds in MS and SS are compared. On the basis of the amount of tobacco burned in the MS and SS of a nonfilter cigarette (see Table 1), the ratio of SS to MS should be 1.2 to 1.5 if the combustion conditions during both phases of smoke generation were comparable. However, this is not the case,

128

as is indicated by the higher SS to MS ratios for carbon monoxide (2.5–4.7), carbon dioxide (8–11), acrolein (8–15), benzene (10), and other smoke constituents.

The high yield of carbon monoxide and carbon dioxide in SS indicates that more carbon monoxide is generated during smoldering than during puff-drawing. After passing very briefly through the hot cone, most of the carbon monoxide gas in both MS and SS is oxidized to carbon dioxide, most likely owing to the high temperature gradient and the sudden exposure to environmental oxygen upon emission.

The higher yields of volatile pyridines in SS compared with MS are probably caused by the preferred formation of these compounds from the alkaloids during smoldering (Schmeltz et al. 1979). In contrast, hydrogen cyanide (HCN) is primarily formed from protein at temperatures above 700° C (Johnson and Kang 1971), and the smoldering of tobacco at about 600° C does not yield the pyrosynthesis of HCN to the extent that it occurs at the higher temperatures present during MS generation. The very high levels of ammonia, nitrogen oxide, and the volatile N-nitrosamines in SS compared with the levels in MS is striking. Studies with ^{15}N-nitrate have underscored that the burning of tobacco results in the reduction of nitrate to ammonia, and that the latter is released to a greater extent during SS formation than during puff-drawing (Johnson et al. 1973). In a blended cigarette, this higher level of ammonia in SS causes its elevated pH to reach levels of 6.7 to 7.5, while the pH of MS is about 6 (Brunnemann and Hoffmann 1974).

The increased release of the highly carcinogenic volatile N-nitrosamines into SS (20 to 100 times greater than into MS) has been well established (Brunnemann et al. 1977). The carcinogenic potential of SS may also be affected by the levels of the oxides of nitrogen (NO_x). Four to ten times more nitrogen oxide (NO) is released into the environment in sidestream smoke than is inhaled with the mainstream smoke. The smoker inhales more than 95 percent of the NO_x in the form of NO, and only a small portion is oxidized to the powerful nitrosating agent nitrogen dioxide (NO_2). Only a fraction of NO is expected to be retained in the respiratory system of smokers by being bound to hemoglobin. The NO_x gases released into the environment are partially oxidized to NO_2 (Vilcins and Lephardt 1975). Therefore, sidestream smoke-polluted environments are expected to contain the hydrophilic nitrosating agent NO_2.

Data for particulate matter and some of its constituents in MS and SS are also listed in Table 2. The release of tobacco-specific N-nitrosamines into SS is up to four times higher than that into MS. Whether the distribution of these agents in the vapor phase and the particulate phase of SS is of major consequence with respect to the carcinogenic potential of SS needs to be determined. It is equally

129

TABLE 2.—Distribution of constituents in mainstream smoke (MS) and the ratio of sidestream smoke (SS) to MS of nonfilter cigarettes

Vapor phase constituents[1]	MS range	SS/MS ratio	Particulate phase constituents[1]	MS range	SS/MS ratio
Carbon monoxide	10–23 mg	2.5–4.7	Particulate matter[2]	15–40 mg	1.3–1.9
Carbon dioxide	20–40 mg	8–11	Nicotine	1–2.5 mg	2.6–3.3
Carbonyl sulfide	18–42 µg	0.03–0.13	Anatabine	2–20 µg	<0.1–0.5
Benzene[1]	12–48 µg	10	Phenol	60–140 µg	1.6–3.0
Toluene	160 µg	6	Catechol	100–360 µg	0.6–0.9
Formaldehyde	70–100 µg	0.1–≈50	Hydroquinone	110–300 µg	0.7–0.9
Acrolein	60–100 µg	8–15	Aniline	360 ng	30
Acetone	100–250 µg	2–5	2-Toluidine	160 ng	19
Pyridine	16–40 µg	6.5–20	2-Naphthylamine[2]	1.7 ng	30
3-Methylpyridine	12–36 µg	3–13	4-Aminobiphenyl[2]	4.6 ng	31
3-Vinylpyridine	11–30 µg	20–40	Benz[a]anthracene[4]	20–70 ng	2–4
Hydrogen cyanide	400–500 µg	0.1–0.25	Benzo[a]pyrene[3]	20–40 ng	2.5–3.5
Hydrazine[3]	32 ng	3	Cholesterol	22 µg	0.9
Ammonia	50–130 µg	40–170	γ-Butyrolactone[4]	10–22 µg	3.6–5.0
Methylamine	11.5–28.7 µg	4.2–6.4	Quinoline [5]	0.5–2 µg	8–11
Dimethylamine	7.8–10 µg	3.7–5.1	Harman	1.7–3.1 µg	0.7–1.7
Nitrogen oxide	100–600 µg	4–10	N'-Nitrosonornicotine[4]	200–3,000 ng	0.5–3

TABLE 2.—Continued

Vapor phase constituents [1]	MS range	SS/MS ratio	Particulate phase constituents [1]	MS range	SS/MS ratio
N-Nitrosodimethylamine [4]	10–40 ng	20–100	NNK [4]	100–1,000 ng	1–4
N-Nitrosopyrrolidine [4]	6–30 ng	6–30	N-Nitrosodienthanolamine [4]	20–70 ng	1.2
Formic acid	210–490 µg	1.4–1.6	Cadmium	100 ng	7.2
Acetic acid	330–810 µg	1.9–3.6	Nickel [3]	20–80 ng	13–30
			Zinc	60 ng	6.7
			Polonium-210 [2]	0.04–0.1 pCi	1.0–4.0
			Benzoic acid	14–28 µg	0.67–0.95
			Lactic acid	63–174 µg	0.5–0.7
			Glycolic acid	37–126 µg	0.6–0.95
			Succinic acid	110–140 µg	0.43–0.62

[1] Values are given for fresh and undiluted MS and SS.

[2] Human carcinogen (IARC 1986).

[3] Suspected human carcinogen (IARC 1986).

[4] Animal carcinogen (IARC 1986).

SOURCE: Elliott and Rowe (1975); Hoffmann et al. (1983); Klus and Kuhn (1982); Sakuma et al. (1983); Sakuma, Kusama, Yamaguchi, Matsuki et al. (1984); Sakuma, Kusama, Yamaguchi, Sugawara (1984); Schmeltz et al. (1975).

important to examine the significance of the abundant release of amines into SS (levels are up to 30 times higher than in MS), indicated by the data for aniline, 2-toluidine, and the alkaloids. This is of concern because certain amines are readily nitrosated to N-nitrosamines. However, analytical data on secondary reactions of amines in polluted environments are lacking.

For a meaningful interpretation of the data on the distribution of the compounds in cigarette smoke presented in Table 2, certain aspects of the methodology should be emphasized. First, the data are based on analyses of nonfilter cigarettes that were smoked under standardized laboratory conditions. Second, the standardized machine-smoking conditions were established according to human smoking patterns observed three decades ago and do not reflect the smoking behavior of contemporary smokers. This caveat applies particularly to smoking patterns observed with filter cigarettes designed for low smoke yields. Most consumers of these cigarettes inhale the smoke more intensely than smokers of nonfilter cigarettes (Herning et al. 1981; Hill et al. 1983). This change in smoking intensity affects the delivery of the sidestream smoke. The conventional filter tips of cigarettes influence primarily the yield of MS and have little impact on SS yield. However, in the case of cigarettes with specially designed filter tips such as perforations, the yield of SS is also affected (Table 3) (Adams et al. 1985).

Radioactivity of Tobacco Smoke

Naturally occurring decay products of radon are found in tobacco and, therefore, also in tobacco smoke. These include the isotopes of lead (Pb-210), bismuth (Bi-210), polonium (Po-210), and radon, which originates from the decay of uranium through radium (Radford and Hunt 1964; Martell 1975). Radon and its short-lived daughters (Po-218, Pb-214, Bi-214, Po-214), which precede long-lived daughters in the decay chain, are ubiquitous in indoor air and are largely derived from sources other than tobacco smoke. Most of the radon daughters are attached to particles in the air, but a small proportion, referred to as the unattached fraction, is not (Raabe 1969; Kruger and Nöthling 1979; Bergman and Axelson 1983).

It has been suggested that the presence of Pb-210 and subsequent decay products in tobacco is dependent upon an absorption of short-lived radon daughters on the leaves of the tobacco plant, especially where phosphate fertilizers that are rich in radium have been used and have caused increased leakage of radon from the ground. These attached short-lived radon daughters then decay to long-lived Pb-210 and subsequent nuclides found in the tobacco (Fleischer and Parungo 1974; Martell 1975). However, the origin of these decay products may

132

TABLE 3.—Distribution of selected components in the sidestream smoke (SS) and the ratio of SS to mainstream smoke (MS) of four U.S. commercial cigarettes

Components	Cigarette A 85 mm NF		Cigarette B 85 mm F		Cigarette C 85 mm F		Cigarette D 85 mm PF	
	SS	SS/MS	SS	SS/MS	SS	SS/MS	SS	SS/MS
Tar (mg/g)	22.6	1.1	24.4	1.6	20.0	2.9	14.1	15.6
Nicotine (mg/g)	4.6	2.2	4.0	2.7	3.4	4.2	3.0	20.0
Carbon monoxide (mg/g)	28.3	2.1	36.6	2.7	33.2	3.5	26.8	14.9
Ammonia (mg/g)	524	7.0	893	46	213.1	6.3	236	5.8
Catechol (μg/g)	58.2	1.4	89.8	1.3	69.5	2.6	117	12.9
Benzo[a]pyrene (ng/g)	67	2.6	45.7	2.6	51.7	4.2	448	20.4
N-Nitrosodimethyamine (ng/g)	735	23.6	597	139	611	50.4	685	167
N-Nitrosopyrrolidine (ng/g)	177	2.7	139	13.6	233	7.1	234	17.7
N-Nitrosonornicotine (ng/g)	857	0.85	307	0.63	185	0.68	338	5.1

NOTE: NF, nonfilter cigarette; F, filter cigarette; PF, cigarette with perforated filter tip; values given are for fresh and undiluted sidestream and mainstream smoke.

SOURCE: Adams et al. (1985).

also depend on the general occurrence of radon in the atmosphere and not on the local emanation of radon (Hill 1982).

In recent years, it has been shown that relatively high levels of radon and short-lived radon daughters may occur in indoor air, and consistent observations in this regard have been made in several countries (Nero et al. 1985). In the air with a very low concentration of particles, the proportion of unattached radon daughters is increased beyond that found with a higher concentration of particles. The unattached daughters are removed more rapidly than those that are attached by plating out on walls and fixtures. The addition of an aerosol, such as tobacco smoke, increases the attached fraction, elevates the concentration of radon daughters, and reduces the rate of removal of radon daughters (Bergman and Axelson 1983). The dose of α radiation received by the airway epithelium depends not only on the concentration of radon daughters but also on the unattached fraction and on the size distribution of the inhaled particles. The interplay among these factors as they are modified by ETS has not yet been fully examined.

Environmental Tobacco Smoke

The air dilution of sidestream smoke, and of other contributors to ETS, causes several physicochemical changes in the aerosol. The concentration of particles in ETS depends on the degree of air dilution and may range from 300 to 500 mg/m^3 to a few μg/m^3. At the same time, the median diameter of particles may decrease as undiluted SS is diluted to form ETS (Keith and Derrick 1960; Wynder and Hoffmann 1967; Ingebrethsen and Sears 1986). Further-more, nicotine volatilizes during air dilution of SS, so that in ETS it occurs almost exclusively in the vapor phase (Eudy et al. 1985). This is reflected in the fairly rapid occurrence of relatively high concentrations of nicotine in the saliva of people entering a smoke-polluted room (Hoffmann, Haley et al. 1984). Most likely there are also redistributions between the vapor phase and the particulate phase of other constituents in SS due to air dilution, which may account for the presence of other semivolatiles in the vapor phase of ETS. However, evidence of such effects needs to be established.

Comparison of Toxic and Carcinogenic Agents in Mainstream Smoke and in Environmental Tobacco Smoke

The combustion products of cigarettes are the source of both environmental tobacco smoke and mainstream smoke. Therefore, comparisons of the levels of specific toxins and carcinogens in ETS with the corresponding levels in the mainstream smoke are relevant to an estimation of the risk of ETS exposure. Although ETS is a far

134

less concentrated aerosol than undiluted MS, both inhalants contain the same volatile and nonvolatile toxic agents and carcinogens. This fact and the current knowledge about the quantitative relationships between dose and effect that are commonly observed from exposure to carcinogens have led to the conclusion that the inhalation of ETS gives rise to some risk of cancer (IARC 1986).

However, comparisons of MS and ETS should include the consideration of the differences between the two aerosols with regard to their chemical composition, including pH levels, and their physicochemical nature (particle size, air dilution factors, and distribution of agents between vapor phase and particulate phase). Another important consideration pertains to the differences between inhaling ambient air and inhaling a concentrated smoke aerosol during puff-drawing. Finally, chemical and physicochemical data established by the analysis of smoke generated by machine-smoking are certainly not fully comparable to the levels and characteristics of compounds generated when a smoker inhales cigarette smoke. This caveat applies particularly to the smoking of low-yield cigarettes, for which the yields of smoke constituents in machine-generated smoking and human smoking activities may be most divergent (Herning et al. 1981).

The levels of certain smoke constituents in the mainstream smoke of one cigarette compared with the amounts of such compounds inhaled as constituents of ETS in 1 hour at a respiratory rate of 10 L per minute are presented in Table 4. Unaged MS does not contain nitrogen dioxide ($NO_2 < 5$ μg/cigarette) because the nitrogen oxides generated during tobacco combustion in the reducing atmosphere of the burning cone are transported in the smoke stream (≈ 10 vol % O_2) to the exit of the cigarette mouthpiece in less than 0.2 seconds, and it takes 500 seconds for half of the nitrogen oxide in MS to oxidize to nitrogen dioxide (Neurath 1972). The relatively low values for nicotine reported in ETS may be explained, in part, by the inefficiency of the trapping devices for collecting all of the available nicotine; the alkaloid is predominantly in the vapor phase, which escapes retention by the filters of such devices.

The assignment of benzene as a "human carcinogen," benzo[a]pyrene as a "suspected human carcinogen," and N-nitrosodimethylamine and N-nitrosodiethylamine as "animal carcinogens" is based on definitions by the International Agency for Research on Cancer (1986). Accordingly, a human carcinogen is an agent for which "sufficient evidence of carcinogenicity indicates that there is a causal relationship between exposure and human cancer." A suspected human carcinogen is an agent for which "limited evidence of carcinogenicity indicates that a causal interpretation is credible, but that alternate explanations, such as chance, bias, or confounding, could not adequately be excluded." An animal carcinogen is an agent

TABLE 4.—Concentrations of toxic and carcinogenic agents in nonfilter cigarette mainstream smoke and in environmental tobacco smoke (ETS) in indoor environments

Agent	Mainstream Smoke		Inhaled as ETS constituents during 1 hour			
			Range		Episodic high values[1]	
	Weight	Concentration	Weight	Concentration	Weight	Concentration
Carbon monoxide	10–23 mg	24,9000–57,300 ppm	1.2–22 mg	1–18.5 ppm	37 mg	32 ppm
Nitrogen oxide	100–600 µg	230,000–1,400,000 ppb	7–90 µg	9–120 ppb	146 µg	195 ppb
Nitrogen dioxide	<5 µg	<7,600 ppb	24–87 µg	21–76 ppb	120 µg	105 ppb
Acrolein	60–100 µg	75,000–125,000 ppb	8–72 µg	6–50 ppb	110 µg	80 ppb
Acetone	100–250 µg	120,000–300,000 ppb	210–720 µg	150–500 ppb	3,500 µg	2,400 ppb
Benzene[2]	12–48 µg	11,000–43,000 ppb	12–190 µg	6–98 ppb	190 µg	98 ppb
N-Nitrosodimethylamine[3]	10–40 ng	9–38 ppb	6–140 ng	0.003–0.072 ppb	140 ng	0.072 ppb
N-Nitrosodiethylamine[3]	4–25 ng	3–17 ppb	<6–120 ng	<0.002–0.05 ppb	120 ng	0.05 ppb
Nicotine	1,000–2,500 µg	430,000–1,080,000 ppb	0.6–30 µg	0.15–7.5 ppb	300 µg	75 ppb
Benzo[a]pyrene[4]	20–40 ng	5–11 ppb	1.7–460 ng	0.0002–0.04 ppb	460 ng	0.04 ppb

NOTE: Values for inhaled mainstream smoke components were calculated from values in Table 2 and on a respiratory rate of 10 L per minute. Values for carbon monoxide and nicotine represent the range in mainstream smoke of U.S. nonfilter cigarettes as reported by the U.S. Federal Trade Commission (1985). Data under ETS are derived from Tables 8 through 15, with data from the unventilated interior compartments of automobiles excluded (Badre et al. 1978).

[1] The designation "episodic high values" was chosen to classify those data in the literature that require confirmation.
[2] Human carcinogen according to the IARC (Vainio et al. 1985) and suspected carcinogen according to the ACGIH (1985).
[3] Animal carcinogen according to the IARC (Vainio et al. 1985).
[4] Suspected human carcinogen, according to the IARC (Vainio et al. 1985) and according to the ACGIH (1985).

"for which there is sufficient evidence of carcinogenicity in animals but for which no data on humans are available."

Polonium-210 is not listed in Table 4 because there are no data on the concentration of this isotope in ETS, although it is a component of both MS and SS. Whereas in clean air the short-lived radon daughters tend to plate out on room surfaces, in the presence of an aerosol such as ETS, some of the short-lived radon daughters become attached to particles and consequently remain available for inhalation. Radon daughter background concentration may more than double in the presence of ETS (Bergman and Axelson 1983).

Number and Size Distribution of Particles in Environmental Tobacco Smoke

Environmental tobacco smoke consists of the combined products of both fresh and aged sidestream smoke and exhaled mainstream smoke. Coagulation, evaporation, and particle removal on surfaces occur simultaneously to modify the physical characteristics of the ETS particles; as a result, the "typical" particle size and chemical composition of ETS may vary with the age of the smoke and the characteristics of the environment. Other factors such as relative humidity, particle concentration, and temperature may also affect the characteristics of ETS.

The rapid dilution of SS smoke as it is emitted into a room leads to a number of physical and chemical changes. For example, the evaporation of volatile species as the ETS ages reduces the median diameter of the smoke particles. Several studies have measured the particle distribution of SS under controlled conditions (Table 5), and indicate that the mass median diameter (MMD) of ETS is between approximately 0.2 μm and 0.4 μm. The differences among the studies reflect the varying analytical methods. ETS particles are in the diffusion-controlled regime for particle removal and therefore will tend to follow stream lines, remain airborne for long periods of time, and rapidly disperse through open volumes.

As indicated, a number of factors can produce variation in the mean size of the particles in ETS; however, in considering transport, deposition, and removal in the human lung, it is useful to assume that the particle sizes of aged ETS will generally be between 0.1 and 0.4 μm. Although the results presented in Table 5 do not permit the assignment of a single value for the diameter of sidestream smoke particles, the difference in deposition efficiency in the human respiratory tract of 0.2 μm particles and 0.4 μm particles is negligible (Chan and Lippmann 1980). Particles in this size range are not efficiently removed by sedimentation or impaction. Although diffusion is the major removal mechanism for particles of this size, it is minimally efficient in the 0.2 to 0.4 μm range. The relatively low

137

TABLE 5.—Summary of sidestream smoke size distribution studies

Study	Cigarette	Method	Chamber concentration ($\mu g/m^3$)	Count median diameter	Mass median diameter	Geometric standard deviation	Number per cm³
Keith and Derrick (1960)	Blended	"Conifuge"	Not reported	0.15	Not reported	Not reported	3.8×10^{11}
Porstendörfer and Schraub (1972)	Not reported	CNC/diffusion tube	Not reported	0.24	Not reported	Not reported	3.3×10^{12}
Hiller et al. (1982)	Not reported	SPART analyzer	50–100	0.32	0.41	1.5	Not reported
Leaderer et al. (1984)	Commercial	EAA	700	Not reported	0.225	2.1	Not reported
Ingebrethsen and Sears (1986)		MC/CNC			0.2	1.5	

NOTE: CNC = Condensation nucleus counter; SPART = Single particle aerodynamic relaxation time analyzer; EAA = Electrical aerosol analyzer; MC = Mobility classifier.

particle deposition efficiency for SS particles in human volunteers observed by Hiller and colleagues (1982) is consistent with particles in this size range.

Several investigators have measured the size distribution of MS smoke (Table 6). As is the case with SS smoke, the different instruments and methodologies employed yielded differing results.

For purposes of comparison, only two sets of studies utilizing similar instruments are discussed. McCusker and colleagues (1983), using a single particle aerodynamic relaxation time (SPART) analyzer to study highly diluted MS smoke particles, found a mass median diameter of 0.42 μm with a geometric standard deviation (GSD) of 1.38. Hiller and colleagues (1982) used the SPART analyzer on SS smoke particles and found a mass median diameter of 0.41 μm and GSD of 1.5. Chang and colleagues (1985) used an electrical aerosol analyzer (EAA) to measure MS for various dilution ratios and reported a MMD of 0.27 μm (GSD 1.26) for the highest dilution. Leaderer and colleagues (1984) used an EAA to determine the size distribution for SS smoke particles in an environmental chamber and determined an MMD of 0.23 μm (GSD 2.08). These results also show that studies utilizing similar instruments provide similar results for the size distribution of both SS and MS particles. As discussed in an earlier section, however, the chemical composition of the MS and ETS particles can be quite different because of the very different conditions of their generation and the subsequent dilution and aging ETS undergoes before inhalation.

Estimating Human Exposure to Environmental Tobacco Smoke

Human exposure to ETS can be estimated using approaches similar to those used for other airborne pollutants. The concentration of ETS to which an individual is exposed depends on factors such as the type and number of cigarettes burned, the volume of the room, the ventilation rate, and the proximity to the source. These factors, along with the duration of exposure and individual characteristics such as ventilatory rate and breathing pattern, dictate the dosage received by an individual.

Ideally, the health effects of exposures to ETS might be assessed by quantifying the time-dependent exposure dose for each of the several thousand compounds in cigarette smoke and defining the dose–response relationships for these compounds in producing disease, both as isolated compounds and in various combinations. The magnitude of this task, given the number of compounds in smoke, and the limited knowledge of the precise mechanisms by which these compounds cause disease have led to a simpler approach, one that attempts to use measures of exposure to individual smoke constituents as estimates of whole smoke exposure. The accuracy with which

TABLE 6.—Summary of mainstream smoke size distribution studies

Study	Cigarette	Method	Dilution ratio	Count median diameter (μm)	Mass median diameter (μm)	Geometric standard deviation	Concentration (number/cm³)
Keith and Derrick (1960)	Blended	"Conifuge"	295	0.23	Not reported	1.6	5.3×10^9
Porstendörfer and Schraub (1972)	Not reported	CNC/diffusion tube	Not reported	0.22	Not reported	Not reported	Not reported
Okada and Matsunama (1974)	Blended	Light scattering	1500	0.18	0.29	1.5	3×10^{10}
Hinds (1978)	Commercial	Cascade impactor	10	Not reported	0.52	1.35	Not reported
		Cascade impactor	50	Not reported	0.44	1.44	Not reported
		Cascade impactor	100	Not reported	0.39	1.43	Not reported
		Aerosol certifuge	100	Not reported	0.38	1.33	Not reported
		Aerosol certifuge	320	Not reported	0.38	1.37	Not reported
		Aerosol certifuge	500	Not reported	0.38	1.35	Not reported
		Aerosol certifuge	700	Not reported	0.37	1.31	Not reported
McCusker et al. (1983)	2R1	SPART analyzer	1.26×10^5	0.36	0.42	1.38	4.2×10^9
Chang et al. (1985)	2R1	EAA	6	0.25	0.30	1.27	4.2×10^9
			10	0.24	0.26	1.18	3.6×10^9
			18	0.22	0.26	1.26	7×10^8

NOTE: CNC = Condensation nucleus counter; SPART = Single particle aerodynamic relaxation time analyzer; EAA = Electrical aerosol analyzer.

measurements of a single compound reflect exposure to whole smoke is limited by the changes in the composition of ETS with time and the conditions of exposure. For this reason, exposures to ETS are often assessed using several measures as markers, including markers of the vapor phase and the particulate phase as well as reactive and nonreactive constituents. Although biological markers show promise as measures of exposure because they measure the absorption of smoke constituents, they too have limitations (discussed in Chapter 4). An individual's exposure is a dynamic integration of the concentration in various environments and the time that the individual spends in those environments.

In specifying an individual's exposure to specific components of ETS, consideration must be given to the time scale of exposure appropriate for the response of interest. Immediate exposures of seconds or hours would be most relevant for irritant and acute allergic responses. Time-averaged exposures, of hours or days, may be important for acute contemporary effects such as upper and lower respiratory tract symptoms or infections; chronic exposures occur ring over a year or a lifetime might be associated with increased prevalence of chronic diseases and risk of cancer.

The spatial dimensions or the proximity of the individual to the source of smoke is important in assessing that individual's exposure to ETS. ETS is a complex, dynamic system that changes rapidly once emitted from a cigarette. Physical processes such as evaporation and dilution of the particles, scavenging of vapors on surfaces, and chemical reactions of reactive compounds are continuously occurring and modify the mixture referred to as ETS. An individual located a few centimeters or a meter from a burning cigarette may be exposed to a high concentration of ETS, ranging from 200 to 300 mg/m^3, and may inhale components of the mostly undiluted smoke plume and of the exhaled mainstream smoke. Ayer and Yeager (1982) reported cigarette plume concentrations of formaldehyde and acrolein in the core smoke stream emitted from the cigarette of up to 100 times higher than known irritation levels. Hirayama, as reported by Lehnert (1984), cites the importance of this "proximity effect" in assessing exposure. Distances on the order of a meter to tens of meters from a burning cigarette are relevant for exposures in offices, restaurants, a room in a house, a car, or the cabin of a commercial aircraft. At these distances, the mixing of ETS throughout the airspace and the factors that affect concentration are of importance in determining exposure for people in the space. In many rooms, mixing is not completely uniform throughout the volume, and significant concentration gradients can be demonstrated (Ishizu 1980). These concentration gradients will affect an individual's exposure by modifying the effectiveness of ventilation in diluting or removing pollutants. The airborne mass concentration may vary by

141

a factor of 10 or more within a room. Short-term measurements in rooms with smokers can yield respirable particulate concentrations of 100 to 1,000 $\mu g/m^3$ (Repace and Lowrey 1980). Multihour measurements average out variations in smoking, mixing, and ventilation and yield concentrations in the range of 20 to 200 $\mu g/m^3$ (Spengler et al. 1981, 1985, 1986). Finally, on a systems scale, as in a house or building, concentrations are influenced by dispersion and dilution through the volume. Most time-integrated samples are taken on this larger scale.

Using a piezobalance, Lebret (1985) found significant variation in respirable suspended particulate (RSP) levels between the living room, kitchen, and bedroom in homes in the Netherlands during smoking or within one-half hour of smoking. Ju and Spengler (1981) studied the room-to-room variation in 24-hour average concentrations of respirable particles in various residences. Although differences between some rooms were statistically significant, absolute differences were relatively small, with a maximum difference of a factor of 2.

Moschandreas and colleagues (1978) released sulfur hexafluoride, a tracer gas, in the living rooms of several residences and observed uniform concentrations in adjacent rooms within 30 to 90 minutes. RSP, which is slightly reactive, and nonreactive gases would be expected to rapidly migrate through adjacent rooms. Therefore, in a setting such as the work environment, where the duration of exposure is several hours or more, ETS would be expected to disseminate throughout the airspace in which smoking is occurring. Smoke dissemination may be reduced when air exchange rates are low, as may occur when internal doors are closed.

Time-Activity Patterns

Individual time-activity patterns are a major determinant of exposure to ETS. The population of the United States is mobile, spending variable amounts of time in different microenvironments. Individual activity patterns depend on age, occupation, season, social class, and sex. For example, Letz and colleagues (1984) surveyed the time-activity patterns of 332 residents of Roane County, Tennessee, and found that 75 percent of the person-hours were spent at home, 10.8 percent at work, 8.5 percent in public places, 2.9 percent in travel, and 2.8 percent in various other places. As expected, occupation and age were strong determinants of time-activity patterns. Housewives and unemployed or retired individuals spent 84.9 percent of their time at home, and occupational groups worked 21 to 24 percent of the hours. Students tended to spend the largest percentage of their time in public places, presumably schools, ranging from 14.7 percent for the youngest group to 19.17 percent for the oldest group of students.

142

TABLE 7.—Mean percent and standard deviation of time allocation in various locations by work or school classification subgroup

Location	Homemaker	Student	Outdoor worker	Office/ Service	Industrial/ Construction	Total, all participants
Home	84.34	60.91	49.97	68.74	57.28	64.21
	(2.02)[1]	(13.92)	(12.24)	(8.72)	(7.05)	(13.99)
Outside	5.52	8.62	19.81	2.47	10.59	8.08
	(3.27)	(5.53)	(8.55)	(2.49)	(10.74)	(7.07)
Motor vehicle	4.28	5.11	8.67	4.69	7.64	5.51
	(3.19)	(3.74)	(6.15)	(2.33)	(7.52)	(4.29)
Other indoors	6.01	23.61	21.55	24.99	24.80	21.58
	(3.27)	(10.61)	(5.32)	(10.24)	(12.86)	(11.37)
Cooking	4.69	0.34	0.00	2.32	0.52	1.24
	(1.88)	(0.79)	(0.00)	(2.30)	(0.86)	(1.98)
Near smokers	2.84	5.20	2.75	11.73	12.03	6.89
	(4.32)	(7.88)	(3.38)	(15.19)	(10.05)	(9.71)
Number	8	32	4	12	8	66[2]

[1] Numbers in parentheses are the standard deviation.
[2] Two unemployed participants were included in the total, but not given a separate category.
SOURCE: Data from Quackenboss et al. (1982).

The time allocations for various population subgroups in Portage, Wisconsin, are summarized in Table 7 (Quackenboss et al. 1982). The data are consistent with the findings of Letz and colleagues (1984) and show that the variability of individual nonsmokers' exposure to smokers can be quite marked between the various occupational subgroups.

Infants have unique time-activity patterns; their mobility is limited and the locations where they spend their time depend primarily on their caretakers. The time-location patterns for 46 infants is illustrated in half-hour segments in Figure 1 (Harlos et al. in press). Although infants spend most of their time in their bedrooms, they are in contact with a caretaker while traveling or in the living room or the kitchen for approximately half of the day. These infant time-activity patterns presumably correspond to the family patterns and may significantly influence the infants' potential exposure.

Although most people spend approximately 90 percent of their time in just two microenvironments (home and work) (Szalai 1972), important exposures can be encountered in other environments. For instance, commuting or being "in transit" accounts for about 0.5 to 1.5 hours per day for most people. Therefore, additional information
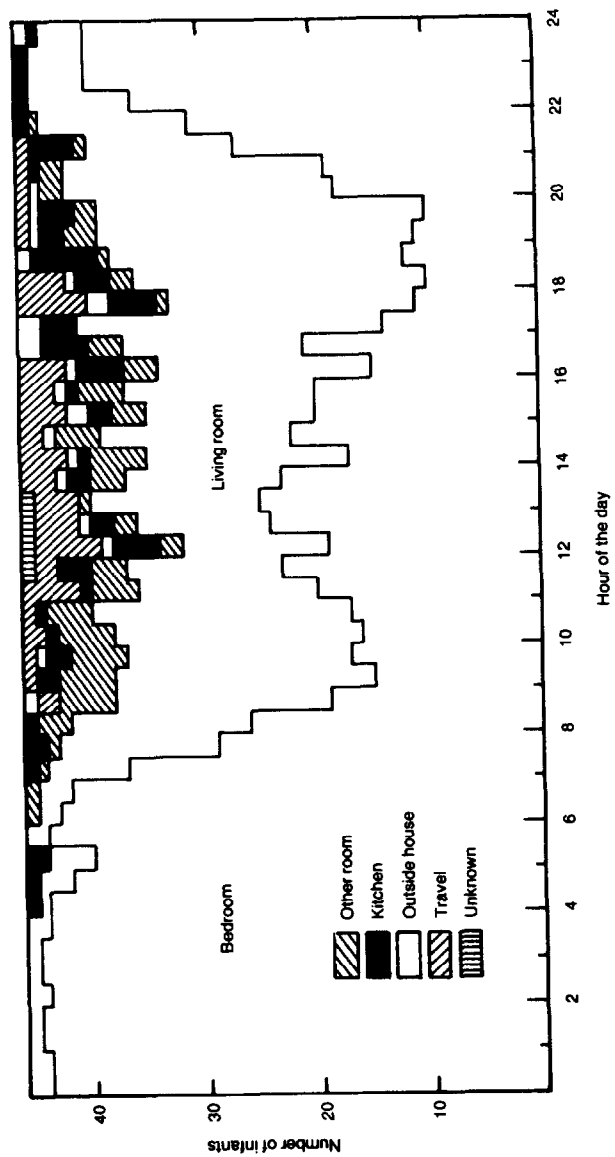
FIGURE 1.—Time location patterns for 46 infants

on the time spent and the ETS concentration in various microenvironments may be useful in defining exposure. This exposure information can be obtained by questionnaire and validated by personal monitoring programs. The characterization of concentra-

144

tions or exposures or both in microenvironments should use time scales appropriate for the health effect of interest. These variations in location and time-activity patterns can make the reconstruction of detailed ETS exposure difficult in studies of long-term health effects.

The limitations in utilizing this time-activity approach in characterizing exposures to other environmental pollutants also apply for ETS exposures. They include the following: the extent to which overall population estimates can be generalized to individual patterns is poorly understood; concentrations in various microenvironments are only partially characterized; the variation in time and activity patterns and their effects on concentration levels are not established; extrapolation to longer time scales either prospectively or retrospectively has not been validated; the differences within structures, i.e., room to room variations, are not well established.

Temporal and Spatial Distribution of Smokers

Exposure to ETS can occur in a wide variety of public and private locations. Approximately 30 percent of the U.S. adult population currently are cigarette smokers. Nationwide, 40 percent of homes have one or more smokers (Bureau of the Census 1985). In a survey of more than 10,000 children in six U.S. cities, the percentage of children living with one or more smoking adults varied from a low of 60 percent to a high of 75 percent (Ferris et al. 1979). Lebowitz and Burrows (1976) reported that 54 percent of children in a study in Tucson had at least one smoker in the home; Schilling and colleagues (1977) reported that 63 percent of homes in a Connecticut study had a smoker in the home. These data indicate that the population potentially exposed to ETS in the home is greater than might be inferred from aggregated national statistics on the prevalence of smoking. A variation in the percentage of homes with smokers may be observed among different regions. Furthermore, within households, smoking does not take place uniformly in time or space. Smoking patterns may change with activity, location, and time of day. These variables all serve to modify a nonsmoker's exposure to ETS.

Exposure to ETS at home may also correlate with ETS exposures outside the home, possibly because nonsmokers married to smokers may have a greater tolerance for ETS-polluted environments or may be in the company of more smokers because of the spouses' tendency to associate with other smokers. Wald and Ritchie (1984) used a biological marker and questionnaires to show that nonsmokers married to smokers reported a duration of exposure to ETS greater outside the home than was reported by nonsmokers married to nonsmokers (10.7 hours and 6.0 hours, respectively).

Smoking prevalence varies widely among different groups (e.g., teenage girls, nonworking adults, and adults employed in various

occupations); this variation modifies the exposure of nonsmokers to ETS. Smokers are present in nearly all environments, including most workplaces, restaurants, and transit vehicles, making it almost impossible for a nonsmoker to avoid some exposure to ETS. The number of cigarettes consumed per hour by the smoker may vary at different times in the day, and the rate and density of smoking will also differ by the type of indoor environment and activity in such locales as schools, autos, planes, offices, shops, and bars.

Although there have been numerous measurements of ETS concentrations in various indoor settings, these data do not represent a comprehensive description of the actual distribution of ETS exposures in the U.S. population. Spengler and colleagues (1985) and Sexton and colleagues (1984) demonstrated by the personal monitoring of respirable particles and the use of time-activity questionnaires that exposures to ETS both at home and at work are significant contributors to personal exposures. However, additional data on the distribution of smokers in the nonsmokers' environment, as well as the distribution of ETS levels in that environment, are needed in order to characterize the actual ETS exposure of the U.S. population.

Determinations of Concentration of Environmental Tobacco Smoke

Environmental tobacco smoke is a complex mixture of chemical compounds that individually may be in the particulate phase, the vapor phase, or both. ETS concentration varies with the generation rate of its tobacco-derived constituents, usually given as micrometer per hour. The generation rate for ETS has been approximated by the number of cigarettes smoked or the number of people present in a room who are actively smoking. Room-specific characteristics such as ventilation rate, decay rate, mixing rate, and room volume also modify the concentration. Because ETS particles have MMDs in the 0.2 to 0.4 μm range, convective flows dominate their movement in air, they remain airborne for long periods of time, and they are rapidly distributed through a room by advection and a variety of mixing forces. Under many conditions, the ventilation rate of a space will dominate chemical or physical removal mechanisms in determining the levels of ETS particles.

Nonreactive ETS components distribute rapidly through an airspace volume, and their elimination depends almost solely on the ventilation rate. For example, Wade and colleagues (1975) simultaneously measured carbon monoxide, a nonreactive gas, and nitrogen dioxide, a reactive gas, in a house and determined their half-lives to be 2.1 and 0.6 hours, respectively. This study demonstrates the need for caution in extrapolating from one vapor phase compound to another. Reactive gases and vapors may be rapidly lost to surfaces or

146

may react with other chemical species. Their removal may be dominated by their reaction or absorption rates. Furthermore, the decay of ETS-derived substances can be a function of the chemical as well as the physical characteristics of room surfaces. For example, Walsh and colleagues (1977) found that sulfur dioxide removal was greater for rooms with neutral and alkaline carpets than for rooms having carpets with acidic pH. Reactions with furnishings and other materials may occur for some ETS components as well.

Microenvironmental Measurements of Concentration

As was discussed earlier, the complex chemical makeup of ETS makes the measurements of individual levels for each compound present in ETS impossible with existing resources; thus, some individual constituents have been measured as markers of overall smoke exposure. Because many of these constituents are also emitted from other sources in the environment, the contribution of ETS to the levels of these constituents is quantified by determining the enrichment of specific compounds found in smoke-polluted environments relative to the concentration measured in nonsmoking areas. Various ETS components have been measured for this purpose, including acrolein, aldehydes, aromatic hydrocarbons, carbon monoxide, nicotine, nitrogen oxides, nitrosamines, phenols, and respirable particulate matter. A summary of the levels found and the conditions of measurement are presented in Tables 8 through 15. The major limitation of using most of these gases, vapors, and particles is their lack of specificity for ETS. The presence of sources, other than tobacco smoke, of these compounds may limit their utility for determining the absolute contribution made by ETS to room concentrations. Levels of nicotine and tobacco-specific nitrosamines, however, are specific for ETS exposure.

Obviously, no single measurement can completely characterize the nonsmoker's exposure to ETS, and many studies have measured several of these components in order to characterize the exposure. Markers should be chosen both because of their accuracy in estimating exposure and because of their relevance for the health outcome of interest.

One widely reported marker of ETS is respirable suspended particulate (RSP) matter. Although lacking specificity for tobacco smoke, the prevalence and number of smokers correlates well with RSP levels in homes and other enclosed areas.

A study of the RSP levels in 80 homes in six cities (Figure 2) (Spengler et al. 1981) showed that indoor concentrations were higher on average and had a greater range than the outdoor concentrations. From these data, it is evident that even one smoker can significantly elevate indoor RSP levels.

TABLE 8.—Acrolein measured under realistic conditions

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels	
					Mean	Range
Badre et al.	Cafes	Varied	Not given	100 mL samples		0.03–0.10 mg/m³
(1978)	Room	18 smokers	Not given	100 mL samples	0.185 mg/m³	
	Hospital lobby	12 to 30 smokers	Not given	100 mL samples	0.02 mg/m³	
	2 train compartments	2 to 3 smokers	Not given	100 mL samples		0.02–0.12 mg/m³
	Car	3 smokers	Natural, open	100 mL samples	0.03 mg/m³	
		2 smokers	Natural, closed	100 mL samples	0.30 mg/m³	
Fischer et al.	Restaurant	50–80/470 m³	Mechanical	27 × 30 min samples	7 ppb	
(1978) and	Restaurant	60–100/440 m³	Natural	29 × 30 min samples	8 ppb	
Weber et al.	Bar	30–40/50 m³	Natural, open	28 × 30 min samples	10 ppb	
(1979)	Cafeteria	80–150/574 m³	11 changes/hr	24 × 30 min samples	6 ppb (5 ppb nonsmoking section)	

TABLE 9.—Aromatic hydrocarbons measured under realistic conditions

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels		Nonsmoking controls	
					Mean	Range	Mean	Range
					Benzene (mg/m³)			
Badre et al. (1978)	Cafes	Varied	Not given	100 mL samples		0.05–0.15		
	Room	18 smokers	Not given	100 mL samples	0.109			
	Train compartments	2 to 3 smokers	Not given	100 mL samples		0.02–0.10		
	Car	3 smokers	Natural, open	100 mL samples	0.04			
		2 smokers	Natural, closed	100 mL samples	0.15			
					Toulene (mg/m³)			
	Cafes	Varied	Not given	100 mL samples		0.04–1.04		
	Room	18 smokers	Not given	100 mL samples	0.215			
	Train compartments	2 to 3 smokers	Not given	100 mL samples	1.87			
	Car	2 smokers	Natural, closed	100 mL samples	0.50			
					Benzo[a]pyrene (ng/m³)			
Elliott and Rowe (1975)	Arena	8,647–10,786 people	Mechanical	Not given	7.1			
		12,000–12,844 people	Mechanical	Not given	9.9			
		13,000–14,277 people	Mechanical	Not given	21.7			
				Separate non-activity days			0.69	
Galuskinova (1964)	Restaurant	Not given	Not given	20 days in summer	6.2			
				18 days in the fall		28.2–144		

TABLE 9.—Continued

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels		Nonsmoking controls	
					Mean	Range	Mean	Range
Just et al. (1972)	Coffee houses	Not given	Not given	6 hr continuous	0.25–10.1		4.0–9.3 (outdoors)	
					Benzo[e]pyrene (ng/m³)			
					3.3–23.4		3.0–5.1 (outdoors)	
					Benzo[ghi]perylene (ng/m³)			
					5.9–10.5		6.9–13.8 (outdoors)	
					Perylene (ng/m³)			
					0.7–1.3		0.1–1.7 (outdoors)	
					Pyrene (ng/m³)			
					4.1–9.4		2.8–7.0 (outdoors)	
					Anthanthrene (ng/m³)			
					0.5–1.9		0.5–1.8 (outdoors)	
					Coronene (ng/m³)			
					0.5–1.2		1.0–2.8	
					Phenols (µ/m³)			
					7.4–11.5			
					Benzo[a]pyrene (ng/m³)			
Perry (1973)[1]	14 public places	Not given	Not given	Samples, 5 outdoor locations	<20–760			<20–43

[1] The correctness of the data is doubtful (Grimmer et al. 1977).

TABLE 10.—Carbon monoxide measured under realistic conditions

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (ppm)		Nonsmoking controls (ppm)	
					Mean	Range	Mean	Range
Badre et al. (1978)	6 cafes	Varied	Not given	20 min samples		2–23	(outdoors)	0–15
	Room	18 smokers	Not given	20 min samples	50		0 (outdoors)	
	Hospital lobby	12 to 30 smokers	Not given	20 min samples	5			
	2 train compartments	2 to 3 smokers	Not given	20 min samples		4–5		
	Car	3 smokers	Natural, open	20 min samples	14		0 (outdoors)	
		2 smokers	Natural, closed	20 min samples	20		0 (outdoors)	
Cano et al. (1970)	Submarines 66 m³	157 cigarettes per day	Yes		<40 ppm			
		94–103 cigarettes per day	Yes		<40 ppm			
Chappell and Parker (1977)	10 offices	Not given	Values not given	17 × 2–3 min samples	2.5 ± 1.0	1.5–4.5	2.5 ± 1.0 (outdoors)	1.5–4.5
	15 restaurants	Not given	Values not given	17 × 2–3 min samples	4.0 ± 2.5	1.0–9.5	2.5 ± 1.5 (outdoors)	1.0–5.0
	14 nightclubs and taverns	Not given	Values not given	19 × 2–3 min samples	13.0 ± 7.0	3.0–29.0	3.0 ± 2.0 (outdoors)	1.0–5.0
	Tavern	Not given	Artificial	16 × 2–3 min samples	8.5			
			None	2 × 2–3 min samples		35 (peak)		
	Office	1440 ft³	Natural, open	2–3 min samples		10.0 (peak)		
				30 min after smoking	1.0			

TABLE 10.—Continued

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (ppm)		Nonsmoking controls (ppm)	
					Mean	Range	Mean	Range
Coburn et al. (1965)	Rooms	Not given	Not given	Not given		4.3–9.0		
				Nonsmokers' rooms			2.2 ± 0.96	0.4–4.5
Cuddeback et al. (1976)	Tavern 1	10–294 people	6 changes/hr	8 hr continuous	11.5	10–12	2 (outdoors)	
				2 hr after smoking	~1			
	Tavern 2	Not given	1–2 changes/hr	8 hr continuous	17	~3–22	Values not given	
				2 hr after smoking	~12		Values not given	
U.S. Dept. of Transportation (1971)[1]	18 military planes	165–219 people	Mechanical	6–7 hr continuous		<2–5		
	8 domestic planes	27–113 people	Mechanical	1¼–2½ hr continuous	≤2			
Elliott and Rowe (1975)[2]	Arena 1	11,806 people	Mechanical	Not given	9.0		3.0 (nonactivity day)	
	Arena 2	2,000 people	Natural	Not given	25.0		3.0 (nonactivity day)	
				Nonsmoking arena			9.0	
Fischer et al. (1978) and Weber et al. (1979)	Restaurant	50–80/470 m²	Mechanical	27 × 30 min samples	5.1	2.1–9.9	4.8 (outdoors)	
	Restaurant	60–100/440 m²	Natural	29 × 30 min samples	2.6	1.4–3.4	1.5 (outdoors)	
	Bar	30–40/50 m²	Natural, open	28 × 30 min samples	4.8	2.4–9.6	1.7 (outdoors)	
	Cafeteria	80–150/574 m²	11 changes/hr	24 × 30 min	1.2	0.7–1.7	0.4 (outdoors)	
				Nonsmoking room			0.5	0.3–0.8

TABLE 10.—Continued

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (ppm)		Nonsmoking controls (ppm)	
					Mean	Range	Mean	Range
Godin et al. (1972)	Ferryboat	Not given	Not given	11 grab samples	18.4 ± 8.7		3.0 ± 2.4 (nonsmoking room)	
	Theater foyer	Not given	Not given	Grab samples	3.4 ± 0.8		1.4 ± 0.8 (auditorium)	
Harke (1974)[3]	Office[4]	~72 m³	236 m³/hr	30 min samples		<2.5–4.6		
	Office[5]	~78 m³	Natural	30 min samples		<2.5–9.0		
Harke and Peters (1974)[6]	Car	2 smokers (4 cigs)	Natural	Samples		42 (peak)	(Nonsmoking runs) 13.5 (peak)	
			Mechanical	Samples		32 (peak)	(Nonsmoking runs) 15.0 (peak)	
Harmsen and Effenberger (1957)[1]	Train	1–18 smokers	Natural	Not given		0–40		
Perry (1973)[1]	14 public places	Not given	Not given	One grab sample	<10			
Portheine (1971)[7]	Rooms	Not given	Not given	Not given		5–25		
Sebben et al. (1977)	9 nightclubs	Not given	Varied	77 × 1 min samples	13.4	6.5–41.9		
				Outdoors			9.2	3.0–35.0
	14 restaurants	Not given	Not given	Spot checks	9.9 ± 5.5		Values not given	
	45 restaurants	Not given	Not given	Spot checks	8.2 ± 2.2		7.1 ± 1.7 (outdoors)	
	33 stores	Not given	Not given	Spot checks	10.0 ± 4.2		11.5 ± 6.9 (outdoors)	
	3 hospital lobbies	Not given	Not given	Spot checks		4–8	Values not given	

TABLE 10.—Continued

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (ppm)		Nonsmoking controls (ppm)	
					Mean	Range	Mean	Range
Seiff (1973)	Intercity bus	Not given	15 changes/hr, 23 cigarettes burning continuously		33 ppm			
			3 cigarettes burning continuously		18 ppm			
Slavin and Hertz (1975)	2 conference rooms	Not given	8 changes/hr	Continuous, morning		8 (peak)	1-2 (separate nonsmoking day)	
			6 changes/hr	Continuous, morning		10 (peak)	1-2 (separate nonsmoking day)	
Szadkowski et al. (1976)	25 offices	Not given	Not given	Continuous	2.78 ± 1.42		2.59 ± 2.23 (separate nonsmoking offices)	

[1] The Drager tube used is accurate only within ± 25 percent.

[2] The MSA Monitaire Sampler used is accurate only within ± 25 percent.

[3] Three cigarettes and one cigar smoked in 20 minutes.

[4] About 40 cigarettes/day were smoked.

[5] About 70 cigarettes/day were smoked.

[6] Four filter cigarettes were smoked.

[7] No experimental description given.

TABLE 11.—Nicotine measured under realistic conditions

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (µg/m³)		Nonsmoking controls	
					Mean	Range	Mean	Range
Badre et al. (1978)	6 cafes	Varied	Not given	50 min sample		25–52		
	Room	18 smokers	Not given	50 min sample	500			
	Hospital lobby	12 to 30 smokers	Not given	50 min sample	37			
	2 train compartments	2 to 3 smokers	Not given	50 min sample		36–50		
	Car	3 smokers	Natural, open	50 min sample	65			
			Natural, closed	50 min sample	1010			
Cano et al. (1970)	Submarines 66 m³	157 cigarettes per day	Yes		32 µg/m³			
		94–103 cigarettes per day	Yes		15–35 µg/m³			
Harmsen and Effenberger (1957)	Train	Not given	Natural, closed	30–45 min samples		0.7–3.1		
Hinds and First (1975)[1]	Train	Not given	Not given	2½ hr samples	4.9		Values not given	
	Bus	Not given	Not given	2½ hr samples	6.3		Values not given	
	Bus waiting room	Not given	Not given	2½ hr samples	1.0		Values not given	
	Airline waiting room	Not given	Not given	2½ hr samples	3.1		Values not given	
	Restaurant	Not given	Not given	2½ hr samples	5.2		Values not given	
	Cocktail lounge	Not given	Not given	2½ hr samples	10.3		Values not given	
	Student lounge	Not given	Not given	2½ hr samples	2.8		Values not given	
Weber and Fischer (1980)[2]	44 offices	Varied	Varied	140 × 3 hr samples	0.9 ± 1.9	13.8 (peak)	Values not given	

TABLE 11.—Continued

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (μg/m³)		Nonsmoking controls	
					Mean	Range	Mean	Range
First	1 public building	Nonsmokers	Mechanical	Not given			5.5	
(1984)	8 public buildings	1 to 5 smokers	Natural and mechanical	Not given	13.2	2.7–30.0		
Muramatsu et al.	Office	Not given	Not given	Not given	19.4	9.3–31.6		
(1984)	Office	Not given	Not given	Not given	22.1	14.6–26.1		
	Laboratory	Not given	Not given	Not given	5.8	1.8–9.6		
	5 conference rooms	Not given	Not given	Not given	38.7	16.5–53.0		
	3 houses	Not given	Not given	Not given	11.1	7.6–14.6		
	Hospital lobby	Not given	Not given	Not given	3.0	1.9–5.0		
	4 hotel lobbies	Not given	Not given	Not given	11.2	5.5–18.1		
	5 restaurants	Not given	Not given	Not given	14.8	7.1–27.8		
	3 cafeterias	Not given	Not given	Not given	26.4	11.6–42.2		
	3 bus and railway waiting rooms	Not given	Not given	Not given	19.1	10.1–36.4		
	4 cars	Not given	Not given	Not given	47.7	7.7–83.1		
	8 trains	Not given	Not given	Not given	16.4	8.6–26.1		
	7 airplanes	Not given	Not given	Not given	15.2	6.3–28.8		

[1] Background levels have been subtracted.
[2] Control values (unoccupied rooms) have been subtracted.

TABLE 12.—Nitrogen oxides measured under realistic conditions

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels Mean	Levels Range	Nonsmoking controls (ppb) Mean	Nonsmoking controls (ppb) Range
Fischer et al. (1978) and Weber et al. (1979)	Restaurant	50–80/470 m²	Mechanical	27 × 30 min samples	NO_2: 76 NO: 120	59–105 36–218	63 (outdoors) 115 (outdoors)	
	Restaurant	60–100/440 m²	Natural	29 × 30 min samples	NO_2: 63 NO: 80	24–99 14–21	50 (outdoors) 11 (outdoors)	
	Bar	30–40/50 m²	Natural, open	28 × 30 min samples	NO_2: 21 NO: 195	1–61 66–414	48 (outdoors) 44 (outdoors)	
	Cafeteria	80–150/574 m²	11 changes/hr	24 × 30 min samples Other—non-smokers room	NO_2: 58 NO: 9	35–103 2–38	34 (outdoors) 4 (outdoors) NO_2: 27 NO: 5	 15–44 2–9
Weber and Fischer (1980)[1]	44 offices	Varied	Varied	348–354 samples	NO_2: 24 ± 22 NO: 32 ± 60	115 (peak) 280 (peak)	Values not given Values not given	

[1] Control values (unoccupied rooms) have been subtracted.

TABLE 13.—Nitrosamines measured under realistic conditions

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (ng/L)	
					Mean	Range
Brunnemann and	Train bar car	Not given	Mechanical	90 min continuous	0.13	
Hoffmann	Train bar car	Not given	Natural	90 min continuous	0.11	
(1978)						
Brunnemann et al.						
(1978)	Bar	Not given	Not given	3 hr continuous	0.24	
	Sports hall	Not given	Not given	3 hr continuous	0.09	
	Betting parlor	Not given	Not given	90 min continuous	0.05	
	Discotheque	Not given	Not given	2¾ hr continuous	0.09	
	Bank	Not given	Not given	5 hr continuous	0.01	
	House	Not given	Not given	4 hr continuous	<0.005	
	House	Not given	Not given	4 hr continuous	<0.003	

TABLE 14.—Particulates measured under realistic conditions

Study	Type of premises	Occupancy (active smokers per 100 m³)	Ventilation	Monitoring conditions (min)	Levels (µg/m³) Mean	SD	Nonsmoking controls (µg/m³) Mean	SD
Repace and	Cocktail party	0.75	Natural	15	351	± 38	24	
Lowrey	Lodge hall	1.26	Mechanical	50	697	± 28	60[1]	
(1980)	Bar and grill	1.78	Mechanical	18	589	± 28	63[1]	
	Firehouse bingo	2.77	Mechanical	16	417	± 63	51[1]	
	Pizzeria	2.94	Mechanical	32	414	± 58	40[1]	
	Bar/cocktail lounge	3.24	Mechanical	26	334	± 120	50[1]	
	Church bingo game	0.47	Mechanical	42	279	± 18	30	
	Inn	0.74	Mechanical	12	239	± 9	22[1]	
	Bowling alley	1.53	Mechanical	20	202	± 19	49[1]	
	Hospital waiting room	2.15	Mechanical	12	187	± 52	58[1]	
	Shopping plaza restaurant							
	Sample 1	0.18	Mechanical	18	153	± 8	59[1]	
	Sample 2	0.18	Mechanical	18	163	± 4	36[1]	

TABLE 14.—Continued

Study	Type of premises	Occupancy (active smokers per 100 m^3)	Ventilation	Monitoring conditions (min)	Levels (µg/m^3)		Nonsmoking controls (µg/m^3)	
					Mean	SD	Mean	SD
	Barbeque restaurant	0.89	Mechanical	10	136	± 17	40[1]	
	Sandwich restaurant A							
	Smoking section	0.29	Mechanical	20	110	± 36	40[1]	
	Nonsmoking section	0	Mechanical	20	55	± 5	30	
	Fast-food restaurant	0.42	Mechanical	40	109	± 38	24[1]	
	Sports arena	0.09[2]	Mechanical	12	94	± 13	55[1]	
	Neighborhood restaurant/bar	0.40	Mechanical	12	93	± 17	55[1]	
	Hotel bar	0.59	Mechanical	12	93	± 2	30	
	Sandwich restaurant B							
	Smoking section	0.13	Mechanical	8	86	± 7	55	
	Nonsmoking section	0	Mechanical	21	51			
	Roadside restaurant	1.12	Mechanical (9.5 ach[3])	18	107[4]		30	
	Conference room	3.54	Mechanical (4.3 ach[3])	6	1947[4]		55	
Repace and	Dinner theater	0.14	Mechanical	44	145	± 43	47	± 10
Lowrey	Reception hall	1.19	Mechanical	20	301	± 30	33[1]	
(1982)	Bingo hall	0.93[2]	Natural	2	1140		40[1]	
		0.93[2]	Mechanical (1.39 ach[3])	6	443[4]		40[1]	

[1] Sequential outdoor measurement (5 minute average).

[2] Estimated.

[3] Air changes per hour.

[4] Equilibrium level as determined from concentration vs. time curve.

TABLE 14.—Continued

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (μg/m³)		Nonsmoking controls (μg/m³)	
					Mean	Range	Mean	Range
Cuddeback et al. (1976)	Tavern	Not given	6 changes/hr	4 × 8 hr continuous	310	233–346		
	Tavern	Not given	1–2 changes/hr	8 hr continuous	986			
U.S. Dept. of Transportation (1971)	18 military planes	165–219 people	Mechanical	72 × 6–7 hr samples		<10–120		
	8 domestic planes	27–113 people	Mechanical	24 × 1¼–2¼ hr samples	Not given			
Dockery and Spengler (1981)	Residences	Not given	Varied	24 hr samples	32			
Elliott and Rowe (1975)	Arena 1	11,806 people	Mechanical	During activities	323		42 (nonactivity day)	
	Arena 2	2,000 people	Natural	During activities	620		92 (nonactivity day)	
	Arena 3 (smoking prohibited)	11,000 people	Mechanical	During activities	148		71 (nonactivity day)	
Harmsen and Effenberger (1957)	Trains	15–120 people	Natural	Not given		46–440 particles/cm³		
				Nonsmokers' cars				20–75 particles/cm³
Just et al. (1972)	4 coffee houses	Not given	Not given	6 hr averages	1150	500–1900	570 (outdoors)	100–1900
Neal et al. (1978)	Hospital unit	Not given	Mechanical	48 hr samples	21 ± 14	3–58	73 ± 25	
	Hospital unit	Not given	Mechanical	48 hr samples	40 ± 21	13–79	72 ± 25	

TABLE 14.— Continued

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels (μg/m³) Mean	Range	Nonsmoking controls (μg/m³) Mean	Range
Spengler et al. (1981)	Residences	2+ smokers	Natural	24 hr samples	70 ± 43		21 ± 12 (outdoors)	
		1 smoker	Natural	24 hr samples	37 ± 15		21 ± 12 (outdoors)	
Weber and Fischer (1980)	44 offices	Varied	Natural and mechanical	429 × 2 min samples	133 ± 130[1]	962[1] (peak)		
Quant et al. (1982)	Office No. 1	0.82[2]	Mechanical	Five 10-hr workday	45	39-54		5-15
	Office No. 2	0.68[2]	Mechanical	averages; continuous	45	37-50		15-20
	Office No. 3	1.46[2]	Mechanical	monitoring	68	42-89		15-20
Brunekreef and Boleij (1982)	26 houses	1 to 3 smokers	Natural	2 mo averages	153[3]	60-340	55	20-90
First (1984)	1 public building	Nonsmokers	Mechanical	2 min			20	
	8 public buildings	1 to 5 smokers	Natural and mechanical	2 min	260	40-660		
Hawthorne et al. (1984)	11 residences	Nonsmokers	0.18-0.96	5-15 min			9-40	
	8 residences	Nonsmokers	0.26-1.98	5-15 min			12-46	
	2 residences	Smokers	0.27-1.47	5-15 min	96-106			
Nitschke et al. (1985)	Outdoor			168 hr			11	11-28
	19 residences	Nonsmokers	Natural	168 hr			26	6-88
	11 residences	Smokers	Natural	168 hr	59	10-144		
Spengler et al. (1985)	Outdoor			24 hr			18	
	73 residences	Nonsmokers	Natural	24 hr			28	
	24 residences	Smokers	Natural	24 hr	74			
Sterling and Sterling (1984)	1 office	Smokers	Not given	Not given	26	15-36		
	22 offices	Smokers	Not given	Not given	32			

[1] Values above background.

[2] Habitual smokers per 100 m².

[3] Weighted mean.

TABLE 15.—Residuals measured under realistic conditions

Study	Type of premises	Occupancy	Ventilation	Monitoring conditions	Levels		Nonsmoking controls	
					Mean	Range	Mean	Range
					Acetone (mg/m³)			
Badre et al. (1978)[1]	6 cafes	Varied	Not given	100 mL samples		0.91–5.88		
	Room	18 smokers	Not given	100 mL samples	0.51			
	Hospital lobby	12 to 30 smokers	Not given	100 mL samples	1.16			
	2 train compartments	2 or 3 smokers	Not given	100 mL samples		0.36–0.75		
	Car	3 smokers	Natural, open	100 mL samples	0.32			
	Car	2 smokers	Natural, closed	100 mL samples	1.20			
					Sulfates (µg/m³)			
Dockery and Spengler (1981)	Residences	Not given	Varied	24 hr samples	4.81			
					Sulfur dioxide (ppb)			
Fischer et al. (1978)	Restaurant	50–80/470 m³	Mechanical	27 × 30 min samples	20	9–32	12 ppb	
	Restaurant	60–100/440 m³	Natural	29 × 30 min samples	13	5–18	6	
	Bar	30–40/50 m³	Natural, open	28 × 30 min samples	30	13–75	8	
	Cafeteria	80–150/574 m³	11 ch/hr	24 × 30 min samples	15	1–27	12	
				Other nonsmokers' room			7	3–13
					Aldehydes (µg/m³)			
Just et al. (1972)	4 coffee houses	Not given	Not given	6 hr continuous	12.0–15.3			

[1] See original paper for nine other residuals.

SOURCE: Sterling et al. (1982).

163
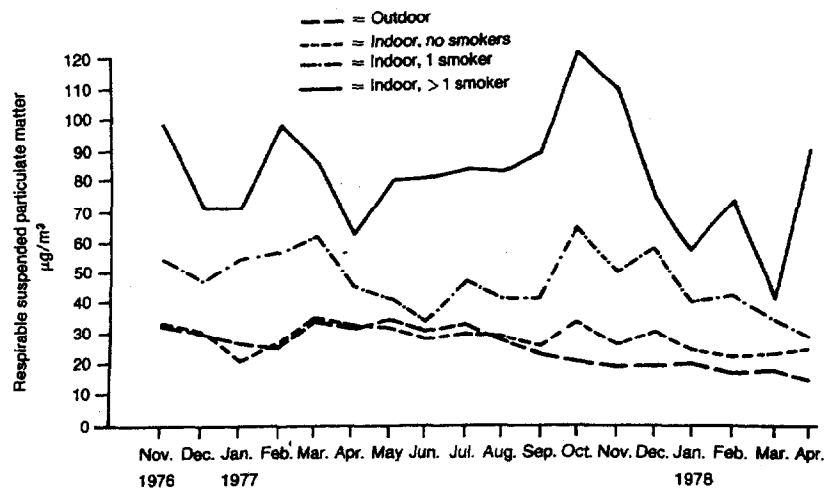
**FIGURE 2.—Monthly mean mass respirable particulate
concentrations (μg/m³) across six cities**
SOURCE: Spengler et al. (1981).

**TABLE 16.—Respirable particulate levels as a function of
number of smokers**

Smoker status	Number	Mean (μg/m³)	Standard deviation
No smokers	35 homes/1,186 samples	24.4	11.6
1 smoker	15 homes/494 samples	36.5	14.5
2 smokers	5 homes/153 samples	70.4	42.9
2+ smokers	4 homes/? samples	51.8	12.3

SOURCE: Spengler et al. (1981).

Spengler and colleagues (1981) collected respirable suspended
particulate samples in 55 homes in six cities. The average concentra-
tions observed between May 1977 and April 1978 are shown in Table
16. The quantity of tobacco smoked was not reported, nor was the
number of hours each smoker spent in the home. The researchers
concluded that the mean RSP levels increased by 20 μg/m³ per
smoker.

Dockery and Spengler (1981) further analyzed these data and
considered the number of cigarettes smoked in the home. They
concluded that the mean RSP concentration increased by 0.88 μg/m³

164

for every cigarette smoked per day in the house. A one-pack-a-day smoker in the home thus raises indoor respirable particulate levels by 17.6 µg/m³. Air conditioning increased the contribution of each cigarette by 1.23 µg/m³, to a total of 2.11 µg/m³ per cigarette in fully air-conditioned homes. These values are annual averages; air-conditioned homes, in which air is recirculated during the warmer months, have higher levels.

Repace and Lowrey (1980) measured RSP concentration using a piezobalance in several public and private locations, including restaurants, cocktail lounges, and halls, in both the presence and the absence of smoking. They then developed an empirical model utilizing the mass-balance equation. Using both measured and estimated parameters as input to the model, they validated the model for predicting an individual's exposure to the RSP constituent of ETS. The model takes the form: $C_{eq} = 650\ D_s/n_v$; where C_{eq} equals the equilibrium concentration of the RSP component of ETS (µg/m³), D_s equals the density of active smokers (number of burning cigarettes per 100 m³), and n_v equals the ventilation rate (in air changes per hour). The ventilation rate is a complex parameter that takes into account all the room-specific constants affecting the removal of ETS, such as ventilation, decay, and mixing.

Measurements in a large number of locations using measures of smoke generation such as the number of people smoking or the number of cigarettes being smoked have shown a definite relationship of smoke generation to particulate levels. First (1984) cautioned against the use of RSP measurements as a measure of ETS in public places because of its nonspecificity for ETS, and noted that other sources may contribute enough to the levels to invalidate the determination of the ETS contribution. However, there are few other sources of RSP in most U.S. homes, and therefore, the relationships of RSP measurements to ETS levels are generally quite accurate in this setting.

Nicotine appears to be a promising tracer for ETS because of its specificity for tobacco and its presence in relatively high concentrations in tobacco smoke. It can also be measured in biological fluids to provide an indication of acute exposure to tobacco smoke. Cotinine, nicotine's major metabolite, can be used as an indicator of more chronic exposure. These biological markers are discussed in a separate chapter of this Report. Recent studies have indicated that nicotine may be primarily associated with the vapor phase of ETS and therefore not a surrogate for the particulate phase as once thought (Eudy et al. 1986). However, the possible usefulness of this compound in estimating exposure to ETS warrants further evaluation. The nicotine content of sidestream smoke does not differ significantly from brand to brand when normalized on a per gram of tobacco basis (Rickert et al. 1984). The use of nicotine as a marker for

165

ETS must also give consideration to its loss to surfaces and its subsequent revolatilization and readmission to the room volume.

Carbon monoxide, a marker for gas phase components, has been measured extensively as a surrogate for ETS. There are many sources of carbon monoxide other than cigarettes, indoors (e.g., stoves, grills) and outdoors (e.g., automobile). This nonspecificity for ETS seriously limits its usefulness for environmental measurements.

In summary, no single compound definitively characterizes an individual's exposure to ETS. Additional research is currently under way to quantify the relationships among various constituents and ETS levels. Because of the complex nature of ETS, investigators may need to measure several markers or to separately record source variables (such as number of cigarettes smoked) in order to estimate exposure to ETS.

Monitoring Studies

Personal monitors can measure the concentrations of ETS in an individual's breathing zone. Personal monitoring is preferable to area monitoring because it integrates the temporal and spatial dimensions of an individual's exposures. At the present time, all of the studies that have used personal monitors to measure ETS constituents have utilized active samplers that provide integrated exposures over differing time periods.

The markers assessed in personal monitoring studies have the same lack of specificity found in area monitoring studies. However, in many of the personal monitoring studies, time-activity diaries were kept to permit greater resolution in attributing exposure to specific sources.

In Topeka, Kansas, 45 nonsmoking adults carried personal RSP monitors for 18 days, and area monitors were placed inside and outside their homes (Spengler and Tosteson 1981). The indoor RSP levels were consistently higher than outdoor levels, and the personal exposures levels were higher than either. The group was divided into those who reported ETS exposure and those who did not (Figure 3). Reported exposure to ETS clearly shifts the distribution to the right. On the average, reported ETS exposure increased an individual's personal concentration by 20 $\mu g/m^3$.

Personal RSP monitors were carried by 101 nonsmoking volunteers for 3 days in Kingston-Harriman, Tennessee (Spengler et al. 1985). The study population was divided into two groups: those who lived with a smoker and those who did not. ETS exposure was reported by 28 of the participants, with the remaining participants reporting none. The RSP distribution for the ambient samples is shown in Figure 4. Clearly, exposure to ETS significantly increases an individual's personal concentration profile.

166
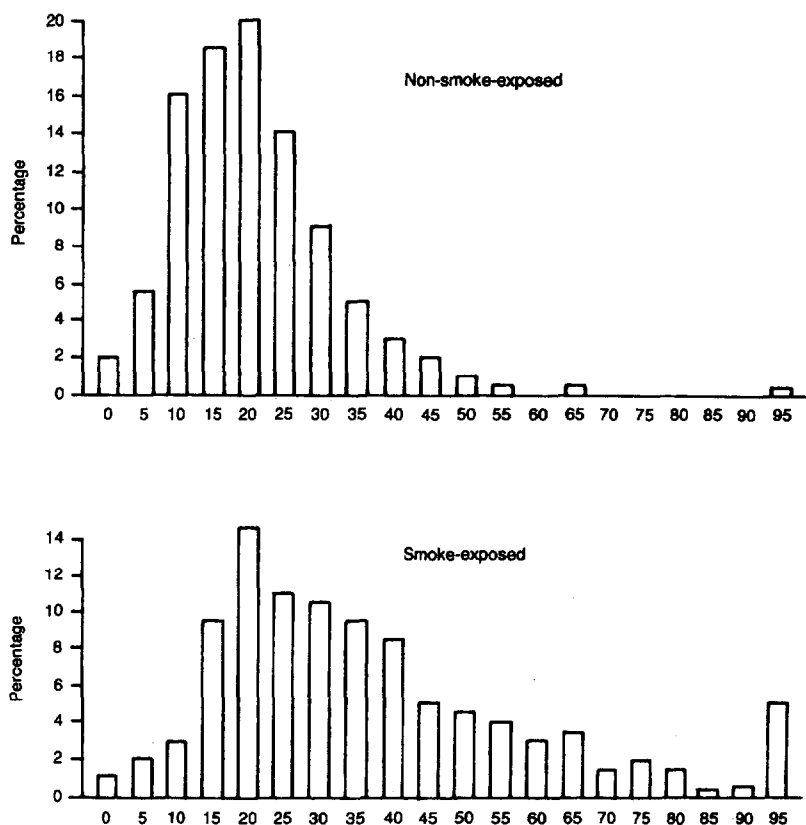
FIGURE 3.—Percentage distribution of personal respirable particulate concentrations, non-smoke-exposed and smoke-exposed samples, Topeka, Kansas

SOURCE: Spengler and Tosteson (1981).

Sexton and colleagues (1984) monitored personal RSP exposure for 48 nonsmokers in Waterbury, Vermont, every other day for 2 weeks. The participants kept activity logs and had simultaneous indoor and outdoor RSP samples collected at their homes. The proportion of time individuals spent exposed to ETS was the single most important determinant of their personal exposure. Volunteers who reported greater than 120 minutes of exposure to ETS had a mean RSP exposure of 50.1 µg/m³, whereas those volunteers who reported no exposure to ETS had a mean exposure of 31.7 µg/m³.
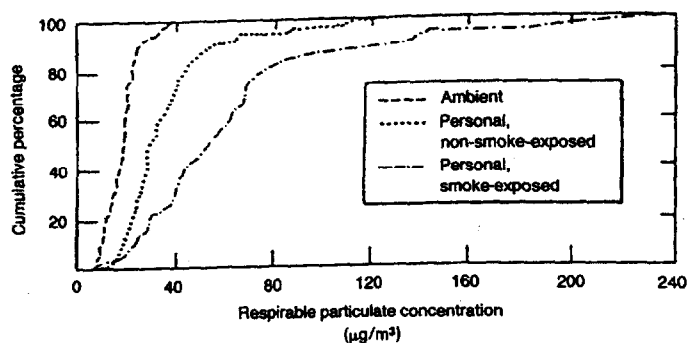
FIGURE 4.—Cumulative frequency distributions of central site ambient and personal smoke-exposed and non-smoke-exposed respirable suspended particulate concentrations

Nicotine, a tobacco-specific compound, should make an excellent tracer for ETS if its usage can be properly validated. Some considerations in its usage are detailed in the section on area sampling. Currently, no published reports are available that utilize this compound for the type of detailed personal monitoring studies carried out for RSP. However, a lightweight personal nicotine monitor has recently been developed (Muramatsu et al. 1984) that may aid this type of research. The researchers measured average nicotine concentrations ranging from 3.0 $\mu g/m^3$ in a hospital lobby to 38.7 $\mu g/m^3$ in a conference room and 47.7 $\mu g/m^3$ in an automobile. No information on the duration of exposure or representativeness of these levels to the general population was given. However, this study does provide information as to the range of exposures an individual may encounter and demonstrates that high nicotine levels can be encountered in various settings. It will be necessary to quantify the relationship between nicotine, a vapor phase component of ETS, and other components of interest such as RSP in order to fully utilize this tracer.

Certain organic gases have been measured as possible indicators of ETS exposure or of specific effects such as irritation. These include formaldehyde and acrolein (Weber and Fischer 1980) and aromatic compounds such as benzene, toluene, xylene, and styrene (Higgins et al. 1983). The U.S. Environmental Protection Agency's recent TEAM study utilized personal monitors, employing Tenax cartridges, to develop profiles of individual exposures to volatile organics (Wallace

et al. in press). The TEAM study has found significantly increased exposure to benzene for individuals exposed to ETS. Again, the nonspecificity of these materials for ETS limits their applicability.

Other materials such as carbon monoxide and nitrogen dioxide have been measured in personal monitoring studies attempting to assess individuals' exposure to ETS. Their nonspecificity and lack of sensitivity for low-level ETS exposure make them inappropriate for population-based studies.

Personal monitoring techniques are currently available that will allow the assessment of individual exposures to various components of ETS. Although not widely used in the past, they can provide valuable input in developing exposure models and in validating other monitoring schemes. Their usefulness is primarily that they sample all of the microenvironments in which individuals find themselves and therefore automatically compensate for the nonuniform temporal and spatial distributions of ETS that affect individual exposure profiles.

Conclusions

1. Undiluted sidestream smoke is characterized by significantly higher concentrations of many of the toxic and carcinogenic compounds found in mainstream smoke, including ammonia, volatile amines, volatile nitrosamines, certain nicotine decomposition products, and aromatic amines.

2. Environmental tobacco smoke can be a substantial contributor to the level of indoor air pollution concentrations of respirable particles, benzene, acrolein, N-nitrosamine, pyrene, and carbon monoxide. ETS is the only source of nicotine and some N-nitrosamine compounds in the general environment.

3. Measured exposures to respirable suspended particulates are higher for nonsmokers who report exposure to environmental tobacco smoke. Exposures to ETS occur widely in the nonsmoking population.

4. The small particle size of environmental tobacco smoke places it in the diffusion-controlled regime of movement in air for deposition and removal mechanisms. Because these submicron particles will follow air streams, convective currents will dominate and the distribution of ETS will occur rapidly through the volume of a room. As a result, the simple separation of smokers and nonsmokers within the same airspace may reduce, but will not eliminate, exposure to ETS.

5. It has been demonstrated that ETS has resulted in elevated respirable suspended particulate levels in enclosed places.

169

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170

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174

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CHAPTER 4

DEPOSITION AND ABSORPTION OF TOBACCO SMOKE CONSTITUENTS

CONTENTS

Introduction

An understanding of the deposition of cigarette smoke particles in the respiratory tract is important because many of the toxic constituents of cigarette smoke are contained in the particles. The quantity retained, which constitutes the dose, is some fraction of the quantity inhaled. Measures of tobacco smoke constituents or their metabolites are also important because they reflect the absorption of tobacco smoke by the individual smoker or nonsmoker, and therefore may be more accurate markers of the actual exposure experienced by an individual. There is little experimental information describing the deposition of environmental tobacco smoke in the respiratory tract (Jarvis et al. 1983). However, cigarette smoke particles probably behave in a manner similar to other inhaled particles. In contrast, there are a number of observations of different markers in the biological fluids of smokers and nonsmokers. This review begins with a discussion of particle deposition in general and the factors that affect deposition. This understanding is then applied to the existing data on tobacco smoke deposition in the human respiratory tract. Subsequently, a variety of biologic markers of smoke absorption are examined, and the levels of these markers found in smokers and nonsmokers under a variety of circumstances are presented. Finally, an attempt is made to quantitate the exposure of nonsmokers relative to that of active smokers using levels of these biologic markers.

Deposition

The term "deposition" refers to the transfer of a particle from inhaled air to the surface of any portion of the respiratory tract, from nose to alveolus. "Retention" is the quantity of deposited material remaining in the respiratory tract at a specified time following deposition. Retention decreases as clearance mechanisms such as mucociliary action and absorption reduce the respiratory tract burden of inhaled particles. Retention is not discussed in this review.

An aerosol is a suspension of particles in a gaseous or vapor medium; cigarette smoke is an aerosol. Aerosols are characterized by such terms as mass median diameter (MMD), the diameter below which lies one-half of the particles by mass, and count median diameter (CMD), the diameter below which lies one-half of the particles by number. Most naturally occurring aerosols have a lognormal size distribution, and the magnitude of the spread of particle size is the geometric standard deviation (GSD). Particle mass is a function of the cube of the diameter; a particle with a diameter of 0.5 μm has one one-thousandth of the mass of a 5 μm particle. Thus, for an aerosol with a large geometric standard deviation, the mass

181

median diameter may be considerably greater than the count median diameter. The smaller particles of an aerosol, despite their relatively small mass, have a large total surface area because of their great number. A monodisperse aerosol has particles of one size, with CMD equal to MMD, and a GSD of 1. For practical purposes, a GSD of 1.2 or less is accepted as monodisperse. Most naturally occurring aerosols are polydisperse, with GSDs in the 2 range. A lognormally distributed aerosol with a GSD of 2 and a CMD of 0.1 will have an MMD of 0.42. In this discussion, when size is referred to, it is the MMD unless otherwise stated. Both the total deposition and the deposition site in the respiratory tract vary substantially with particle size.

Size Distribution of Cigarette Smoke

Mainstream Smoke

The size distribution of cigarette smoke has been of interest to investigators for many years. The important relationship between size and respiratory tract deposition is discussed below. Most studies have been performed using mainstream smoke. Mainstream smoke is the smoke exiting from the butt of the cigarette during puff-drawing, and sidestream smoke is the smoke plume that drifts into the environment from the burning tip of a cigarette between puffs. Environmental tobacco smoke (ETS) is the ambient burden of sidestream smoke and the smoke exhaled by a smoker. Involuntary smoking is the consumption of ETS by people, either smokers or nonsmokers, from the environment. One purpose in discussing the size distribution and respiratory tract deposition of particles is to illustrate the discrepancy between the measured particle size of mainstream smoke and its measured deposition in the human respiratory tract. The deposition fraction of mainstream smoke is several times higher than would be predicted on the basis of its particulate size. The measured deposition of sidestream smoke is more in keeping with its measured size (Hiller, McCusker et al. 1982).

The standard laboratory smoke-generation technique is to force air through the cigarette as would be done by a smoker, followed by the rapid dilution of the resulting mainstream smoke so that particle size can be measured. A standard 35 cm³, 2-second puff is usually used, although actual puff volume was shown to average 45 cm³ in one study (Mitchell 1962) and 56 cm³ in another; for individuals, the puff volume can vary from 20 to 30 cm³ up to 70 to 80 cm³ (Hinds et al. 1983).

The size distribution of the diluted mainstream smoke aerosol is then measured by one of a variety of techniques such as light scattering devices, microscopic measurement, or impactor collecting

devices. Using various diluting and sizing techniques, particle siz measurements of mainstream cigarette smoke have been reportea from many laboratories (Table 1). One potential cause of error in measuring the size distribution of mainstream cigarette smoke is the relative insensitivity to ultrafine particles of some previously used measurement methods. More recent studies using newer measurement techniques support the suggestions by the earlier investigators (Sinclair 1950) that there is an ultrafine (<0.1 μm) component to the cigarette smoke. Size characteristics have been measured by electron microscopic methods, following rapid fixation of undiluted fresh tobacco smoke, as CMD 0.2 μm and GSD 1.5 (Keith 1982). The size distribution measured with an electrical aerosol analyzer has been reported as CMD 0.1 μm, GSD 2.0, suggesting more ultrafine particles than previously recognized (Anderson and Hiller 1985). Smaller particles (<0.4 μm) of tobacco smoke have been shown to have a chemical composition different from that of larger particles (Stöber 1984), possibly because of the large surface area of smaller particles.

Laboratory methods, such as rapid dilution, commonly used to study mainstream smoke, are highly artificial and may not accurately duplicate the generation, dilution, and inhalation of mainstream smoke by the smoker. Smoking technique and respiratory tract conditions may promote changes in particle size. Therefore, the particulate sizes in the respiratory tract may differ from the sizes measured when mainstream smoke is diluted for size analysis or when diluted sidestream smoke is inhaled by the involuntary smoker. The smoker's puff is taken as a bolus in a relatively small volume of air into the humid upper respiratory tract. Smoking techniques vary widely (Griffiths and Henningfield 1982) and have been shown to vary significantly among groups classified as healthy smokers compared with those with emphysema and also between those with emphysema and those with bronchogenic carcinoma and bronchitis (Medici et al. 1985). Some smokers hold the puff in the mouth for several seconds prior to deep inhalation. The initial puff is highly concentrated, with approximately 10^9 particles/cm^3. At this concentration, particle coagulation can occur rapidly, causing a tenfold to a hundredfold reduction in particle number and an increase in particle size (Hinds 1982). Also, the accumulation of water in or on the particles in the high humidity of the respiratory tract can increase particle diameter (Muir 1974), and may increase the diameter as much as 30 percent (Mitchell 1962). Some evidence suggests, however, that at least for dilute cigarette smoke, hygroscopic growth occurs only under supersaturated conditions (Kousaka et al. 1982). Coagulation and water uptake by particles in the respiratory tract may considerably alter particle size distributions so that measurements under laboratory conditions probably do not

TABLE 1.—Size distribution of mainstream tobacco smoke

Study	Size (μm), concentration [no. particles/cm³]	Dilution	Method	Comment
Wells and Gerke (1919)	CMD 0.27	Not given	Oscillation amplitude	
Sinclair (1950)	CMD 0.0–0.3 fresh CMD 0.4–0.5 aged		Light scattering	Aged: size increase attributed to water accumulation
DallaValle et al. (1954)	0.1–0.25	Not given	Electrostatic separation	
Langer and Fisher (1956)	CMD 0.5 filter CMD 0.6 plain [2–5 x 10⁹]	143:1	Microscopic impinger collection	Compared with electrostatic precipitation GSD 1.75
Keith and Derrick (1960)	CMD 0.23 MMD 0.45	295:1	Aerosol centrifuge Microscopic	GSD 1.64 Calculated
Porstendörfer and Schraub (1972)	CMD 0.22 [5–7 x 10⁹]	100,000:1	Related rate of deposition of radioactive decay products onto particles to particle size	Also measured deposition
Porstendörfer (1973)	CMD 0.42 CMD 0.22	10:1 3,100:1	Radon daughter attached and deposited in spiral centrifuge	
Okada and Matsunuma (1974)	CMD 0.18 MMD 0.29	1,500:1	Light scattering	GSD 1.48

TABLE 1.—Continued

Study	Size (μm), concentration [no. particles/cm³]	Dilution	Method	Comment
Hinds (1978)	MMD 0.38–0.52 CMD 0.4 CMD 0.27	10:1–700:1 10:1 3,100:1	Aerosol centrifuge	Size distribution decreases as dilution increases GSD 1.3–1.5
McCusker et al. (1982)	MMD 0.29–4.3 [4.2 x 10⁹]	126,000:1	Laser doppler velocimetry	Aerodynamic diameter GSD 1.4
Chang et al. (1984)	CMD 0.24–0.26 [3.6 x 10⁹] MMD 5.5 secondary mode	6:1–18:1 1–8 x 10⁶	Electrical aerosol analyzer (EAA) Anderson Cascade Impactor (CI)	Bimodal distribution Primary mode (EAA) GSD 1.18 Second mode (CI) 5%–30% of total mass

NOTE: CMD = count median diameter; MMD = mass median diameter; GSD = geometric standard deviation.

TABLE 2.—Size distribution of sidestream tobacco smoke

Study	Size (μm)	Dilution	Method	Comment
Keith and Derrick (1960)	CMD 0.15	295:1 Centrifuge	Aerosol centrifuge	Nature of sidestream smoke generation process makes difficult exact determination of concentration at generation and dilution
Porstendörfer and Schraub (1972)	CMD 0.24	Not given	Related rate of deposition of radioactive decay products onto particles to particle size	
Hiller, McCusker et al. (1982)	CMD 0.31	Not given	Laser doppler velocimetry	GSD 1.6

NOTE: CMD = count median diameter; GSD = geometric standard deviation.

represent distributions found in actual mainstream smoking conditions.

Sidestream Smoke

Sidestream smoke is generated by cigarettes burning spontaneously between puffs and is quantitatively the major contributor to ETS. Fifty-five percent of the tobacco in a cigarette is burned between puffs, forming sidestream smoke (see Chapter 3). Dilution takes place as smoke rises in the ambient air currents. This dilution with air reduces, but probably does not eliminate entirely, the coagulation that causes the particulate to increase in size, as they may in the highly concentrated state that occurs when a smoker draws a puff of mainstream smoke into the mouth and holds it briefly before inhalation. The size distribution of sidestream smoke might be expected to resemble that of diluted mainstream smoke. The results of several reports of sidestream smoke size measurements (Table 2) support this impression.

Particle Deposition in the Respiratory Tract

Total Deposition

Total deposition has been studied both theoretically and experimentally. Mathematical equations can be used to predict deposition by combining mathematical models of lung anatomy with equations describing the behavior of particles in tubes. The major property to be considered is particle size and its influence on impaction, sedimentation, and diffusion. Inertial impaction is the mechanism

that causes particles moving in an airstream to be unable, because of excessive mass, to follow the airstream around a bend. Large particles impact at the bend in the airstream or in the lung on or near a site of airway branching. The larger the particle the greater its chance of depositing by impaction. Impaction is a relatively unimportant form of deposition for particles smaller than 0.5 μm. The effect of gravity on suspended particles causes them to fall, a process called sedimentation, which also becomes relatively unimportant for particles less than 0.5 μm in size. Larger particles fall faster, and for all particles, the greater the residence time (in the lung) the greater the likelihood of deposition by sedimentation. Diffusion is the net transport of particles caused by Brownian motion. It becomes increasingly important for particles less than 0.5 μm in size (Hinds 1982). The mass median diameter of sidestream smoke is in the 0.3 to 0.5 μm size range. Total deposition for inhaled particles is in the 10 to 30 percent range for 0.5 μm sized particles.

In Figure 1, Lippmann's review (1977) of the measurements of total deposition of monodisperse aerosols in human subjects is modified to include more recent data and data on ultrafine particle deposition.

The respiratory pattern clearly affects particle deposition. Most important for all particles, including environmental tobacco smoke, is the residence time in the lung. Deposition increases with slow deep inspiration (Altshuler et al. 1957) and with breath holding (Palmes et al. 1966; Anderson and Hiller 1985). In hamsters, the deposition of 0.38 μm particles rises in a nearly linear fashion with oxygen consumption (Harbison and Brain 1983). These data indicate that deposition of ETS during involuntary smoking increases with the increasing activity level of the exposed individual.

The presence of an electrical charge on particles may increase deposition. Mainstream smoke is highly charged (Corn 1974). The addition of either a positive charge or a negative charge to inhaled particles increases deposition in animals (Fraser 1966), and neutralization of the charge reduces deposition 21 percent in rats (Ferin et al. 1983). There is little information describing the effect of a charge on the deposition of either mainstream or sidestream smoke in human subjects.

Particle growth by water absorption may affect deposition. Mathematical models that describe the effect of humidity on particle growth indicate the potential for a considerable change in size of some particles during transit in the humid re ˜iratory tract (Ferron 1977; Cocks and Fernando 1982; Renninger et al. 1981; Martonen and Patel 1981) and that these changes could significantly alter deposition (Ferron 1977). Growth of 0.4 to 0.5 μm particles should increase their deposition fraction, but growth of a 0.07 μm particle to 0.1 μm, for example, would reduce its deposition (see Figure 1). Such
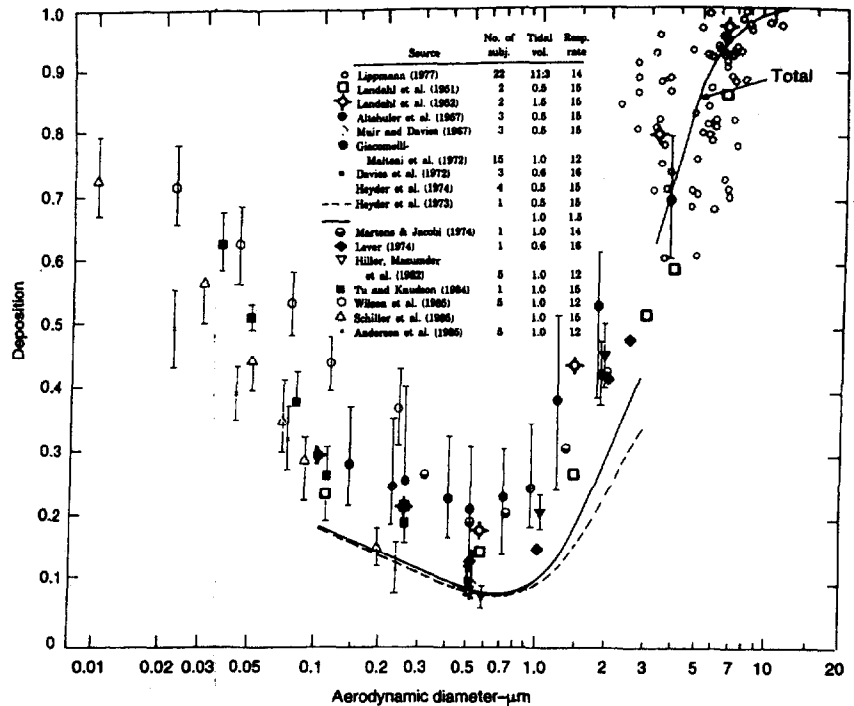
**Figure 1.—Total respiratory tract deposition of inhaled
inert particles during oral inhalation**

NOTE: The portion of the figure from 0.01 to 0.1 μm was added to a previously published illustration of total deposition (Lippmann 1977); sources for both are indicated. The original and the additions together encompass the complete smoke particle size range.

an effect has been shown for laboratory-generated aerosols in human subjects (Blanchard and Willeke 1983; Tu and Knudson 1984). While hygroscopic growth has been postulated for tobacco smoke (Muir 1974), it has been demonstrated in the laboratory to occur, at least for dilute smoke, only in supersaturated conditions (Kousaka et al. 1982).

Many reports describe measured deposition of mainstream cigarette smoke in the human respiratory tract (Table 3). Although few studies of total sidestream smoke deposition are available, those few (Table 3) suggest that sidestream smoke does indeed deposit in a manner similar to that found for laboratory-designed research aerosols. The deposition fraction of mainstream smoke diluted 1:30 and inhaled by rats from chamber air containing 1.68 mg/L (assuming a rat tidal volume of 1.5 mL and a respiratory rate of 85) is

188

8.1 percent (Binns et al. 1978). Deposition for the sidestream smoke has been measured in mouth-breathing human volunteers at 11 percent, similar to that for similarly sized polystyrene latex spheres (Hiller, Mazumder et al. 1982). Environmental tobacco smoke exposure frequently occurs with breathing through the nose rather than through the mouth, but inert particles in the size range of ETS (0.2 to 0.4 μm) are not substantially reduced in number by passage through the nose. The fraction of inert 0.2 μm particles deposited in the alveolar region of the lung is similar for mouth breathing and nasal breathing (Raabe 1984). It is possible that the charged or reactive particles of ETS may behave somewhat differently than inert particles, but it seems unlikely that nasal breathing substantially alters the deposition of the small particles of ETS in comparison with mouth breathing.

Regional Deposition

Total deposition is subdivided into the fractions depositing in the upper respiratory tract (larynx and above), the tracheobronchial region (trachea to and including terminal bronchioles), and the pulmonary region (respiratory bronchioles and beyond) (Figure 2). Deposition in these areas is referred to as regional deposition. Particle size is a major determinant of both total and regional deposition. A mathematical model prediction of regional deposition of polydisperse aerosols is shown in Figure 2 (ICRP 1966).

Experimental verification of mathematical models of regional deposition is limited. Using isotope-labeled particles, it is possible to quantitate the upper respiratory tract deposition as a fraction of total deposition. By assuming that the aerosol depositing in the tracheobronchial region will be cleared within 24 hours, it is possible to measure alveolar deposition as the fraction of the total initial deposition below the larynx that is remaining at 24 hours and tracheobronchial deposition as the difference between the initial deposition and what is remaining at 24 hours. Using this method, the deposition of 3.5 μm particles was this: total deposition, 0.79; upper respiratory tract, 0.10; tracheobronchial region, 0.24; and pulmonary region (alveolar), 0.45 (Emmett et al. 1982). These measurements are below the estimated regional deposition for upper respiratory tract deposition and higher for the pulmonary deposition than are the measurements calculated by using the Task Group on Lung Dynamics model (ICRP 1966).

The regional deposition of mainstream cigarette smoke in smokers has also been studied. Subjects inhaled smoke from cigarettes labeled with radioactive 1-iodohexadecane (Black and Pritchard 1984; Pritchard and Black 1984). The results indicate that less than 40 percent of the particulate mass deposited in the pulmonary region, compared with an expected 90 percent deposition in the

TABLE 3.—Respiratory tract deposition of mainstream and sidestream cigarette ᴅᴍᴜᴋᴏ

Study	Deposition fraction	Puff volume (mL)	Puff time (second)	Smoke dilution	Respiratory pattern
Mainstream smoke					
Baumberger (1923)	88%	Not given	Not given	None	Inhalation
Schmahl et al. (1954)	98%				
Polydorova (1961)	80% (22–89 range)			None	Usual spontaneous smoking pattern
Mitchell (1962)	82% (70–90 range)	45 ± 9.8 SD (33–65 range)	1.9 ± 0.6 SD	300:1	"Deep inhalation"
Dalhamn et al. (1968)	96% ± 3.1% SD (86–99 range)	35	2	None	Pretrained standardized pattern (not described)
Hinds et al. (1983)	47% (22–75 range)	53		None	Usual spontaneous smoking pattern
Sidestream smoke					
Binns et al. (1978)	8%	Not applicable		30:1 (in chamber)	Spontaneous (rats)
Hiller, McCusker et al. (1982)	11%	Not applicable		50–100 µg/m³	1 L tidal volume, 12 breaths/min
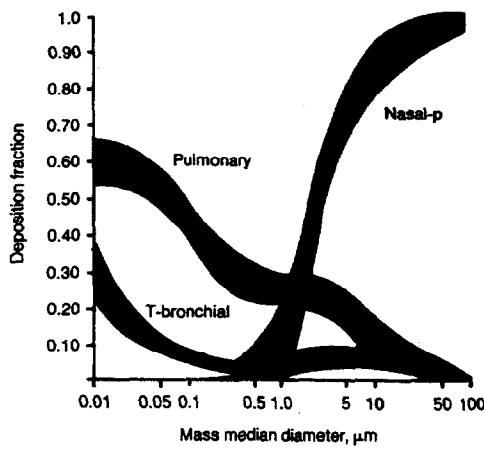
Figure 2.—Regional deposition of particles inhaled during
nasal breathing, as predicted using the
deposition model proposed by the Task Group
on Lung Dynamics

pulmonary region for 0.5 μm particles, the size reported for cigarette
smoke (Table 1). This finding further supports the concept that
mainstream smoke particles increase in size in the respiratory tract
by coagulation, hygroscopic growth, or both, and that this growth
affects total and regional deposition. The same group studied the
effect of switching the tar content of cigarettes on regional deposi-
tion. Using cigarettes with between 16 and 17 mg tar, extrathoracic
deposition was found to be 14 percent of the total deposition and
intrathoracic deposition to be 86 percent, with 51 percent in the
tracheobronchial area and 35 percent in the pulmonary region
(Pritchard and Black 1984). After switching to cigarettes with
between 8 and 9 mg tar, total deposition was 74 percent of that
measured from cigarettes with the higher tar content, the extratho-
racic deposition was unchanged, the tracheobronchial deposition was
from 34 to 42 percent, and the pulmonary deposition was 18 to 25
percent of the total mass deposited with the higher tar cigarettes.
With the use of mathematical deposition modeling, the observed
deposition pattern was consistent with one predicted for an aerosol
with an MMD of 6.5 μm, more than 10 times greater than the MMD
described for cigarette smoke (Black and Pritchard 1984).

The deposition of particles is probably not uniform within a lung
region. The mass deposited in the airways, for instance, may vary

191

widely. Enhanced deposition at specific anatomic sites may be especially important for some inhalants. For example, the concentration of carcinogenic substances at a site may favor that site for cancer development. This may be especially important for cigarette smoke, since lung cancer may occur at sites of high deposition such as airway bifurcations. Deposition of a 0.3 μm laboratory-generated stable aerosol has been shown to favor right upper lobe deposition, and on the basis of surface density of deposition, the lobar bronchi (Schlesinger and Lippmann 1978). The deposition per airway generation has been calculated for large particles, but has not received sufficient attention for particles in the size range of mainstream or sidestream smoke. A deposition peak has been predicted, using a lung model for the fourth airway generation (trachea is 0) for 5 μm particles, and a peak in airway surface concentration density was predicted for 8 μm particles at the fourth generation (Gerrity et al. 1979). Both of these deposition peaks are calculated for particles substantially larger than those of cigarette smoke.

Depositions may be quite nonuniform even within a single airway generation. An enhanced deposition at bifurcations with highly concentrated deposition on carina ridges within bifurcations has been demonstrated in a five airway generation model of the human respiratory tract for both cigarette smoke (Martonen and Lowe 1983a) and research aerosols (Martonen and Lowe 1983b).

Epidemiological studies of the pathophysiologic consequences of involuntary smoking have emphasized, among other things, an increase in the incidence of respiratory illness in children (see Chapter 2). The issue of the respiratory tract deposition of particles in children has been addressed only recently. Using morphometric measurements from casts of the lungs of children and young adults aged 11 days to 21 years, a mathematical growth model was created. Using this model and conventional methods for predicting the behavior of particles in tubes, the deposition of particles at various ages can be predicted. On the basis of these calculations, tracheobronchial depositions per kilogram of body weight for 5 μm particles was estimated to be six times higher in the resting newborn than in a resting adult (Phalen et al. 1985). Differences are predicted also for particles the size of sidestream smoke, with tracheobronchial deposition in infancy being twofold to threefold higher in adulthood. Total deposition has also been estimated using mathematical modeling, with the total deposition estimated at approximately 15 percent at age 6 months and at 10 percent in adults (Xu and Yu 1986).

192

Respiratory Tract Dose of Environmental Tobacco Smoke

Cigarette Smoke Particulate Mass Deposited

The dose of environmental tobacco smoke to the respiratory tract is the product of the mass in inhaled air and the deposition fraction. To this point, particle size and deposition fraction, which is related to both size and respiratory pattern as well as to other less understood factors such as particle charge and hygroscopicity, have been addressed. To estimate dose, the content of smoke in inhaled air must be known, as well as the respired minute volume. Mass content in inhaled air varies widely, as does minute volume, which depends considerably on activity level. Sidestream smoke concentrations have been raised as high as 16.5 mg/m^3 in experimental chambers (Hoegg 1972). High levels, 2 to 4 mg/m^3, have also been estimated using measured carbon monoxide concentrations for rooms 140 m^3 in size containing 50 to 70 persons (Bridge and Corn 1972). Such levels far exceed the EPA air quality standards for total suspended particulate of 75 μg/m^3 annual average and the 260 μg/m^3 24-hour average in the United States and the 250 μg/m^3 24-hour average for the United Kingdom.

Measurements of environmental smoke concentrations vary widely, depending upon the location and measurement technique (Tables 4 and 5). Levels of total suspended particulates (TSP) measured under realistic circumstances have been found to be from 20 to 60 μg/m^3 in no-smoking areas, and can range from 100 to 700 μg/m^3 in the presence of smokers (Repace and Lowrey 1980). These measurements include all suspended particulates, and so could include particles other than tobacco smoke. However, in a smoky indoor setting where measurements as high as 600 μg/m^3 have been found, tobacco smoke is the major contributor to particulate mass, with the non-tobacco-smoke contribution being small and similar to that measured for nonsmoking areas, namely in the 20 to 60 μg/m^3 range. This concept is supported by studies in which tobacco smoke concentration in the environment was determined by measuring the nicotine content of suspended particulates. Using this technique (Hinds and First 1975), ETS levels have been estimated to be 20 to 480 μg/m^3 in bus and airline waiting rooms and as high as 640 μg/m^3 in cocktail lounges. These calculations of smoke concentrations were based on an average weighted nicotine fraction of 2.6 percent, an approach that may underestimate tobacco smoke particulate concentration.

The mass deposition in the respiratory tract can be estimated if the atmospheric burden of cigarette smoke particulates, minute volume, and deposition fraction is known. Assuming a smoke concentration of 500 μg/m^3, a minute volume of 12 liters per minute,

TABLE 4.—Indoor concentration of total suspended particulates (TSP) measured in ordinary living or working situations

Study	Location	Conditions of location, occupancy, smoking (S), nonsmoking (NS)	TSP µm/m³ x ±SD	Background µm/m³	Comments
Just et al. (1972)	Coffee shop	4 locations	1,150	570[1]	
Hinds and First (1975)	Bus waiting room		40 (16–58)	Not applicable	Suspended particulates collected on filter; nicotine content measured for calculation; TSP = nicotine/0.026
	Restaurant	Not given	200 (51–450)		
	Cocktail lounge	Not given	400 (170–640)		
Elliott and Rowe (1975)	Arena A	Attendance 9,600 Air conditioned (S)	224	42	High volume sampler for suspended particulates; also measured CO at all locations and benzo[a]pyrene in arena A
		Attendance 14,300 Air conditioned (S)	481	42	
	Arena B	Attendance 2,000 Not air conditioned (S)	620	92	
	Arena C	Attendance 11,000 Natural ventilation (NS)	148	71	
Cuddeback et al. (1976)	Tavern	6 air changes/hr	0.31 ± 0.05 (0.23–0.34)		8-hr air sample collected on filter (5 µm pore size); TSP measured gravimetrically
	Tavern	None apparent	0.99		
Neal et al. (1978)	Hospital intensive care units	Independent ventilation systems	30	68	Anderson personnel sampler used

TABLE 4.—Continued

Study	Location	Conditions of location, occupancy, smoking (S), nonsmoking (NS)	TSP μm/m³ x ±SD	Background μm/m³	Comments
Weber and Fischer (1980)	44 offices	Window ventilation; 32/44 allowed unrestricted smoking	202	Subtracted from TSP	TSP measured with piezoelectric balance (see above)
		Air conditioned	120	Same	
Repace and Lowrey (1980)	Residences	5 locations, 6 measurements; 10 ± 8 persons/100 m³, all NS	38 ± 16	Not done	All samples collected using piezoelectric balance with very high collection efficiency at 3.5 μm and 10% at 4 μm; sample time 1–50 min, outdoors 5–15 min
	Libraries, churches, restaurants	9 locations; 10 ± 10 persons/100 m³, all NS	38 ± 16	36 ± 10[1] (4 locations)	
	Restaurants, bars, bingo game	19 locations, 20 samples, 11 ± 8 persons/100 m³, all S locations	242 ± 175 (86–697)	47 ± 13[1] (13 locations)	
		7 locations with >1 smoker/m³ (mean 2.2 smokers/m³) 18 ± 7 persons/100 m³, with 1 smoker/100 m³	406 ± 188 (187–697)	53 ± 8[1]	

TABLE 4.—Continued

Study	Location	Conditions of location, occupancy, smoking (S), nonsmoking (NS)	TSP $\mu m/m^3$ x ±SD	Background $\mu m/m^3$	Comments
Spengler et al. (1981)	35 homes	No smokers	24.4 ± 11.6[1]	21.1 ± 11.9 all 55 homes	Annual mean: respirable mass collected on filters after removal of nonrespirable fraction; 24-hr sample collected every 6 days
	15 homes	1 smoker	36.5 ± 14.5		
	5 homes	2 smokers	70.4 ± 42.9		
	1 home[2]	2 smokers, tightly sealed, central air conditioning	144		

[1] Ambient particulate concentration at site, but outdoors.

[2] This home is one of the five homes above.

TABLE 5.—Indoor concentration of total suspended particulates (TPM) generated by smoking cigarettes under laboratory conditions

Study	Test conditions	Ventilation	Chamber size	Cigarette consumption	TPM mg/m³	Comments
Penkala and de Oliveira (1975)	Well mixed	None	9.2 m³	3 simultaneously, 2 q puffs	3.8	
Hoegg (1972)	Sealed chamber; experimenter and test equipment in chamber; measured 18 min postsmoking	Portable fans circulated air	25 m³	24 simultaneously by machine	16.65	TPM measured gravimetrically after collection of suspended particulates on filters; sidestream smoke collected in chamber; mainstream smoke discharged
	Same, 150 min postsmoking	Same		4 simultaneously by machine	1.51	
Hugod et al. (1978)	Sealed room	Unventilated	68 m³	20 simultaneously by machine	5.75	TPM measured gravimetrically from 3-hr collection on filter; mainstream smoke in chamber
Cain et al. (1983)	4–12 occupants Climate-controlled chamber	11 ft³/min/occupant	11 m³	4/hr (by occupants)	0.350	Piezoelectric balance measured total mass over 0.01–20 μm
		68 ft³/min/occupant	11 m³	4/hr (by occupants)	0.15	
		11 ft³/min/occupant	11 m³	16/hr (by occupants)	1.25	
		68 ft³/min/occupant	11 m³	16/hr (by occupants)	0.40	
Muramatsu et al. (1983)	Climate-controlled chamber	15.4 air changes/hr	30 m³	1/8 min to 60 min	0.19–0.26	Piezoelectric balance
	Climate-controlled chamber	15.4 air changes/hr	30 m³	3 simultaneously, then 2/8 min	0.47–0.522	

and a deposition fraction of 11 percent (Hiller, McCusker et al. 1982), mass deposition over an 8-hour work shift would be 0.317 mg.

The Concept of "Cigarette Equivalents"

Many investigators have attempted to estimate the potential toxicity of involuntary smoking for the nonsmoker by calculating "cigarette equivalents" (C.E.). To inhale one C.E. by involuntary smoking, the involuntary smoker would inhale the same mass quantity of ETS as is inhaled from one cigarette by a mainstream smoker. This approach has led to estimates from as low as 0.001 C.E. per hour to as high as 27 C.E. per day (Hoegg 1972; Hinds and First 1975; Hugod et al. 1978; Repace and Lowrey 1980). These differences of up to three orders of magnitude seem illogical when most reports of measurements of environmental concentrations of smoke, from the most clean to the most polluted with environmental tobacco smoke, are within tenfold to fiftyfold of each other. The following discussion demonstrates why the C.E. can vary so greatly as a measure of exposure.

The calculation of C.E. is as follows: $PMI_{(p)} = TSP$ (mg/m^3) x $\dot{V}_E$; where $PMI_{(p)}$ equals the particulate mass inhaled by passive smoking, TSP equals the total suspended particulate, and $\dot{V}_E$ equals the inhaled volume. C.E. $= PMI_{(p)}/PMI_{(ms)}$; where C.E. equals cigarette equivalent and $PMI_{(ms)}$ equals the mass inhaled by (mainstream) smoking one cigarette. (This is taken to be the tar content of a cigarette as reported by the U.S. Federal Trade Commission.)

Cigarette equivalents can be calculated for any time interval chosen, i.e., per hour, per day. Although the example given is for particulate mass, C.E. can be calculated for any component of cigarette smoke, such as carbon monoxide and benzo[a]pyrene. The following calculations illustrate the different results from two different approaches to the calculation of C.E.

	Example 1	Example 2
$\dot{V}_E$	0.36 m^3/hr	20 m^3/day
$PMI_{(ms)}$	16.1 mg tar/cig	0.55 mg tar/cig
TSP	40 µg/m^3	700 µg/m^3

Example 1

$$
\begin{aligned}
PMI_{(p)} &= TSP \times \dot{V}_E \\
&= 40 \text{ µg/m}^3 \times 0.36 \text{ m}^3/\text{hr} \\
&= 14.4 \text{ µg/hr}
\end{aligned}
$$

$$
\begin{aligned}
C.E. &= PMI_{(p)}/PMI_{(ms)} \\
&= (0.0144 \text{ mg/hr})/(16.1 \text{ mg/cig}) \\
&= 0.001 \text{ cig/hr}
\end{aligned}
$$

198

Example 2

$$PMI_{(p)} = TSP \times \dot{V}_E$$
$$= 700 \ \mu g/m^3 \times 20 \ m^3/day$$
$$= 14,000 \ \mu g/day$$

$$C.E. = PMI_{(p)}/PMI_{(ms)}$$
$$= (14 \ mg/day)/(0.55 \ mg/cig)$$
$$= 25 \ cig/day$$

These calculations of C.E. approximate the approaches used in two reports—Example 1 by Hinds and First (1975) and Example 2 by Repace and Lowrey (1980)—and the results are similar. The examples are the extremes used in the two studies, and are at the extremes of commonly cited reports of C.E. Even if the TSP concentration used in the two examples were the same, the results would differ 24-fold because Example 1 is calculated per hour and Example 2 is calculated per day; 2.3-fold because of the difference in inhaled minute volume; and 29-fold because of the difference in what is considered to be a "standard" cigarette. Even using the same TSP concentration, the results would be 1.6×10^3 different. If C.E. is to be calculated, all of the factors used in the calculation should be standardized.

The calculation of C.E. is deficient in several other ways. The deposition fraction of the total inhaled particulate mass in the respiratory tract from mainstream smoke is higher than from involuntary smoking. The deposition fraction for involuntary smoking is approximately 11 percent for mouth breathing (Hiller, Mazumder et al. 1982). The deposition from mainstream smoke has been reported to vary from 47 to 90 percent (Table 3). The cigarette equivalent calculation considers only the quantity inhaled, and if mass dose deposited is considered, one C.E. from passive smoking will cause several times less mass to be deposited than the mainstream smoke of one cigarette.

The differences in the chemical composition between sidestream smoke and mainstream smoke make the C.E. concept misleading unless C.E. is calculated for each smoke constituent. This has been accomplished (Hugod et al. 1978) using measured levels of various smoke constituents in a chamber filled with sidestream smoke. The results indicate that one C.E. for carbon monoxide could be inhaled 5.5 times faster, and for aldehyde, 2.9 times faster, than for particulate mass. Measurements of total particulate matter and benzo[a]pyrene taken in an arena with active smoking revealed a fivefold rise in TSP above background and an eighteenfold increase in benzo[a]pyrene over background. Using the measured benzo[a]pyrene concentration of 21.7 ng/m^3, an inhaled volume of 2.4 m^3, and 8.2 ng benzo[a]pyrene per cigarette, the occupant of such an environment would consume 6.4 C.E. for benzo[a]pyrene (IARC 1986, p. 87). The C.E. TSP would be 1.7. Therefore, a C.E. for the

carcinogen benzo[a]pyrene would be inhaled 3.6 times more rapidly than a C.E. for TSP (Elliott and Rowe 1975).

The wide latitude in the results of C.E. calculations demonstrates the dependence of the C.E. calculation on the numerical values of the variables chosen, and correspondingly demonstrates the marked limitations of the use of C.E. as an atmospheric measure of exposure to the agents in environmental tobacco smoke. When the quantification of an exposure is needed, it is far more precise to use terms that define the milligrams of exposure to the agent of interest per unit time. However, the term cigarette equivalent is frequently used, not simply as a measure of exposure, but as a unit of disease risk that translates the measured exposures into a risk of disease using the known dose–response relationships between the number of cigarettes smoked per day and the risk of disease. If C.E. is to be used as a unit of risk, the variables used to convert atmospheric measures into levels of risk for the active smoker need to be determined on the basis of the deposition and smoke exposure measures for the average smoker. The deposition fraction of individual smoke constituents in the population of active smokers is needed rather than the range observed in a few individuals. In addition, the actual average yield of the cigarettes smoked by the subjects in the prospective mortality studies would be needed to compare the dose–response relationships accurately. The yield using the Federal Trade Commission (FTC) method may dramatically underestimate the actual yield of a cigarette when the puff volume, rate of draw, or number of puffs is increased; therefore, calculations using the FTC numbers may be inaccurate, particularly for the low-yield cigarettes. These limitations make extrapolation from atmospheric measures to cigarette equivalent units of disease risk a complex and potentially meaningless process.

Markers of Absorption

In contrast, measures of absorption of environmental tobacco smoke, particularly cotinine levels, can potentially overcome some of the limitations in translating environmental tobacco smoke exposures into expected disease risk. Urinary cotinine levels are a relatively accurate dosage measure of exposure to smoke; they have been measured in populations of smokers and nonsmokers, and are not subject to errors in estimates of the minute ventilation or yield of the average cigarette. Potential differences in the half-life of cotinine in smokers and nonsmokers, differences in the absorption of nicotine relative to other toxic agents in the smoke, and differences in the ratio of nicotine to other toxic agents in mainstream smoke and sidestream smoke remain sources of error, but the accuracy with which active smoking and involuntary smoking exposure can be

compared is almost certainly substantially greater with measures of absorption than with atmospheric measures.

Tobacco smoke contains many substances, but only a few have been measured in human biological fluids. Of the gaseous components, markers include carbon monoxide and thiocyanate. The latter is not a gas but a metabolite of gaseous hydrogen cyanide. Concentrations of nicotine and its metabolite cotinine are markers of nicotine uptake. In mainstream smoke, nicotine uptake reflects exposure to particulates. In environmental tobacco smoke, nicotine becomes vaporized and therefore reflects gas phase exposure (Eudy et al. 1985). Quantitating tar consumption is more difficult; urinary mutagenic activity has been used as an indirect marker.

The relative exposures of nonsmokers to various tobacco smoke constituents differs from that of smokers. Assuming that exposure to a single tobacco smoke constituent accurately quantifies the exposure of both smokers and nonsmokers to other constituents is inaccurate because mainstream smoke and environmental tobacco smoke differ in composition (see Chapter 3).

To understand the usefulness and limitations of various biochemical markers, it is important to appreciate the factors that influence their absorption by the body and their disposition kinetics within it.

Carbon Monoxide

Carbon monoxide is absorbed in the lungs, where it diffuses across the alveolar membrane (Lawther 1975; Stewart 1975). It is not appreciably absorbed across mucous membranes or bronchioles. Within the body, carbon monoxide binds, as does oxygen, to hemoglobin, where it can be measured as carboxyhemoglobin. Carbon monoxide may also be bound to myoglobin and to the cytochrome enzyme system, although quantitative details of binding to the latter sites are not available. Carbon monoxide is eliminated primarily by respiration. The amount of ventilation influences the rate of elimination. Thus, the half-life of carbon monoxide during exercise may be less than 1 hour, whereas during sleep it may be greater than 8 hours (Castleden and Cole 1974). At rest, the half-life is 3 to 4 hours.

The disposition kinetics of carbon monoxide explain the temporal variation of carbon monoxide concentration in active smokers during a day of regular smoking. With a half-life averaging 3 hours and a reasonably constant dosing (that is, a regular smoking rate), carbon monoxide levels will plateau after 9 to 12 hours of cigarette smoking. This has been observed in studies of circadian variation of carbon monoxide concentrations in cigarette smokers (Benowitz, Kuyt et al. 1982). Smoking is not a constant exposure source, but results in pulsed dosing. There is a small increment in carboxyhemoglobin level immediately after smoking a single cigarette, which then

declines until the next cigarette is smoked. But after several hours of smoking, the magnitude of rise and fall is small compared with the trough values. For this reason, carboxyhemoglobin levels at the end of a day of smoking are satisfactory indicators of carbon monoxide exposure during that day.

Carbon monoxide exposure may be more constant during environmental tobacco smoke exposure than during active smoking. The major limitation in using carbon monoxide as a means of measuring involuntary smoke exposure is its lack of specificity. Endogenous carbon monoxide generation from the metabolism of hemoglobin results in a low level of carboxyhemoglobin (up to 1 percent) (Lawther 1975; Stewart 1975). Carbon monoxide is generated by any source of combustion, including gas stoves, machinery, and automobile exhaust. Thus, nonsmokers in a community with moderate home and industrial carbon monoxide sources may have carboxyhemoglobin levels of 2 or 3 percent (Woebkenberg et al. 1981). A carbon monoxide level of 10 in room air results in an increment of 0.4 and 1.4 percent carboxyhemoglobin at 1 and 8 hours of exposure time, respectively (Lawther 1975; Stewart 1975). Thus, small increments of carbon monoxide due to environmental tobacco smoke may be indistinguishable from that due to endogenous and non-tobacco-related sources.

Measurement of carbon monoxide is straightforward and inexpensive. Alveolar carbon monoxide pressures are proportional to the concentration of carboxyhemoglobin in blood; therefore, end-tidal carbon monoxide tension accurately reflects blood carboxyhemoglobin (Jarvis and Russell 1980). Expired carbon monoxide can be measured using an instrument (Ecolyzer) that measures the rate of conversion of carbon monoxide to carbon dioxide as it passes over a catalytically active electrode. Blood carboxyhemoglobin can be measured directly and quickly using a differential spectrophotometer.

Thiocyanate

Hydrogen cyanide is metabolized by the liver to thiocyanate. In addition to tobacco smoke, certain foods, particularly leafy vegetables and some nuts, are sources of cyanide. Cyanide is also present in beer.

Thiocyanate is distributed in extracellular fluid and is eliminated slowly by the kidneys. The half-life of thiocyanate is long, about 7 to 14 days. Thiocyanate is also secreted into saliva, with salivary levels about 10 times that of plasma levels (Haley et al. 1983). The long half-life of thiocyanate means that there is little fluctuation in plasma thiocyanate concentrations during a day or from day to day. Thus, the time of sampling is not critical. On the other hand, a given level of thiocyanate reflects exposure to hydrogen cyanide over

202

several weeks preceding the time of sampling. When a smoker stops smoking, it takes an estimated 3 to 6 weeks for thiocyanate levels to reach that individual's nonsmoking level.

Because of the presence of cyanide in foods, thiocyanate is not specific for exposure to cigarette smoke. Although active smokers have plasma levels of thiocyanate two to four times those of nonsmokers (Vogt et al. 1979; Jacob et al. 1981), light smokers or involuntary smokers may have little or no elevation of thiocyanate. When thousands of subjects are studied, involuntary smokers have been found to have slightly higher thiocyanate levels than those without exposure (Friedman et al. 1983). Other studies of smaller numbers of subjects have shown no difference in thiocyanate level between exposed or nonexposed nonsmokers (Jarvis et al. 1984).

Serum or plasma thiocyanate levels can be measured using spectrophotometric methods or, alternatively, gas chromatography.

Nicotine

Nicotine is absorbed through the mucous membranes of the mouth and bronchial tree as well as across the alveolar capillary membrane. The extent of mucosal absorption varies with the pH of the smoke, such that nicotine is absorbed in the mouth from alkaline (cigar) smoke or buffered chewing gum, but very little is absorbed from acidic (cigarette) mainstream smoke (Armitage and Turner 1970). With aging, environmental tobacco smoke becomes less acidic; pH may rise to 7.5, and buccal or nasal absorption of nicotine by the nonsmoker could occur (see Chapter 3).

Nicotine is distributed rapidly to body tissues and is rapidly and extensively metabolized by the liver. Urinary excretion of unmetabolized nicotine is responsible for from 2 to 25 percent of total nicotine elimination in alkaline and acid urine, respectively; nicotine excretion also varies with urine flow (Rosenberg et al. 1980). Exposure to environmental tobacco smoke, active smoking, and use of smokeless tobacco markedly elevate salivary nicotine transiently out of proportion to serum and urinary levels (Hoffmann et al. 1984). Nicotine is present in breast milk (Luck and Nau 1985), and the concentration in the milk is almost three times the serum concentration in the mother (Luck and Nau 1984).

The rate of nicotine metabolism varies considerably, as much as fourfold among smokers (Benowitz, Jacob et al. 1982). There is evidence that nicotine is metabolized less rapidly by nonsmokers than by smokers (Kyerematen et al. 1982). A given level of nicotine in the body reflects the balance between nicotine absorption and the metabolism and excretion rates. Thus, in comparing two persons with the same average blood concentration of nicotine, a rapid metabolizer may be absorbing up to four times as much nicotine as a slow metabolizer. To determine daily uptake of nicotine directly,

203

both the nicotine blood concentrations and the rates of metabolism and excretion must be known. These variables can be measured in experimental studies (Benowitz and Jacob 1984; Feyerabend et al. 1985), but are not feasible for large-scale epidemiologic studies.

The time course of the decline of blood concentrations of nicotine is multiexponential. Following the smoking of a single cigarette or an intravenous injection of nicotine, blood concentrations of nicotine decline rapidly owing to tissue uptake, with a half-life of 5 to 10 minutes. If concentrations are followed over a longer period of time or if multiple doses are consumed so that the tissues are saturated, a longer elimination half-life of about 2 hours becomes apparent (Benowitz, Jacob et al. 1982; Feyerabend et al. 1985). Because of the rapid and extensive distribution in the tissues, there is considerable fluctuation in nicotine levels in cigarette smokers during and after smoking. As predicted by the 2-hour half-life, nicotine blood concentrations increase progressively and plateau after 6 to 8 hours of regular smoking (Benowitz, Kuyt et al. 1982). Nicotine concentrations have been sampled in the afternoon in studies of nicotine uptake during active cigarette smoking (Benowitz and Jacob 1984), and similar timing might be appropriate in assessing the plateau levels that result from continuous ETS exposure, such as during a workday.

Russell and colleagues (1985) quantitated nicotine exposure by comparing blood nicotine concentrations during intravenous infusions (0.5 to 1.0 mg over 60 minutes) in nonsmokers to the blood nicotine concentrations in nonsmokers exposed to environmental tobacco smoke. The data suggest that nicotine uptake in a smoky bar in *2 hours* averaged 0.20 mg per hour.

The presence of nicotine in biologic fluids is highly specific for tobacco or tobacco smoke exposure. Nicotine concentration is sensitive to recent exposure because of nicotine's relatively rapid and extensive tissue distribution and its rapid metabolism. Urinary nicotine concentration has been examined in a number of studies of environmental tobacco smoke exposure. Although influenced by urine pH and flow rate, the excretion rate of nicotine in the urine reflects the concentration of nicotine in the blood over the time period of urine sampling. In other words, nicotine excretion in a timed urine collection is an integrated measure of the body's exposure to nicotine during that time. When timed urine collections are not available, nicotine excretion is commonly expressed as a ratio of urinary nicotine to urinary creatinine, which is excreted at a relatively constant rate throughout the day. Urinary nicotine excretion is highly sensitive to environmental tobacco smoke exposure (Hoffmann et al. 1984; Russell and Feyerabend 1975). Saliva levels of nicotine rise rapidly during exposure to sidestream smoke and fall rapidly after exposure has ended (Hoffmann et al. 1984).

204

Presumably, this time course reflects local mouth contamination, followed by absorption or the swallowing of nicotine.

Blood, urine, or saliva concentrations of nicotine can be measured by gas chromatography, radioimmunoassay, or high pressure liquid chromatography. Sample preparation is problematic in that contamination of samples with even small amounts of tobacco smoke can substantially elevate the normally low concentrations of nicotine in the blood. Thus, careful precautions against contamination during sample collection and processing for analysis are essential. Because the concentrations are so low, the measurement of nicotine in blood has been difficult for many laboratories in the past, but with currently available assays, it is feasible for large-scale epidemiologic studies.

Cotinine

Cotinine, the major metabolite of nicotine, is distributed to body tissues to a much lesser extent than nicotine. Cotinine is eliminated primarily by metabolism, with 15 to 20 percent excreted unchanged in the urine (Benowitz et al. 1983). Urinary pH does affect the renal elimination of cotinine, but the effect is not as great as for nicotine. Since renal clearance of cotinine is much less variable than that of nicotine, urinary cotinine levels reflect blood cotinine levels better than urinary nicotine levels reflect blood nicotine levels. Plasma, urine, and saliva cotinine concentrations correlate strongly with one another (Haley et al. 1983; Jarvis et al. 1984).

The elimination half-life for cotinine averages 20 hours (range, 10 to 37 hours) (Benowitz et al. 1983). Because of the relatively long half-life of cotinine, blood concentrations are relatively stable throughout the day for the active smoker, reaching a maximum near the end of the day. Because each cigarette adds relatively little to the overall cotinine level, sampling time with respect to smoking is not critical. Assuming that smoke exposure occurs throughout the day, a midafternoon or late afternoon level reflects the average cotinine concentration.

The specificity of cotinine as a marker for cigarette smoking is excellent. Because of its long half-life and its high specificity, cotinine measurements have become the most widely accepted method for assessing the uptake of nicotine from tobacco, for both active and involuntary smoking.

Cotinine levels can be used to generate quantitative estimates of nicotine absorption. Galeazzi and colleagues (1985) defined a linear relationship between nicotine uptake and plasma cotinine levels in six healthy volunteers who received several i.v. doses of nicotine (≤ 480 µg/kg/day) for 4 days. The ability to extrapolate from this model to levels in nonsmokers is limited, however, because the elimination half-life of cotinine may be shorter in smokers than in

nsmokers, as is the elimination half-life of nicotine (Kyerematen ι al. 1982).

Cotinine can be assayed by radioimmunoassay, gas chromatography, and high pressure liquid chromatography.

Urinary Mutagenicity

Tobacco smoke condensate is strongly mutagenic in bacterial test systems (Ames test) (Kier et al. 1974). A number of compounds, including polycyclic aromatic hydrocarbons, contribute to this mutagenicity. The urine of cigarette smokers has been found to be mutagenic, and the number of bacterial revertants per test plate is related to the number of cigarettes smoked per day (Yamasaki and Ames 1977). Urinary mutagenicity disappears within 24 hours after smoking the last cigarette (Kado et al. 1985).

For several reasons, the measurement of mutagenic activity of the urine is not a good quantitative measure of tar absorption. Individuals metabolize polycyclic aromatic hydrocarbons and other mutagenic substances differently. Only a small percentage of what is absorbed is excreted in the urine as mutagenic chemicals. The bacterial system is differentially sensitive to different mutagenic compounds. The urine of smokers presumably contains a mixture of many mutagenic compounds. In addition, the test lacks specificity, in that other environmental exposures result in urinary mutagenicity. The test may also be insensitive to very low exposures such as involuntary smoking. However, one study, by Bos and colleagues (1983), indicated slightly increased mutagenic activity in the urine of nonsmokers following tobacco smoke exposure.

The presence of benzo[a]pyrene and 4-amino biphenyl covalently bound to DNA and hemoglobin in smokers (Tannenbaum et al., in press) suggests other potential measures of carcinogenic exposure. Whether such measures will be sensitive to ETS exposure is unknown. The development of specific chemical assays for human exposure to components of cigarette tar remains an important research goal.

Populations In Which Exposure Has Been Demonstrated

Absorption of tobacco smoke components by nonsmokers has been demonstrated in experimental and natural exposure conditions.

Experimental Studies

Nonsmokers have been studied after exposures in tobacco-smoke-filled rooms. The smoke may be generated by a cigarette smoking machine or by active smokers placed in the room by the investigator, or the location may be a predictably smoke-filled environment such as a bar. The level of environmental smoke has most often been

206

quantitated by measuring ambient carbon monoxide concentrations. In nonsmokers exposed for 1 hour in a test room with a carbon monoxide level of 38 ppm, carboxyhemoglobin levels increased by 1 percent and urinary nicotine increased about eightfold (Russell and Feyerabend 1975). Seven subjects in a similar study sat for 2 hours in a public house (bar) with a carbon monoxide level of 13 ppm; their expired carbon monoxide increased twofold and their urinary nicotine excretion increased ninefold (Jarvis et al. 1983). In a study exposing eight nonsmokers to a smoke-filled room for 6 hours, a small increase in urinary mutagenic activity was measured (Bos et al. 1983).

Nonexperimental Exposures

Exposure studies performed in real-life situations have compared biochemical markers of tobacco smoke exposure in different individuals with different self-reported exposures to tobacco smoke. Absorption of nicotine (indicated by urinary cotinine levels) was found to be increased in adult nonsmokers if the spouse was a smoker (Wald and Ritchie 1984). In another study (Matsukura et al. 1984), urinary cotinine levels in nonsmokers were increased in proportion to the presence of smokers and the number of cigarettes smoked at home and the presence and number of smokers at work. Blood and urinary nicotine levels were increased after occupational exposure to ETS such as a transoceanic flight by commercial airline flight attendants (Foliart et al. 1983). Nicotine absorption, documented by increased salivary cotinine concentration, has been shown in schoolchildren in relationship to the smoking habits of the parents (Jarvis et al. 1985), and using plasma, urinary, and saliva measures, in infants in relation to the smoking habits of the mother (Greenberg et al. 1984; Luck and Nau 1985; Pattishall et al. 1985).

Quantification of Absorption

Evidence of Absorption in Different Populations

One questionnaire survey indicated that 63 percent of individuals report exposure to some tobacco smoke (Friedman et al. 1983). Thirty-four percent were exposed for 10 hours and 16 percent for 40 or more hours per week. The distribution of cotinine levels in a few populations has been reported. In men attending a medical screening examination, there was a tenfold difference in mean urinary cotinine in nonsmokers with heavy exposure (20 to 80 hours per week) compared with those who reported no ETS exposure (Wald et al. 1984). The median and 90th percentile urinary cotinine concentrations for all nonsmokers who reported exposure to other people's smoke were 6.0 and 22.0 ng/mL, respectively, compared with a median of 1645 ng/mL for active smokers. In 569 nonsmoking

schoolchildren, salivary cotinine concentrations were widely distributed. Values were strongly influenced by parental smoking habits (Jarvis et al. 1985). The median and 25 to 75 percent ranges (in ng/mL) were 0.20 (0–0.5), 1.0 (0.4–1.8), 1.35 (0.7–2.7), and 2.7 (1.5–4.4) for children whose parents did not smoke or whose father only, mother only, or both parents smoked, respectively.

Quantification of Exposure

Expired carbon monoxide, carboxyhemoglobin, plasma thiocyanate, plasma or urinary nicotine, and plasma, urinary, or salivary cotinine have been used to evaluate exposure to ETS. However, successful attempts to quantify the degree of exposure have been limited largely to measurements of nicotine and cotinine. Expired carbon monoxide and carboxyhemoglobin have been found to be increased up to twofold after experimental or natural exposures (Russell et al. 1973), but not in more casually exposed subjects. Thiocyanate was slightly increased in one very large study of heavily exposed individuals (Friedman et al. 1983), but most studies report no differences as a function of involuntary smoking exposure. The most useful measures appear to be nicotine and cotinine. The data on nicotine and cotinine measurements are presented in Tables 6 and 7 and suggest the following:

(1) Both nicotine and cotinine are sensitive measures of environmental tobacco smoke exposure. Levels in body fluids may be elevated 10 or more times in the most heavily exposed groups compared with the least exposed groups.

(2) The time course of change in the levels of biochemical markers depends on which marker is selected and which fluid is sampled. There is a lag between peak blood levels of nicotine and peak blood levels of cotinine, owing to the time required for metabolism (Hoffmann et al. 1984). Salivary levels of nicotine, because of the local deposition of smoke in the nose and mouth, peak early and decline rapidly.

(3) With nicotine, salivary levels increase considerably after environmental tobacco smoke exposure, but decline rapidly following the end of exposure. Blood nicotine levels are too low to be very useful in quantitating environmental nicotine exposure. Urinary nicotine is a sensitive indicator of passive smoke exposure, but because of its relatively short half-life, urinary nicotine levels decline within several hours of the time of exposure.

(4) Cotinine levels are less susceptible than nicotine to transient fluctuations in smoke exposure. Blood or plasma, urine, and saliva concentrations correlate strongly with one another. Because of the stability of cotinine levels measured at different times during an exposure and the availability of noninvasive (i.e., urine or saliva)

TABLE 6.—Nicotine measures in nonsmokers with environmental tobacco smoke (ETS) exposure and comparisons with active smoking

Study	Number of subjects	Smoking status	Exposure level	Plasma nicotine (ng/mL) Before	Plasma nicotine (ng/mL) After	Urine nicotine (ng/mL) Before	Urine nicotine (ng/mL) After	Saliva nicotine (ng/mL) Before	Saliva nicotine (ng/mL) After
Russell and Feyerabend (1975)	12	NS	78 min in smoke-filled room	0.73	0.90	—	80 (13–206)	—	—
	14	NS	Hospital	—	—	—	12.4 (0.8–64.3)	—	—
	13	NS	employees	—	—	—	8.9 (0–26)	—	—
	18	S	Average 24 cigs/day	—	—	—	1236 (104–2733)	—	—
Feyerabend et al. (1982)	26	NS	No S exposure	—	—	—	7.5	—	5.9
	30	NS	Work exposure	—	—	—	21.6	—	10.1
	8	S	Noninhalers	—	—	—	397	—	152
	15	S	Slight inhalers	—	—	—	1261	—	421
	32	S	Medium inhalers	—	—	—	1349	—	454
	27	S	Deep inhalers	—	—	—	1527	—	905
Foliart et al. (1983)	6	NS	Flight attendants	1.6 (0.8–2.7)	3.2 (1.6–4.5)	—	15.2 (8.3–34.4)	—	—
Jarvis et al. (1983)	7	NS	Before, 11:30 a.m. After, public house x 2 hr	0.8	2.5	10.5	92.6	1.9	43.6
Hoffmann et al. (1984)	10	NS	Experimental chamber						
			2 cigs burned	1.1	1.1	24[1]	51[1]	8	427
			3 cigs burned	ND	1.3	20	94	1	893
			4 cigs burned	0.2	0.5	17	100	3	730

TABLE 6.—Continued

Study	Number of subjects	Smoking status	Exposure level	Mean or median concentration and range					
				Plasma nicotine (ng/mL)		Urine nicotine (ng/mL)		Saliva nicotine (ng/mL)	
				Before	After	Before	After	Before	After
Jarvis et al.			Hospital clinic patients						
(1984)	46	NS	No exposure	—	1.0	—	3.9	—	3.8
	27	NS	Little exposure	—	0.8	—	12.2	—	4.8
	20	NS	Some exposure	—	0.7	—	11.9	—	4.4
	7	NS	Lot of exposure	—	0.9	—	12.2	—	12.1
	94	S		—	14.8	—	1750	—	672
Greenberg	32	NS	Infants, mother S	—	—	—	53 [1] (0–370)	—	12.7 (0–166)
et al. (1984)	19	NS	Infant, mother NS	—	—	—	0 (0–59)	—	0 (0–17)
Luck and Nau	10	NS, neonates	No exposure	—	—	—	0 [1] (0–14)	—	—
(1985)	10	NS, neonates	Nursed by S mother; no ETS exposure	—	—	—	14 (5–110)	—	—
	10	NS, infants	S mother, not nursed	—	—	—	35 (4–218)	—	—
	9	NS, infants	Nursed by S mother; ETS exposure	—	—	—	12 (3–42)	—	—

[1] ng/mg creatinine.

TABLE 7.—Cotinine measures in nonsmokers with environmental smoke exposure and comparisons with active smoking

Study	Number of subjects	Smoking status	Exposure level	Mean or median concentration and range					
				Plasma cotinine (ng/mL)		Urine cotinine (ng/mL)		Saliva cotinine (ng/mL)	
				Before	After	Before	After	Before	After
Jarvis et al. (1983)	7	NS	Before, 11:30 a.m. After, public house x 2 hr	1.1	7.3	4.8	12.9	1.5	8.0
Jarvis et al. (1984)	46	NS	Hospital clinic patients No exposure	—	0.8	—	1.5	—	0.7
	27	NS	Little exposure	—	1.8	—	6.5	—	2.2
	20	NS	Some exposure	—	2.5	—	8.6	—	2.8
	7	NS	Lot of exposure	—	1.8	—	9.4	—	2.6
	94	S		—	275	—	1391	—	310
Hoffmann et al. (1984)	10	NS	Experimental chamber 2 cigs burned	1.7	2.6 (peak	14	21	1.2	2.3
			3 cigs burned	1.0	3.0 change)	14	38	1.7	2.5
			4 cigs burned	0.9	3.3	14	55	1.0	1.4
Wald and Ritchie (1984)	101	NS	Wife abstinent	—	—	8.5 (median 5.0)			
	20	NS	Wife smoker	—	—	25.2 (median 9.0)			

TABLE 7.—Continued

Study	Number of subjects	Smoking status	Exposure level	Plasma cotinine (ng/mL)		Urine cotinine (ng/mL)		Saliva cotinine (ng/mL)	
				Before	After	Before	After	Before	After
Wald et al. (1984)	221	NS	Med screening clinic patients			—	11.2		
	43	NS	Research colleagues			—	2.8		
	47	NS	0–1.5 hr ETS exposure/wk			—	3.4		
	43	NS	1.5–4.5 hr ETS exposure/wk			—	5.3		
	43	NS	4.5–8.6 hr ETS exposure/wk			—	14.7		
	45	NS	8.6–20 hr ETS exposure/wk			—	29.6		
	131	S	20–80 hr ETS exposure/wk			—	1645 (537–3326)		
	59	S	Cigarettes			—	396 (61–2138)		
	42	S	Cigars			—	1920 (1008–4569)		
			Pipes			—	510[1]		
Matsukura et al. (1984)	200	NS	No home exposure			—	790		
	272	NS	All home exposure						
			Home exposure:			—	310		
	25	NS	1–9 cig/day			—	420		
	57	NS	10–19 cig/day			—	870		
	99	NS	20–29 cig/day			—	1030		
	38	NS	30–39 cig/day			—	1560		
	28	NS	>40 cig/day			—	680		
	472	NS	All			—	8520		
	392	S	All			—	220		
	76	NS	No workplace exposure			—	720		
	201	NS	Workplace exposure						

TABLE 7.—Continued

Study	Number of subjects	Smoking status	Exposure level	Plasma cotinine (ng/mL)		Urine cotinine (ng/mL)		Saliva cotinine (ng/mL)	
				Before	After	Before	After	Before	After
Greenberg et al. (1984)	32	NS, infants	S mother			—	351 (41–1885)	—	9 (0–25)
	19		NS mother			—	4 (0–125)	—	0 (0–3)
Jarvis et al. (1985)	269	NS	Children aged 11–16 Neither parent SM					—	0.4 (median 0.2)
	96	NS	SM father					—	1.3 (1.0)
	76	NS	SM mother					—	2.0 (1.7)
	128	NS	Both parents SM					—	3.4 (2.4)
Luck and Nau (1985)	10	NS, neonates	No exposure	—	—	—	0[1] (0–56)	—	—
	19	NS, neonates	Nursed by S mother; no ETS exposure	—	—	—	100 (10–555)	—	—
	10	NS, infants	S mother, not nursed	—	—	—	327 (117–780)	—	—
	9	NS, infants	S mother, nursed; ETS exposure	—	—	—	550 (225–870)	—	—

Study	Number of subjects	Smoking status	Exposure level	Serum cotinine (ng/mL)					
				Before	After				
Pattishall et al. (1985)	20	NS, children	Smokers in home	—	4.1	—	—	—	—
	18	NS, children	No smokers in home	—	1.0	—	—	—	—

213

TABLE 7.—Continued

| Study | Number of subjects | Smoking status | Exposure level | Mean or median concentration and range | | | | | |
| | | | | Plasma cotinine (ng/mL) | | Urine cotinine (ng/mL) | | Saliva cotinine (ng/mL) | |
				Before	After	Before	After	Before	After
Coultas	68	NS aged <5	No smokers in home	—	—	—	—	—	0, 1.7[a]
et al.	41	NS aged <5	1 smoker in home	—	—	—	—	—	3.8, 4.1
(1986)	21	NS aged <5	2 or more smokers in home	—	—	—	—	—	5.4, 5.6
	200	NS aged 6–17	No smokers in home	—	—	—	—	—	0, 1.3
	96	NS aged 6–17	1 smoker in home	—	—	—	—	—	1.8, 2.4
	25	NS aged 6–17	2 or more smokers in home	—	—	—	—	—	5.3, 5.6
	316	NS aged >17	No smokers in home	—	—	—	—	—	0, 1.5
	60	NS aged >17	1 smoker in home	—	—	—	—	—	0.6, 2.8
	12	NS aged >17	2 or more smokers in home	—	—	—	—	—	0, 3.7

[1] ng/mg creatinine.
[a] median, mean.

measurements, cotinine appears to be the short-term marker of choice for epidemiological studies.

(5) Mean levels of urinary nicotine and of cotinine in body fluids increase with an increasing self-reported ETS exposure and with an increasing number of cigarettes smoked per day. There is considerable variability in levels among individuals at any given level of self-reported exposure.

Comparison of Absorption From Environmental Tobacco Smoke and From Active Smoking

Epidemiologic studies show a dose–response relationship between number of cigarettes smoked and lung cancer, coronary artery disease, and other smoking-related diseases. Assuming that dose–response relationships hold at the lower dose end of the exposure–response curve, risks for nonsmokers can be estimated by using measures of absorption of tobacco smoke constituents to compare the relative exposures of active smokers and involuntary smokers.

As discussed previously, measures of nicotine uptake (i.e., nicotine or cotinine) are the most specific markers for ETS exposure and provide the best quantitative estimates of the dose of exposure. Although the ratio of nicotine to other tobacco smoke constituents differs in mainstream smoke and sidestream smoke, nicotine uptake may still be a valid marker of total ETS exposure. Nicotine uptake in nonsmokers can be estimated in several ways.

Russell and colleagues (1985) infused nicotine intravenously to nonsmokers and compared resultant plasma and urine nicotine levels with those observed in nonsmokers with ETS exposure. An infusion of 1 mg nicotine over 60 minutes resulted in an average plasma nicotine concentration of 6.6 ng/mL and an average urinary nicotine concentration of 224 ng/mL. Using these data in combination with measured plasma and urinary nicotine levels in nonsmokers after 2 hours in a smoky bar, nicotine uptake was estimated as 0.22 mg per hour. Since the average nicotine uptake per cigarette is 1.0 mg (Benowitz and Jacob 1984; Feyerabend et al. 1985), 0.22 mg of nicotine is equivalent to smoking about one-fifth of a cigarette per hour. In making these calculations, it is assumed that the disposition kinetics of inhaled and intravenous nicotine are similar and that the rate of nicotine exposure from ETS is constant.

Steady state blood cotinine concentrations can also be used to estimate nicotine uptake. Galeazzi and colleagues (1985) measured cotinine levels in smokers receiving various doses of intravenous nicotine, simulating cigarette smoking, for 4 days. They described the relationship: [steady state plasma cotinine concentration] (ng/mL) = (0.783) x [daily nicotine uptake] (µg/kg/day). With such data, a 70 kg nonsmoker with a plasma cotinine concentration of 2.5 ng/mL would have an estimated uptake of 3.2 µg nicotine/kg/day, or

215

0.22 mg nicotine/day, equivalent to one-fifth of a cigarette. This approach assumes that the half-life for cotinine and nicotine eliminations is similar in smokers and nonsmokers, an assumption that may not be correct (Kyerematen et al. 1982).

A third approach is to compare cotinine levels in nonsmokers with those in smokers. Jarvis and colleagues (1984) measured plasma, saliva, and urine nicotine and cotinine levels in 100 nonsmokers selected from outpatient medical clinics and in 94 smokers. Ratios of average values for nonsmokers compared with smokers were as follows: plasma cotinine, 0.5 percent; saliva cotinine, 0.5 percent; urine cotinine, 0.4 percent; urine nicotine, 0.5 percent; and saliva nicotine, 0.7 percent. These data suggest that, on average, nonsmokers absorb 0.5 percent of the amount of nicotine absorbed by smokers. Assuming that the average smoker consumes 30 mg nicotine per day (Benowitz and Jacob 1984), this ratio predicts an exposure of 0.15 mg nicotine, or one-sixth of a cigarette per day. The most heavily exposed group of nonsmokers had levels almost twice the overall mean for nonsmokers, indicating that their exposure was equivalent to one-fourth of a cigarette per day. Most studies (see Tables 6 and 7) report similar ratios when comparing nonsmokers with smokers. The exception is Matsukura and colleagues (1984), who reported urine cotinine ratios of nonsmokers to smokers of 6 percent. The reason for such high values in this one study is unknown.

Personal air monitoring data for nicotine exposure can also be used to estimate nicotine uptake. For example, Muramatsu and colleagues (1984) used a pocketable personal air monitor to study environmental nicotine exposures in various living environments. They reported air levels of from 2 to 48 μg nicotine/m^3. Assuming that respiration is 0.48 m^3 per hour and exposure is for 8 hours per day, nicotine uptake is estimated to range from 8 to 320 μg per day. The average values are consistent with other estimates of one-sixth to one-third cigarette equivalents per day in general populations of nonsmokers exposed to ETS.

As noted before, these estimates must be interpreted with caution. Relative absorption of nicotine in smokers and nonsmokers may substantially underestimate exposure to other components of ETS.

Conclusions

1. Absorption of tobacco-specific smoke constituents (i.e., nicotine) from environmental tobacco smoke exposures has been documented in a number of samples of the general population of developed countries, suggesting that measurable exposure to environmental tobacco smoke is common.

216

2. Mean levels of nicotine and cotinine in body fluids increase with self-reported ETS exposure.
3. Because of the stability of cotinine levels measured at different times during exposure and the availability of noninvasive sampling techniques, cotinine appears to be the short-term marker of choice in epidemiological studies.
4. Both mathematical modeling techniques and experimental data suggest that 10 to 20 percent of the particulate fraction of sidestream smoke would be deposited in the airway.
5. The development of specific chemical assays for human exposure to the components of cigarette tar is an important research goal.

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CHAPTER 5

TOXICITY,
ACUTE IRRITANT EFFECTS,
AND CARCINOGENICITY
OF ENVIRONMENTAL
TOBACCO SMOKE

CONTENTS

Irritation: Acute Exposure

Irritants in Environmental Tobacco Smoke

Tobacco smoke is a complex aerosol that contains several thousand different constituents (Hoffmann, Haley, Brunnemann 1983). Little is known about the health effects of most of these compounds individually and even less is known about their interactions. Tobacco smoke contains compounds established as irritants, toxins, mutagens, and carcinogens. The main irritants identified in environmental tobacco smoke (ETS) to date are respirable particulates, certain aldehydes, phenol, ammonia, nitrogen oxides, sulfur dioxide, and toluene. The range of concentrations of these irritants measured in mainstream smoke, in sidestream smoke, and in smoky air under "realistic" and "natural" conditions or as results of field studies is summarized in Table 1.

The levels of irritants in air contaminated with ETS vary considerably (Table 1). Some of this variation is due to differences in the number of cigarettes smoked, the amount of ventilation, the adsorptive properties of the surroundings, and measurement methodology. Triebig and Zober (1984) compared the measured concentrations of these irritants with the maximum permissible concentration (MAK) values for working areas and the maximum emission concentration (MIK) values for outdoor air pollution in the Federal Republic of Germany. They concluded that concentrations approximating or in excess of the MIK values can be found for respirable particulates, nitrogen dioxide, and acrolein. The other irritants generally do not reach the existing threshold limit values under realistic conditions. For phenol there is no MIK value. An evaluation of the hygienic and medical importance of the compounds in ETS based on threshold limit values is problematic for two reasons: first, MAK values for industries are established for healthy adults with an 8-hour exposure per day; MIK values are for the outdoor environment, and no indoor limit values exist for "everyday life." Second, the threshold limit values are valid only for single compounds; ETS contains many different irritants, which might interact to produce more toxicity than anticipated from the concentrations of individual compounds.

Many of the constituents of tobacco smoke are also produced by other sources that contribute contaminants to the indoor or outdoor environment. For example, sources unrelated to smoking such as urea formaldehyde foam insulation or certain wood materials can emit formaldehyde and may give rise to mean air concentrations as high as 100 to 400 ppb (Triebig and Zober 1984). In measuring the contribution of tobacco smoke to the levels of these constituents, some researchers (Weber et al. 1979a; Weber and Fischer 1980) have subtracted the measured indoor concentrations from the levels

TABLE 1.—Major irritants in environmental tobacco smoke (ETS), their concentrations in mainstream smoke (MS), sidestream smoke (SS) to mainstream smoke (MS) ratios, and levels in smoky air under realistic and natural conditions

Irritant	MS (per cigarette)	SS/MS (ratio)	Smoky air (range)
Acrolein	10–140 µg	10–20	6–120 ppb
Formaldehyde	20–90 µg	≈ 50	30–60 ppb[a]
			(CO: 1–43 pbb)
Ammonia	10–500 µg	44–100	1000–4580 pbb[b]
Nitrogen oxides	16–600 µg	4.7–50	1–370 ppb NO[c]
			0–50 pbb NO_x[c]
Pyridine	32 µg	10	NA[d]
Sulfur dioxide	1–75 ppb	NA	1–69 ppb[c]
Phenol	20–150 µg	2.6	7.4–115 µg/m³
Toluene	108 µg	5.6	0.04–1.04 mg/m³
Respirable particulates	0.1–40 mg	1.3–1.9	55–962 mg/m³

[a] Measured under experimental conditions only.
[b] Fischer (1979).
[c] Difference: indoor concentration minus control value (unoccupied room or outdoors).
[d] NA = not available.

SOURCE: Data from Collishaw et al. (1984), Remmer (1985), Triebig and Zober (1984), US DHHS (1984), except where noted.

measured either in the unoccupied room or in the outdoor environment near the room.

The measured concentrations of irritants listed in Table 1 are primarily the mean values in air samples collected over intervals of one-half hour to several hours. Substantial variation in levels can occur, depending on the proximity to a smoker and the air-mixing conditions in the room. Weber and Fischer (1983) measured peak concentrations of 3,330 to 99,680 ng/m³ for the particulates and 41 to 750 ppb for nitrogen oxide in the "blowing cloud" 1 meter from the smoker immediately after smoke exhalation. These high concentrations decreased very rapidly with time (half-life between 2 and 20 seconds) and distance from the smoker. Ayer and Yeager (1982) measured formaldehyde and acrolein concentrations in the sidestream smoke plume rising from a cigarette between puffs and obtained concentrations of some constituents up to three orders of magnitude above the occupational limits established for more extended exposures.

Water
solubility

Places
of impact

Compounds

High

Eyes
Larynx
Trachea

Ammonia
Formaldehyde
Acrolein
Particulates

Medium

Bronchia
Bronchioles

Sulfur dioxide
Particulates

Low

Bronchioles
Alveoli
Capillaries

Nitrogen dioxide
Particulates
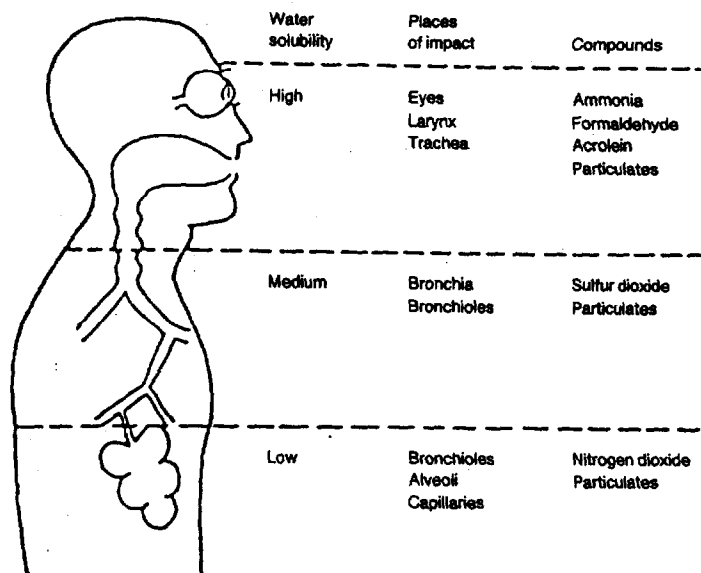
FIGURE 1.—Places of impact, and irritants in the eyes and respiratory tract in relation to water solubility

SOURCE: Valentin (1985).

Irritating and Annoying Effects of Environmental Tobacco Smoke

The main effects of the irritants present in ETS occur in the conjunctiva of the eyes and in the mucous membranes of the nose, throat, and lower respiratory tract. The main ocular symptoms are reddening, itching, and increased lachrymation; the main respiratory tract symptoms are itching, cough, and sore throat. The relationship of the site of the effect of some irritants in the eyes and in the respiratory tract to their water solubility is illustrated in Figure 1. The penetration of the particulates into the lung depends on their size; because most of the particulates in tobacco smoke are smaller than 1 μm, they can penetrate to the smallest airways.

Studies of Healthy Individuals
Field Studies

Several studies have shown that annoyance and irritation are the most common acute effects of ETS exposure. Shephard and Labarre (1978) surveyed more than 1,000 Canadian citizens aged 10 to 80 years. The interviewed population was representative of southern

231

Ontario with respect to both income and profession but underrepresentative of the elderly. Seventy-three percent of the nonsmokers were disturbed by tobacco smoke in restaurants and 53 percent by tobacco smoke in offices. The most frequently reported symptom was eye irritation. Complaints of nausea, dizziness, and wheezing as well as rhinorrhea were also reported, although much less frequently than stinging eyes.

Similar results were obtained in a survey conducted in three restaurants in Switzerland (Weber et al. 1979a). A multiple-choice questionnaire was administered to 220 guests. One-third to two-thirds of the respondents complained about air quality, and up to 12 percent reported eye irritation. In another survey of more than 2,100 white-collar employees, Barad (1979) found that nearly one-fourth of the nonsmokers reacted to smoke exposure with frustration and hostility.

Weber and Fischer (1980) surveyed employees in 44 worksite workrooms, located in seven different companies, that included offices, rooms for design and technical and clerical work, and conference rooms. The choice of companies and worksites was based on availability and therefore was not a random sample. In all workrooms, the concentrations of carbon monoxide (CO), nitrogen oxide (NO), acrolein, particulate matter (PM), and nicotine were measured in the air. The contribution of tobacco smoke to these levels was obtained by subtracting background levels obtained before working hours from the concentrations during working hours. These differences from the background levels were called δCO, δNO, and so on. Measurements were conducted in each room on 2 successive days (12 1-hour mean values per workroom), and 472 employees were questioned about irritation and annoyance as well as about their opinions on involuntary smoking.

Some of the exposure results are summarized in Table 2. The comparison of these δ values with the measured absolute indoor concentrations revealed that 30 to 70 percent of the measured indoor concentrations of carbon monoxide, nitrogen oxide, and particulate matter were due to tobacco smoke. The correlations between the gas phase components δCO and δNO were relatively high (Pearson correlation coefficient $r=0.73$). However, the correlations of δCO with δnicotine and δPM were low. Nicotine values were generally in the range of the lower detection limit of the method of measurement used (gas chromatography). The low correlation of the gaseous components with the particulate matter is probably due to the different physical properties (sedimentation, adsorption, and desorption of the particulates) and to the fact that the δPM values include particulates from sources other than tobacco smoke.

Approximately one-third of the employees described the quality of air at work as "bad" with regard to tobacco smoke. Forty percent

TABLE 2.—Air pollution due to tobacco smoke in 44 workrooms

Component	Number of samples	Mean values	Standard deviation	Maximum
δCarbon monoxide (ppm)	353	1.1	1.3	6.5
δNitrogen oxide (ppb)	348	32	60	280
δParticulate matter ($\mu g/m^3$)	429	133	130	962
δNicotine ($\mu g/m^3$)	140	0.9	1.9	13.8

NOTE: δ value = "indoor concentration during work" minus "indoor concentration before work."
SOURCE: Weber and Fischer (1980).

were disturbed by smoke. One-fourth reported eye irritation at work. Seventy-two percent of the interviewed nonsmokers and 67 percent of the smokers were in favor of a separation of the workrooms into smoking and nonsmoking sections; 49 percent supported a partial or total prohibition of smoking at work.

Contradictory results were reported by Sterling and Sterling (1984), who found no relationship between smoking conditions in offices and comfort complaints. A self-administered work environment questionnaire was given to approximately 1,100 employees working in nine buildings. Data were analyzed according to the smoking habits of the respondents and the office rules regulating smoking. The distribution of the responses to questions assessing the presence of symptoms (headache; fatigue; nose, throat, and eye irritations; sore throat and cold symptoms) were similar in environments with and without smoking. The researchers concluded that "smoking is not a pivotal source of indoor pollution of health-related building complaints." No objective measurements of air pollution were carried out, however, and there were no descriptions of building ventilation. The researchers used a "building illness index" that included several different symptoms in addition to irritation (e.g., headache, fatigue), and the irritating effects on the most sensitive organ—the eyes—may have been masked by this use of an overall symptom index.

Experimental Studies

Harke and Bleichert (1972) examined the acute physiological response to ETS in a 170 m^3 room. The electrocardiogram, blood pressure, heart rate, and skin temperature showed no change with exposure to ETS, even at extremely high exposure levels (150 cigarettes smoked in 30 minutes, corresponding to a carbon monoxide concentration of 60 ppm at the end of the exposure).

The influence of the temperature and humidity of room air on odor perception and irritation was investigated by Kerka and Humphrey (1956). They found that odor intensity was somewhat reduced by increasing the temperature at a constant humidity. Both odor and irritation intensity were reduced by increasing the humidity. Johansson and Ronge (1966) also observed that acute irritation is increased in warm and dry air. Johansson (1976) exposed 12 subjects in a 6.7 m^3 climatic chamber for 29 minutes to the ETS produced by the smoking of 10 cigarettes. The air in the chamber was cold (18° or 19° C) or warm (25° or 26° C), and at each temperature, the relative humidity was evaluated at three levels from 30 to 80 percent. Under all conditions, subjective irritation, assessed by a questionnaire, increased during exposure; eye irritation increased more than nose irritation. No marked effect of temperature on the degree of irritation was observed, probably owing to the limited temperature range studied (18° to 26° C). Kerka and Humphrey (1956) demonstrated a thermal effect when the temperature range was greater than 8° C. The low relative humidity (7 to 20 percent) in aircraft may be responsible for the substantial level of perceived irritation due to ETS among passengers, despite the low levels of pollutants measured n aircraft (WHO 1984).

Basu and colleagues (1978) studied the effects of ETS on human tear film and observed a reduction in the stability of the precorneal tear film in subjects exposed to a smoke concentration corresponding to approximately 20 ppm CO. In the presence of ETS, the tear film breakup time was significantly reduced by 35 to 40 percent compared with baseline measurements without smoke. The researchers suggested that this reflects an alteration in the relative proportions of the constituents of tear film.

In these studies, the quantitative exposures to ETS either were not measured or were determined in a relatively imprecise way. More systematic studies, including measurements of several compounds of ETS, were carried out by Weber and collaborators (Weber et al. 1976, 1979a,b; Weber, Fischer, Grandjean 1977; Weber, Fischer, Gierer et al. 1977; Weber and Fischer 1983) and Muramatsu, Weber, and colleagues (1983). These experiments were carried out in a climatic chamber of 30 m^3, with an air temperature of 20° to 24° C and a relative humidity between 40 and 60 percent. The ventilation rate could be varied between 0.1 and 16 air changes per hour. The smoke was produced by a Borgwald smoking machine under standardized conditions, and only the sidestream smoke of cigarettes was used. Healthy students were exposed to the sidestream smoke of cigarettes in groups of two or three in the climatic chamber. They all also participated in a control exposure with identical conditions, but without sidestream smoke in the air. The concentrations of the following compounds were continuously recorded: carbon monoxide,

234

nitrogen oxide, formaldehyde, acrolein, and particulate matter. The background levels before smoke production were subtracted from the measured concentrations during smoking; the resulting values were called δCO, δNO, and so forth. The degree of irritating and annoying effects of the exposed subjects was determined every 10 minutes by means of questionnaires and by measuring the eye blink rate, considered an objective measure for eye irritation.

In the first study, 33 subjects were exposed to continuously increasing smoke concentrations (Weber et al. 1976). The main results are summarized in Figure 2. The concentrations of CO, NO, formaldehyde (HCHO), and acrolein increased with the number of cigarettes smoked. Both mean subjective eye irritation and mean eye blink rate increased with increasing smoke concentration. Subjective nose and throat irritation was also evaluated. Nasal symptoms were less pronounced than eye symptoms, and the throat was the least affected.

In a second series of studies, acute effects were analyzed in relation to smoke concentration and duration of exposure (Weber et al. 1979; Muramatsu, Weber et al. 1983). The tobacco smoke concentrations corresponded to 1.3, 2.5, 5, and 10 ppm CO (δCO). Subjects were exposed to these smoke concentrations for 1 hour, each smoke concentration increasing linearly during the first 5 to 10 minutes and then remaining constant at the desired level for the rest of the hour. Because very high correlations ($r > 0.9$) were obtained in the first experimental series between δCO and each of the other compounds, only δCO was used to quantify the level of exposure to ETS.

The results obtained for subjective eye irritation and eye blink rate are shown in Figures 3 and 4. The mean reported level of eye irritation as well as the eye blink rate increased with increasing smoke concentration. Both irritation parameters also increased with the duration of exposure under conditions of constant smoke concentration. The same, but less pronounced, results were observed for nose and throat irritation.

Annoyance increased rapidly as soon as smoke production began and increased with increasing smoke concentration, but after 10 to 15 minutes the level of annoyance remained approximately constant during the rest of the exposure. Thus, the intensity of exposure was important in determining the degree of annoyance and the duration of exposure was less important.

These experiments demonstrated an objective irritant response in healthy adult subjects at levels of smoke exposure substantially lower than the levels at which an airway response has been demonstrated. Whether this difference represents a difference in threshold for irritation in the eye and airway or a limitation in the ability to measure subtle changes in the airway is uncertain.

235

Eye irritation   Eye blink rate/min
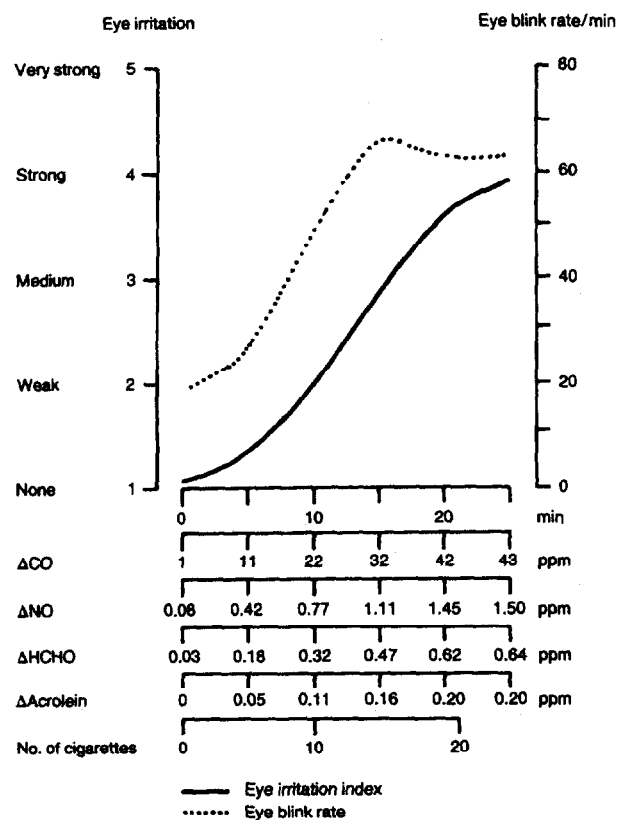
FIGURE 2.—Mean subjective eye irritation, mean eye blink
        rate, and concentrations of some pollutants
        during continuous smoke protection in an
        unventilated climatic chamber

NOTE: 33 subjects; 0 min: measurement before smoke production.
SOURCE: Weber et al. (1976).

Hugod and colleagues (1978) and Weber and colleagues (Weber,
Fischer, Grandjean 1977; Weber, Fischer, Gierer et al. 1977; Weber
et al. 1979b) carried out several experiments in order to determine
which compounds in ETS are responsible for irritation and annoy-
ance. The results of the two studies were somewhat conflicting.
Hugod and colleagues exposed 10 subjects in an unventilated 68 m³
room to high concentrations of sidestream smoke (concentrations
corresponding to 20 ppm CO), to the gas phase of sidestream smoke
alone, and to acrolein alone at concentrations three times those
found in sidestream smoke alone. Irritation was assessed via a

236
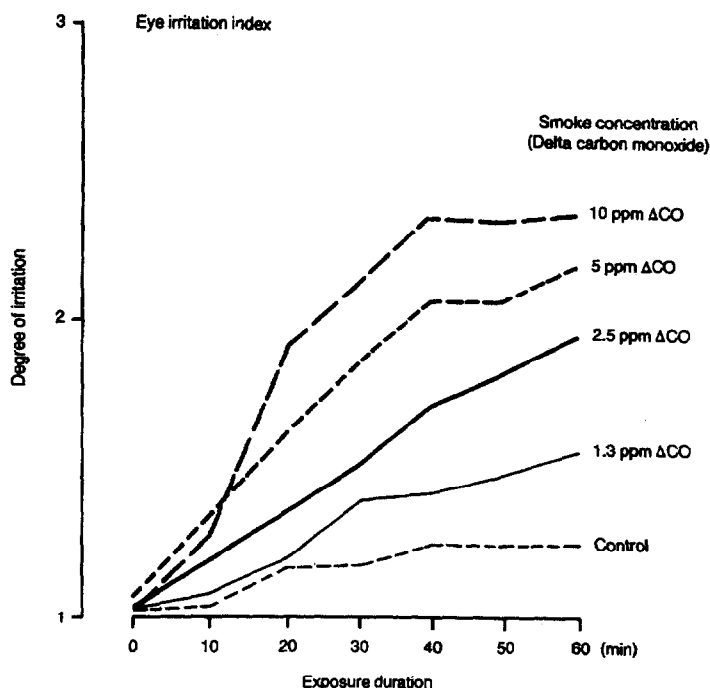
FIGURE 3.—Mean subjective eye irritation related to smoke concentrations (ppm delta CO) and duration of exposure

NOTE: 32 to 43 subjects; 0 min: measurement before smoke production; 0 to 5 min; increasing smoke concentration; 6 to 60 min: constant smoke production.

SOURCE: Muramatsu, Weber et al. (1983).

questionnaire. Both annoyance and irritation were reported at similar levels in the subjects exposed to the whole sidestream smoke or to the gas phase only. Exposure to acrolein caused only slight discomfort.

Weber and colleagues (Weber, Fischer, Grandjean 1977; Weber, Fischer, Gierer et al. 1977; Weber et al. 1979b) exposed students in groups of two or three in a 30 m³ climatic chamber to whole sidestream smoke, to acrolein alone, to formaldehyde alone, or to the gas phase of smoke. Subjective irritation and annoyance as well as eye blink rate were measured. The results indicated that acrolein and formaldehyde did not produce substantial irritation or annoyance at the levels used. The gas phase exposure resulted in high levels of reported annoyance, but was less important as a determinant of irritation. The objectively measured eye blink rate, as well as subjective eye irritation, was much lower with the gas phase alone

237
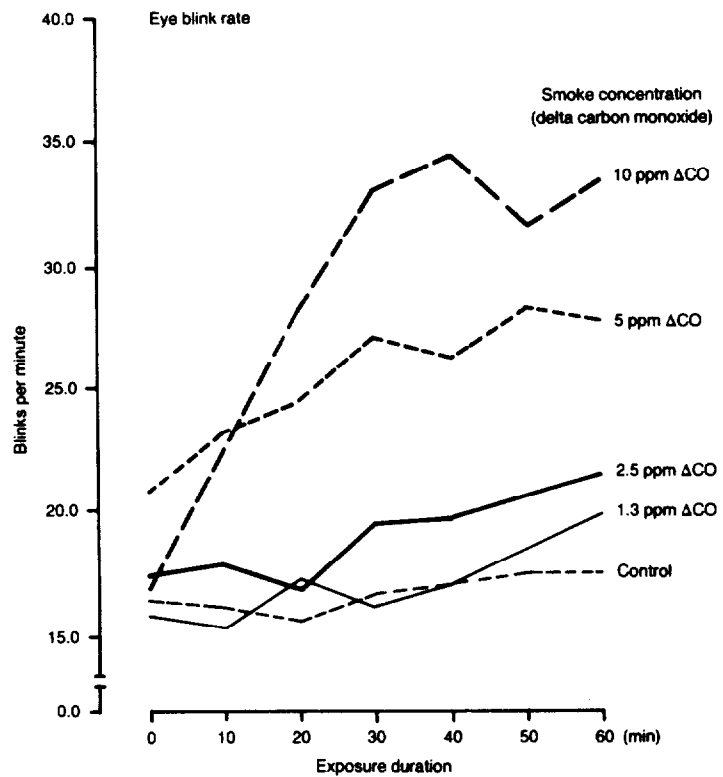
FIGURE 4.—Mean effects of environmental tobacco smoke on eye blink rate

NOTE: 32 to 43 subjects; 0 min: measurement before smoke production; 0 to 5 min: increasing smoke concentration; 6 to 60 min: constant smoke production.

SOURCE: Muramatsu, Weber et al. (1983).

than with the total sidestream smoke, suggesting that the particulate phase is the major determinant of irritation. The researchers postulated that the irritating effects of the particulate phase are due to the semivolatile irritant compounds. These compounds, which volatilize rapidly during the process of combustion, recondense on the particulates with cooling and may deposit irritants in relatively high concentrations on the mucous membranes.

238

Studies of Sensitive Individuals

Children

Several investigators have used questionnaires to examine the subjective symptoms of children and young people with ETS exposure (Cameron 1972; Muramatsu 1977; Muramatsu, Muramatsu et al. 1983). The last group found that 81 percent of 13-year-old children disliked involuntary smoking and 82 percent complained of one or more kinds of irritation, the most common being eye irritation. Several epidemiological studies have shown that children with parents who smoke have an increased risk for respiratory illness (see Chapter 2).

Allergic Individuals

A few studies have assessed the effects of ETS on allergic individuals. Speer (1968) found that allergic individuals report irritation more frequently than healthy individuals. Weber and Fischer (1980) observed that employees suffering from hay fever reported significantly more eye irritation at work than those without hay fever.

Effects on the Lung

Cigarette smoking is associated with prominent changes in the numbers, types, and functions of respiratory epithelial and inflammatory cells. These alterations have been implicated in the development of pulmonary emphysema, chronic bronchitis, and respiratory tract cancers and in an increased susceptibility to infections. Chronic exposure to environmental tobacco smoke might cause similar changes. Because studies that directly address the effect of chronic exposure to environmental tobacco smoke on lung structure and biochemistry have not been conducted, this section reviews those studies in humans and animals that provide evidence on smoke exposures that may be relevant to ETS exposure.

Effects of Cigarette Smoking on Respiratory Epithelium: Studies in Humans

Extensive evidence shows that exposure to cigarette smoke has adverse effects on respiratory epithelial cells, and dose-response relationships have been established from these changes (Auerbach et al. 1961; Auerbach, Hammond, Garfinkel 1970). Studies involving the systematic examination of the bronchial mucosa from large numbers of human smokers have recorded three principal types of epithelial changes: epithelial hyperplasia, loss of cilia, and nuclear atypia. In an autopsy study of 402 adult male subjects (Auerbach et al. 1961), 98 percent of the sections of the tracheal and bronchial

239

TABLE 3.—Sections with one or more epithelial changes, by packs of cigarettes per day

Group	Number of subjects	Number of sections	Total with one or more changes	
			Number	Percentage
Subjects without lung cancer				
Never smoked regularly	65	3,324	559	16.8
Smoked < 1/2 pack/day	36	1,824	1,683	92.3
Smoked 1/2–1 pack/day	59	3,016	2,938	97.4
Smoked 1–2 pack/day	143	7,062	7,021	99.4
Smoked ≥ 2 pack/day	36	1,787	1,780	99.6
Subjects with lung cancer	63	2,784	2,778	99.8
Totals	402	19,797	16,759	
Average				84.7

SOURCE: Auerbach et al. (1961).

epithelium of the men who had smoked had epithelial changes. The most common abnormality observed was atypical nuclei, and a large proportion of sections had hyperplasia. Denudation of the ciliated epithelium was also present in most of those who had smoked. Other studies have observed that goblet cells were frequently increased in the airways of cigarette smokers (Regland et al. 1976; Jones 1981). The extent and severity of the abnormalities have been closely related to the intensity of smoking. A similar relationship of smoking habits to laryngeal lesions has been observed (Auerbach, Hammond, Garfinkel 1970), although the laryngeal lesions were less frequent and less advanced than those in the bronchi for a given smoking history.

The frequency and severity of epithelial lesions observed in smokers contrasts sharply with those in individuals who do not smoke regularly. In the study by Auerbach and colleagues (1961) (Table 3), 98 percent of the sections from the tracheobronchial tree from smokers contained abnormal epithelial changes; however, similar changes were observed in only 16.8 percent of the sections from nonsmokers. The most common lesion in nonsmokers was epithelial hyperplasia (9.4 percent); atypical cells were seen in only 4.8 percent of the sections from nonsmokers.

If it is assumed that the nonsmoking group included a subgroup of individuals who were chronically exposed to environmental tobacco smoke, an assumption that seems reasonable in light of the largely U.S. veteran population under consideration in the Auerbach group's study, then some information on the effect of chronic exposure to environmental tobacco smoke on the respiratory epithe-

240

lium can be inferred. Epithelial hyperplasia or nuclear atypia due to chronic exposure to environmental tobacco smoke may occur in some nonsmokers, but these findings are not common in the majority of nonsmokers.

Cigarette smoking also has adverse effects on the bronchial wall beneath the epithelium. Submucosal gland hypertrophy has been observed frequently (Auerbach et al. 1961; Regland et al. 1976; Jones 1981). The prevalence is related to the intensity of cigarette smoking. Mucous gland hypertrophy is seen in nonsmokers, but is not prevalent and is usually not extensive (Auerbach et al. 1961).

The loss of ciliary epithelium, the increased numbers of goblet cells, and the mucous gland hypertrophy frequently observed in cigarette smokers would predict mucociliary dysfunction. Indeed, available evidence indicates that long-term cigarette smoking impairs mucociliary transport (Wanner 1977). Once a cigarette smoker develops chronic bronchitis, mucus transport appears to be irreversibly damaged. Impairment persists even in patients who have abstained from cigarette smoking for many years (Santa Cruz et al. 1974). Prior to the development of chronic bronchitis, however, partial recovery of function has been observed (Camner et al. 1973). Studies examining mucociliary dysfunction in humans due solely to chronic environmental smoke exposure have not been reported.

Effect of Cigarette Smoking on Lung Inflammatory Cells

Studies in Humans

One of the earliest pathologic lesions found in the lungs of young smokers is a respiratory bronchiolitis (Anderson and Foraker 1961; McLaughlin and Tueller 1971; Niewoehner et al. 1974). Clusters of pigment-laden phagocytes, predominantly alveolar macrophages (AM), lodge in the respiratory bronchioles of cigarette smokers precisely at the sites of the earliest lung injury. The infiltration by AM precedes the development of emphysema and focal fibrosis (Cosio et al. 1978). Analyses of cells harvested by bronchoalveolar lavage complement the morphologic studies. Lavage fluid yields five to seven times more AM from the lungs of cigarette smokers than from nonsmokers' lungs (Harris et al. 1970; Reynolds and Newball 1974; Warr et al. 1976; Hunninghake et al. 1979; Hoidal et al. 1981). The alveolar macrophages from smokers appear to be activated morphologically and metabolically. The AM from smokers have increased size, endoplasmic reticulum, Golgi apparatus, glucose metabolism, hydrolytic and proteolytic enzyme activities (Pratt et al. 1971; Cohen and Cline 1971; Harris et al. 1970; Rodriguez et al. 1977; Hinman et al. 1980; Martin 1973; Cantrell et al. 1973), and increased rates of oxidative metabolism resulting in increased production of reactive oxygen species (superoxide radical, hydrogen peroxide, and hydroxyl radical) (Hoidal et al. 1981; Hoidal and Niewoehner 1982).

The strategic location of the alveolar macrophages and their altered function have led to the hypothesis that they may contribute to the alteration of the protease–antiprotease balance of the lower respiratory tract and thus foster the development of emphysema in smokers. Two plausible mechanisms have been identified by which AM may influence the protease–antiprotease balance in cigarette smokers. The first is by directly increasing the lung protease burden. Human AM release enzymes with elastolytic activity in vitro, whereas those from nonsmokers do not (Rodriguez et al. 1977). The activity may originate from endogenous or exogenous sources. A metalloenzyme with activity against synthetic amide substrates, which have specificity for elastase, was detected in the bronchoalveolar washings of cigarette smokers (Janoff et al. 1983; Niederman et al. 1984) and was also found in the cell culture fluid of smokers' AM (Hinman et al. 1980). Alveolar macrophages can synthesize a metalloprotease capable of solubilizing elastin; they also contain a thiolprotease with such activity (Chapman and Stone 1984). The metalloprotease, if analogous to that of murine macrophage elastase, would be resistant to inactivation by alpha$_1$-protease inhibitor (α_1PI) (Banda et al. 1980). These enzymes have not been demonstrated to cause emphysema. The content of elastolytic activity in AM at a given time is less than that of equal numbers of polymorphonuclear leukocytes (PMN); thus, AM may be only a minor source of enzymes capable of lung parenchymal destruction. However, their potential importance must be considered in light of their demonstrated ability to degrade elastin in the presence of serum protease inhibitors (Chapman and Stone 1984) and their capability of ongoing synthesis of elastolytic enzymes. Cell matrix contact may be critical for their matrix-degrading action, since the AM-derived enzymes are likely to be membrane bound.

Human AM also acquire elastolytic activity from exogenous sources. AM can bind and internalize neutrophil elastase by virtue of possessing a specific membrane receptor for this and other neutrophil glycoproteins (Campbell et al. 1979; Campbell 1982; McGowan et al. 1983). Studies to date suggest that the scavenged elastase accounts for much of the elastolytic activity in AM lysates. Sequestered PMN elastase may subsequently be released by AM over an extended period of time.

The second mechanism by which AM may influence the protease–antiprotease balance in cigarette smokers is by inactivating α_1PI, a major antiprotease of the lower respiratory tract in humans (Gadek et al. 1981). Smokers' AM can inactivate α_1PI through oxidant mechanisms in vitro (Carp and Janoff 1980). Studies on bronchoalveolar lavage fluids have identified oxidatively inactivated α_1PI in some human smokers (Gadek et al. 1979; Carp et al. 1982), but this has not been a consistent finding (Stone et al. 1986; Boudier et al.

242

1983). Studies that directly assess the status of α_1PI activity in the alveolar space and interstitium of cigarette smokers are needed to clarify this issue.

The phagocytic capabilities of AM from cigarette smokers and nonsmokers are similar in most studies (Harris et al. 1970; Cohen and Cline 1971; Reynolds et al. 1975; Territo and Golde 1979), although a few studies (Martin and Warr 1977; Fisher et al. 1982) have suggested a modest decrease in the phagocytic abilities of AM from smokers. The experimental design of these studies has differed considerably, and technical factors may be responsible for the variable results. In particular, there are differences in cellular culture conditions. In view of the increased number of AM in cigarette smokers, it seems unlikely that a primary phagocytic defect of AM would account for the bacterial colonization observed in some cigarette smokers.

The possibility that increased numbers of PMN may be present in the lungs of cigarette smokers has been examined primarily because of the attention given these cells in the study of the pathogenesis of emphysema. PMN elastase is the only purified human enzyme with ready access to the lung parenchyma that has been demonstrated to cause emphysema when administered to animals. The number of PMN is increased in the distal airways and lung parenchyma of cigarette smokers. Bronchoalveolar lavage from some smokers yields increased PMN (Reynolds and Newball 1974; Hunninghake et al. 1979). More compelling evidence for increased PMN in the lungs of smokers comes from the morphologic evaluation and direct cellular analysis of the lung parenchyma. A fourfold increase in PMN infiltration has been observed in the lungs of cigarette smokers compared with the lungs of nonsmokers, using morphometric techniques (Ludwig et al. 1985). Analysis of cell suspensions from lung biopsies has also demonstrated increased PMN in the lung parenchyma of smokers (Hunninghake and Crystal 1983). The alveolar septa are the primary site of the PMN accumulation. Increased PMN are present in the alveolar walls of smokers both with and without emphysema, which suggests that other factors must also be involved in the development of the destructive lesion.

Factors that might influence the destruction of lung parenchyma by PMN elastase include the intensity of PMN influx, the amount of elastase per cell, the quantity and site of elastase released, and local factors that enhance or inhibit the elastolytic activity. Investigations of the relation of PMN elastase levels and the development of emphysema have provided discrepant results. Some studies have shown elevated levels of PMN elastase in patients with chronic obstructive pulmonary disease (Galdston et al. 1977; Rodriquez et al. 1979; Kramps et al. 1980), but others have not (Taylor and Keuppers 1977; Abboud et al. 1979). Other alterations in the PMN function of

243

cigarette smokers include the enhanced generation of reactive oxygen species in certain smokers (Ludwig and Hoidal 1982). After stimulation, the release of superoxide anion by PMN was 50 percent greater from smokers with peripheral white blood counts (WBC) greater than 9,000 per mm^3 than from nonsmokers with similar WBC or from smokers or nonsmokers with WBC less than 9,000 per mm^3. (Cigarette smokers have increased peripheral WBC counts compared with nonsmokers.)

The influence of cigarette smoking on many aspects of the immune system has been examined. Immunoglobulin (Ig) levels in the peripheral blood of smokers have been reported to be decreased (Gerrard et al. 1980; Ferson et al. 1979), but similar results have not been observed in all studies (Bell et al. 1981; Merrill et al. 1985). In contrast to the decrease of IgG in peripheral blood, cigarette smokers appear to have increased IgG levels in bronchoalveolar lavage fluid (Bell et al. 1981), primarily owing to an increase in IgG_1 (Merrill et al. 1985). Cell-mediated immunity may also be affected by cigarette smoking, but again, the results are somewhat conflicting. Peripheral blood T-lymphocytes and mitogen responsiveness have been reported to be increased (Silverman et al. 1975), unchanged (Daniele et al. 1977), or decreased (Petersen et al. 1983). Natural killer-cell activity in the peripheral blood of cigarette smokers appears decreased (Ginns et al. 1985; Ferson et al. 1979). Analysis of peripheral blood lymphocyte populations by monoclonal antibodies has demonstrated increased T-lymphocytes (OKT3+), with a decreased proportion of OKT4+ (helper/inducer), and an increased proportion of OKT8+ (suppressor/cytotoxic) subsets in smokers with greater than 50 pack-years of smoking (Miller et al. 1982). Analysis of bronchoalveolar lavage fluid from cigarette smokers with a mean smoking history of 14 $^-$ __ 9 pack-years demonstrated a decreased proportion of OKT4+ lymphocytes and an increased proportion of OKT8+ lymphocytes (Costabel et al. 1986). In the latter study, the alterations in T-lymphocyte subsets observed in bronchoalveolar lavage were not present in peripheral blood. This finding and the increase in IgG in bronchoalveolar lavage fluid, but not in serum, raise the possibility of regional effects of cigarette smoking on the immune system.

The extent to which the alterations of inflammatory cell numbers and functions observed in smokers are also present in individuals who are chronically exposed to environmental tobacco smoke remains unknown. Studies in humans have not directly addressed this issue. Studies of dose–response relationships are absent, except for those cited that document a relationship of peripheral white blood cell count and lymphocyte T-cell subsets. If it is assumed that a subgroup of nonsmokers is composed of individuals who are chronically exposed to environmental tobacco smoke, then some inferences

244

are possible. As has been stated, the most common pathologic feature in the lungs of young cigarette smokers is an accumulation of pigment-laden macrophages in the respiratory bronchioles. In the study by Niewoehner and colleagues (1974), all 19 male cigarette smokers who died suddenly elsewhere than in a hospital had such lesions, which were present in all sections studied in 16 of the 19 subjects. In contrast, only 5 of 20 nonsmokers had similar lesions, and they were minimal in all but 2. One of the two individuals was a stoker in a foundry and the other was undergoing desensitization for severe hay fever. Although the inflammatory cell accumulation cannot be absolutely attributed to these extenuating circumstances, it is clear that the respiratory bronchiolitis is not common in young, healthy individuals who do not smoke regularly. In contrast, autopsy studies have observed focal inflammatory changes quite frequently in older subjects who had not smoked, but the lesions were of much less severity than in age-matched subjects who had smoked (Cosio et al. 1978). Similar changes have not been observed in studies on bronchoalveolar lavage fluids. The metabolic activation of the AM from younger and older nonsmokers is similar (Hoidal and Niewoehner 1982). These findings suggest that the characteristic inflammatory lesions seen in the lungs of smokers are usually absent or are modest in those individuals who do not smoke cigarettes and who are not exposed to an alternative inciting agent.

Experimental Models

The effect of cigarette smoke inhalation on lung inflammation and inflammatory cell function has been extensively studied in experimental animal models; however, studies have not investigated inflammatory cell alterations in models intended to simulate chronic environmental tobacco smoke exposure. Several studies have demonstrated that chronic cigarette smoke exposure produces an accumulation of AM within the respiratory bronchioles of many animal species, including dogs (Hernandez et al. 1966; Frasca et al. 1971, 1983; Park et al. 1977), rats (Kendrick et al. 1976; Coggins et al. 1980; Huber et al. 1981), hamsters (Bernfeld et al. 1979; Hoidal and Niewoehner 1982), and mice (Matulionis and Traurig 1977), that is strikingly similar to that seen in human smokers. In most studies, the accumulation of AM has been dependent on the duration and intensity of the smoke exposure (Hoidal and Niewoehner 1982; Huber et al. 1981). Increases in lysosomal enzyme activities have been observed in rats (Etherton et al. 1979) and mice (Matulionis and Traurig 1977) following tobacco smoke exposure. Increased elastase secretion by alveolar macrophages from mice chronically exposed to cigarette smoke has also been observed (White et al. 1979). Oxygen consumption, superoxide anion release, hydrogen peroxide production, and hexose monophosphate shunt activity were reported to be

increased in AM harvested by bronchoalveolar lavage from hamsters (Hoidal and Niewoehner 1982) and rats (Drath et al. 1978; Huber et al. 1981) chronically exposed to tobacco smoke. Accumulation of PMN in the alveolar septa of cigarette smoke-exposed hamsters, strikingly similar to that observed in human smokers, has also been reported (Ludwig et al. 1985). In contrast to the focal nature of the AM accumulation, the accumulation of PMN was diffuse. Studies of PMN function have not been systematically evaluated in smoke-exposed animals. One distinctive feature in rats has been a lymphocytic periairway infiltration (Innes et al. 1956; Huber et al. 1981). Similar alterations are not seen in humans. The lymphocytic infiltration may be due to complicating respiratory infections with mycoplasma or a respiratory virus, which have been common in rats.

Effects of Cigarette Smoking on Lung Parenchyma: Studies in Humans

The most striking alteration of the lung parenchyma associated with cigarette smoking is centrilobular emphysema. The relationships between smoking history, age, and the degree of emphysema have been examined. The effect of smoking on the development of emphysema is believed to be cumulative (Anderson et al. 1972; Auerbach et al. 1974). In a study of 1,824 autopsies from individuals who had died in the hospital, Auerbach and associates, using a semiquantitative scoring system, detected emphysematous lesions in all individuals who had smoked two or more packs of cigarettes per day, including 111 who had been under 60 years of age at the time of death. The extent of emphysema strongly correlated with the number of cigarettes smoked per day. However, some emphysematous changes, usually of a mild degree, were noted in 94 percent of the individuals who had regularly smoked less than one-half pack per day. In contrast, no emphysema was detected in 95 percent of the 175 individuals who had not smoked regularly, and only one case of emphysema of moderate severity had occurred in a person who had not smoked. These findings suggest that emphysema is rare in individuals who do not smoke regularly and do not have a genetic predisposition for the disease.

Summary of Lung Effects

Substantial evidence documents that active cigarette smoking produces adverse effects on respiratory epithelial cells and causes lung inflammation and alveolar septal disruption. Whether these effects occur following chronic exposure to environmental tobacco smoke cannot be definitively answered by the fragmentary data now available. It is possible that clinically significant pulmonary consequences of chronic exposure to environmental tobacco smoke in adults might occur only when this exposure interacts with other

246

factors in particularly susceptible individuals. In this regard, future studies directed at selected high-risk populations or animal models incorporating exposure to environmental tobacco smoke along with other exposures might be the most fruitful areas of investigation into the effects of chronic exposure to environmental tobacco smoke.

Carcinogenicity of Environmental Tobacco Smoke

This section reviews some of the more widely employed methods of evaluation of the carcinogenicity of mainstream smoke that may also be extended to the evaluation of ETS. The similarities, differences, and technical difficulties in employing these various bioassays with MS, smoke condensate, and ETS are discussed.

Inhalation Experiments

Because inhalation is the primary mode of exposure for both active and involuntary smoking, animal inhalational assays would appear to be the ideal approach to developing an animal system for carcinogenicity testing. However, the acute toxicity (mainly due to carbon monoxide and nicotine) have limited the exposures to whole smoke that can be tolerated by laboratory animals.

Two types of passive exposure systems offer the primary approaches to inhalation studies with small laboratory animals. These systems provide either the forced exposure of the whole body to tobacco smoke or exposure of the head only. The amount of smoke that is retained in the lower respiratory tract of the animals is the dosage variable of interest in assessing these studies. The particulate matter content of whole smoke is probably of greater importance than the vapor phase content (Wynder and Hoffmann 1967; Davis et al. 1975) for studies of carcinogenesis. Labeled particulate phase components have been used for determining the deposition of the particulate phase in the respiratory tract in smoke inhalation studies (Mohr and Reznik 1978). However, since such markers are applied to the tobacco column, they may be partially volatilized during smoking. Thus, some of the values reported in deposition studies of inhaled smoke aerosols in mice, rats, and hamsters reflect the deposition of the trapped particulate phase plus the gas phase of cigarette smoke in the respiratory tract. A less ambiguous tracer is decachlorobiphenyl (DCBP). It is added to the tobacco column of cigarettes, and after exposure of the animals to the smoke of the treated cigarettes, this tracer can be determined in extracts of various segments of the respiratory tract by gas chromatography with an electron capture detector (GC-ECD). The detection limit of DCBP is $< 5 \times 10^{-11}$ g (Lewis et al. 1973; Hoffmann et al. 1979). Using these techniques, only a small percentage of the smoke particulates of cigarette mainstream smoke can be shown to reach regions in the

lower respiratory tract of small laboratory animals. This may explain, at least in part, why the lifetime inhalation exposures of small animals to tobacco smoke have led only to limited numbers of lung tumors.

In mice, inhalation assays with cigarette smoke have generally led to hyperplasia and metaplasia in the trachea and bronchi of the animals (Wynder and Hoffmann 1967; Mohr and Reznik 1978). In one of the most extensive studies, the Leuchtenbergers (1970) induced pulmonary adenoma and adenocarcinoma in Snell's mice. However, only the gas phase, not the total smoke, induced a statistically significant number of lung tumors.

In another inhalation bioassay, male and female C57Bl mice (100 in each group) were exposed, nose only, to fresh mainstream smoke diluted with air (1:39) for 12 minutes every other day for the duration of their lives. Four lung tumors were detected in both the treated male mice and the treated female mice. No lung tumors were found among controls. A similar experimental design was used to examine the possible differences between the smoke of flu-cured Bright tobacco cigarettes and the smoke of air-cured Bright tobacco cigarettes (Harris et al. 1974). Female Wistar rats (408 animals) were exposed, nose only, to a 1:5 smoke-to-air mixture for 15 seconds of every minute during an 11-minute exposure twice a day, 5 days per week, for the lifespan of the animals. Three of the rats exposed to cigarette smoke developed pulmonary squamous neoplasms of uncertain malignancy and one animal had an invasive squamous-cell carcinoma of the lung. No tumors were found in the 104 sham-control animals or in the 104 untreated female rats (Davis et al. 1975).

Fischer-344 rats (80 animals) were exposed, nose only, to a 1:10 smoke-to-air mixture for approximately 30 seconds of every minute that a cigarette was being smoked (Dalbey et al. 1980). In this manner, the animals were exposed to the smoke of one cigarette per hour, 7 hours per day, 5 days per week, for 128 weeks. The mean pulmonary particulate deposition during the smoke-aerosol exposure was 0.25 mg per cigarette, or 1.75 mg per rat per day. Ten respiratory tumors were observed in seven smoke-exposed rats. One alveologenic carcinoma and two adenomatoid lesions were observed in 3 of the 93 control rats employed in this study. A similar protocol was used to evaluate the effects of the inhalation of the smoke of cigarettes with varying tar deliveries. In this study (Wehner et al. 1981), squamous metaplasia of the laryngeal and tracheal epithelium was significantly increased in the smoke-exposed Fischer-344 rats.

Syrian golden hamsters (80 males and 80 females) were exposed, nose only, to a 1:7 smoke-to-air mixture for 10 to 30 minutes, 5 days per week, for a period no longer than 52 weeks. The incidence of

248

laryngeal leukoplakias ranged from 11.3 percent for the animal receiving the low dose to 30.6 percent for those animals receiving the highest dose of cigarette smoke. Such changes were not observed in the controls or in the hamsters exposed to the gas phase only (Dontenwill 1974). Exposing 102 male BIO 87.20 and BIO 15.16 hamsters, nose only, twice a day, 5 days a week, for up to 100 weeks, resulted in almost 90 percent of the animals having hyperplastic or neoplastic changes in the larynx (Bernfeld et al. 1974). Laryngeal cancer was five times more frequent in the BIO 15.16 strain. Two animals in this strain also developed nasopharyngeal tumors. Another study using nose-only exposures and similar extents of exposure reported similar changes in the larynx of the smoke-exposed animals (Wehner et al. 1974). Increasing the exposure duration to the lifespan of the animals resulted in the development of squamous papilloma of the larynx.

Thirty rabbits in an inhalation chamber were exposed to the smoke generated from 20 cigarettes for up to 5 1/2 years. Thirty-one animals were used as controls. No tumors were found among the treated animals that could be related to the exposure to cigarette smoke (Holland et al. 1963).

Eighty-six beagle dogs, trained to inhale cigarette smoke through tracheostomata, were actively exposed to smoke from either filter or nonfilter cigarettes (Auerbach, Hammond, Kirman et al. 1970). Tumors of the lung were reported in 23 of the 62 dogs exposed to smoke from the nonfilter cigarettes. Two of the dogs in this group had small bronchial carcinomas. Noninvasive bronchioalveolar tumors were reported in 4 of the 12 dogs exposed to the smoke of filter cigarettes and in 2 of the 8 control dogs. The bronchioalveolar tumors tended to be multiple, with as many as 20 per lung, and were reported in 40 of the 203 lung lobes in the 29 dogs with such tumors.

Inhalation studies with SS or ETS have not been reported thus far with any of the laboratory animal inhalational assays. This lack of experiments has in large part been due to the absence of exposure devices that allow the appropriate delivery of the inhalant without incurring the loss of the test animals due to the toxicity of carbon monoxide and nicotine.

Other In Vivo Bioassays

Among alternative methods used to assess the relative carcinogenicity of mainstream cigarette smoke, the most widely utilized test is to collect the cigarette smoke condensate (CSC) and to bioassay this material for carcinogenicity. In the process of preparing CSC, many of the volatile and semivolatile components are lost. Furthermore, there are serious concerns regarding the influence of aging of the CSC, which can affect both the chemical composition and the biological activity. Despite these shortcomings, bioassays using CSC

have provided insight into mechanisms by which tumor induction in animal tissues is likely to occur. The application of CSC to mouse skin has helped to identify those agents that are active as tumor initiators and has shown that within the CSC subfractions are components that can act as tumor promoters or cocarcinogens, respectively. Thus, this approach allows the comparison of various condensates, especially when large groups of animals are used (>50 per group).

The application of CSC to mouse skin is the most widely employed assay for the evaluation of its carcinogenic potential. The mouse skin bioassays in tobacco carcinogenesis have been reviewed (Hoffmann, Wynder et al. 1983). A typical experiment uses two to three dose levels of condensate, generally 25, 50, and 75 mg of CSC, which are administered topically to the shaved backs of mice three to six times weekly for approximately 78 weeks. The CSC is most frequently applied as an acetone suspension (25, 33, or 50 percent). At the conclusion of such a study, skin tumors, some of which are malignant, generally are observed among the treated animals in a dose-related fashion. Such studies have shown that the carcinogenic activity of CSC is also a function of tobacco variety, is influenced by replacement materials such as tobacco sheet or semisynthetics, and may be influenced by the use of additives. Although such bioassays have been extensively performed for the tars from mainstream cigarette smoke, only one study has examined the carcinogenic potential of the condensate of sidestream cigarette smoke.

Cigarette tar from the sidestream smoke of nonfilter cigarettes that had settled on the funnel covering a multiple-unit smoking machine was suspended in acetone and applied to mouse skin for 15 months (Wynder and Hoffmann 1967). Out of a group of 30 Swiss-ICR mice, 14 animals developed benign skin tumors and 3 animals had carcinomas. In a parallel assay of MS from the same cigarettes, a 50 percent CSC:acetone suspension applied to deliver a comparable dose of CSC to 100 Swiss-ICR female mice led to benign skin tumors in 24 mice and to malignant skin tumors in 6 mice. This indicates that this smoke condensate of SS had greater tumorigenicity on mouse skin than MS tar ($p > 0.05$).

In Vitro Assays

Several short-term bioassays have been performed to evaluate the genotoxicity of the MS of cigarettes. These studies have been the subject of two reviews (DeMarini 1983; Obe et al. 1984). Although most of these studies have evaluated the effects of CSC, some investigations were focused on either the gas phase or the whole smoke. In recent years, there has been increased use of short-term assays to attempt to evaluate the relative genotoxic potential of environmental tobacco smoke.

250

The most commonly employed assay for mutagenic activity is done with various strains of *Salmonella typhimurium*. Whole smoke as well as CSC from four types of tobacco were found to be mutagenic in *S. typhimurium* TA1538 (Basrur et al. 1978). Sidestream smoke was also found to be mutagenic in a system where the smoke was tested directly on the bacterial plates (Ong et al. 1984). These studies lend support to the extensive assays performed with CSC that establish that tobacco smoke has significant mutagenic potential.

Several of the studies with CSC from mainstream smoke have been aimed at comparing the effects of various tobaccos, various tester strains, and various systems selected for metabolic activation. Most of the mutagenic activity was associated with the basic fraction of CSC (DeMarini 1983). For the CSC from mainstream smoke, mutagenic activity was primarily detected with the strains TA1538 and TA98, thus indicating the presence of the frame-shift type of mutagens. Except for studies on the effects of nitrate-treated cigarettes, metabolic activation was required to demonstrate mutagenic activity for most of the CSC studied.

Several short-term tests have been performed in eukaryotic systems. A solution of the gas phase of mainstream cigarette smoke dissolved in a phosphate buffer induced reciprocal mitotic recombination in *Saccharomyces cerevisiae* D3 and petite mutants in an isolate of strain D3 (Izard et al. 1980). Whole mainstream cigarette smoke induced mitotic gene conversion, reverse mutation, and reciprocal mitotic recombination in strain D7 of *S. cerevisiae* (Gairola 1982).

Transformation of mammalian cells was also induced in several cell systems using the CSC from mainstream cigarette smoke (Lasnitzki 1968; Inui and Takayama 1971; Rhim and Huebner 1973; Benedict et al. 1975; Takayama et al. 1978; Rivedal and Sanner 1980). Transplacental exposure to mainstream CSC was reported to transform Syrian hamster foetal cells (Rasmussen et al. 1981). Transforming activity was reported in the acidic and basic fractions as well as the neutral fractions of CSC. Studies on subfractions of CSC have shown that the basic fraction and some of the acidic fractions are the most active in cell transformation (Benedict et al. 1975). The neutral fraction of CSC was also reported to inhibit DNA repair in normal human lymphocytes (Gaudin et al. 1972). Transformation of mammalian cells with SS or ETS has not been reported.

Summary of Carcinogenicity

At present, the scientific literature offers some information on the physicochemical nature of the sidestream smoke from tobacco products and of environmental tobacco smoke. Chemical analytical studies have already demonstrated that SS and ETS contain a wide spectrum of carcinogens such as polynuclear aromatic hydrocarbons,

volatile and tobacco-specific N-nitrosamines, and polonium-210. To date, only one study has demonstrated the carcinogenic activity of the particulate matter of sidestream smoke and a few isolated reports have dealt with the genotoxicity of SS and ETS. Therefore, bioassay studies with the mainstream smoke and the environmental tobacco smoke of cigarettes are needed. Although the resulting bioassay data will derive from tests of concentrations of environmental smoke that do not realistically occur in the human setting, these results will provide information about the relative carcinogenic potential of sidestream smoke in comparison with the mainstream smoke of the same cigarettes. In a comprehensive analytical approach, data should be generated to systematically determine the concentrations of toxic and tumorigenic agents in the ETS samples and to simultaneously measure the uptake of tobacco-specific agents by the body fluids of nonsmokers exposed to ETS.

Conclusions

1. The main effects of the irritants present in ETS occur in the conjunctiva of the eyes and the mucous membranes of the nose, throat, and lower respiratory tract. These irritant effects are a frequent cause of complaints about poor air quality due to environmental tobacco smoke.
2. Active cigarette smoking is associated with prominent changes in the number, type, and function of respiratory epithelial and inflammatory cells; the potential for environmental tobacco smoke exposure to produce similar changes should be investigated.
3. Animal models have demonstrated the carcinogencity of cigarette smoke, and the limited data that exist suggest that more carcinogenic activity per milligram of cigarette smoke concentrate may be contained in sidestream smoke than in mainstream cigarette smoke.

252

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253

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254

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255

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258

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260

CHAPTER 6

POLICIES RESTRICTING
SMOKING IN PUBLIC PLACES
AND THE WORKPLACE

CONTENTS

Introduction

Since the 1970s, the accumulating evidence on the health risks of involuntary smoking has been accompanied by a wave of social action regulating tobacco smoking in public places. Initiatives in the public sector and in the private sector have aimed at protecting individuals from exposure to sidestream smoke by regulating the circumstances in which smoking is permitted. Smoking in public places has been regulated primarily by government action at the local level and at the Federal level. Legislation has been the most common vehicle at the local and State level; agency regulations have predominated in the Federal Government. There has been relatively little judicial action to restrict smoking in public places; most cases have focused on nonsmoking employees' right to a smoke-free workplace (Feldman et al. 1978; Eriksen, in press; Walsh and Gordon 1986). Private sector initiatives have gained momentum in the 1980s. Businesses in a wide variety of industries have adopted smoking policies to protect employee health. Other private initiatives include no-smoking sections in restaurants, no-smoking rooms in hotels and motels, and smoking restrictions in hospitals.

Though this trend was fueled by growing evidence about the health effects of involuntary smoking, it also reflects the changing public attitudes about smoking since 1964, when public attention was focused on the health hazards of cigarette smoking by the Report of the Advisory Committee to the Surgeon General (US PHS 1964). The acceptability and desirability of tobacco smoking in public places has fallen dramatically over time, as reflected in public opinion surveys. A majority now support the right of nonsmokers to breathe smoke-free air and favor policies that ensure that right (ALA 1985b; Hanauer et al. 1986; BNA 1986; US DHEW 1969).

This chapter addresses the scope and impact of these diverse policies. It begins with a review of the current status of policies restricting smoking. Issues specific to smoking regulation in transportation vehicles and motels, restaurants, stores, schools, health care facilities, and the workplace are addressed. The effects of smoking policies on air quality, attitudes, and smoking behavior are considered.

Current Status of Restrictions on Smoking in Public Places

Smoking regulations in public places represent a mix of public and private actions. A public place may be defined as any enclosed area in which the public is permitted or to which the public is invited. Smoking restrictions are generally limited to indoor enclosed spaces (Hanauer et al. 1986). This broad definition of a public place encompasses a diverse group of facilities that differ in the degree to which smoking is restricted, the ease of introducing new regulations,

265

and the methods by which new smoking restrictions have been proposed and adopted.

Smoking in Federal, State, and local government facilities has been addressed by legislative and regulatory action. These facilities include government offices, public schools and libraries, and publicly owned transportation, health care, cultural, and sports facilities. In public facilities under private ownership, smoking restrictions are a mixture of government-sponsored regulation and private initiative. These facilities include retail stores, restaurants and bars, hotels and motels, and privately owned transportation, health care, cultural, and sports facilities.

The extent and acceptability of smoking restrictions in public places is influenced by (1) whether ownership is public or private; (2) the historical acceptance of smoking in the facility; (3) the degree to which nonsmokers are exposed to involuntary smoking, determined by the facility's size, degree of ventilation, and ease of separating smokers and nonsmokers; and (4) the degree of inconvenience that smoking restrictions pose to smokers. Smoking restrictions are still most widespread and least controversial in facilities where smoking has traditionally been prohibited by fire codes, such as theaters or libraries, or where smoking is negatively associated with the activity taking place, such as gyms or health care facilities (Feldman et al. 1978). Small crowded areas with poor ventilation, such as elevators and public transit vehicles, are also frequently regulated. On the other hand, the strong association of smoking with eating and drinking contributes to the controversial nature of smoking restrictions in restaurants and bars.

Legislative Approaches

Federal Legislation

Congress has enacted no Federal legislation restricting smoking in public places, although bills have been introduced in Congress several times since 1973 (Feldman et al. 1978).

State Legislation

Most legislation restricting smoking has been enacted at the State level. Although legislation regulating smoking for health reasons is largely a phenomenon of the past decade, cigarette smoking has been the subject of restrictive legislation for nearly a century. Early legislation had two different rationales. The first, a relatively noncontroversial rationale, was the protection of the public from fire or other safety hazards, largely in the workplace (Warner 1981b).

The second, more controversial motivation for early legislative action was a moral crusade against cigarettes similar in tone and coincident with the moral crusade against alcohol that emerged at

266

the turn of the century (Dillow 1981; Sobel 1978). Its goal was a total ban on cigarettes, which were blamed for social evils and physical ills, based largely on unfounded claims. By 1887, three States (North Dakota, Iowa, and Tennessee) had completely banned the sale and use of cigarettes. At the peak of the movement, cigarettes were banned in a dozen States (Nuehring and Markle 1974; Sobel 1978). Most were in the Midwest where cigarette consumption was low and anticigarette feeling high. The movement lost momentum when enforcing the regulations proved controversial. As part of the strong reaction to alcohol prohibition, all State laws banning smoking were repealed by 1927.

During the 1960s, as the health risks of smoking became widely recognized, public policy on smoking began to focus on encouraging the smoker to quit. However, the few existing State laws regulating smoking in public places were old and limited in scope. Even newly enacted laws—in Delaware (1960) and in Michigan (1967, 1968)—restricted smoking in limited areas: public buses and trolleys, elevators, and retail food establishments (US DHHS 1985b). Protecting the health or comfort of nonsmokers was not cited as a rationale of these laws. As of 1970, statutes restricting smoking were in force in 14 States (US DHHS 1985b).

In the early 1970s, a new wave of smoking legislation emerged. It covered smoking in a larger number of places and extended for the first time to privately owned facilities. The language became more restrictive, moving from permitting a no-smoking section to requiring one and making nonsmoking the principal or assumed condition. The language also changed to make it clear that the specific intent was the safety and comfort of nonsmokers.

The pace of new legislation increased in the mid-1970s. Between 1970 and 1974, 9 laws were enacted in 8 States; between 1975 and 1979, 29 new laws were passed and 15 additional States adopted smoking regulations. Minnesota passed its landmark Clean Indoor Air Act in 1975 "to protect the public health, comfort, and environment by prohibiting smoking in public places and at public meetings except in designated smoking areas" (Minnesota Statutes Annual 1985). It covered restaurants, private worksites, and a large number of public places, and soon became the model for other State legislation. Within the next 5 years, Utah, Montana, and Nebraska enacted similar comprehensive legislation (US DHHS 1985b). The language of statutes passed by 11 States during the 1970s made it clear that the specific purpose was to protect nonsmokers from involuntary smoking (US DHHS 1985b). Model legislation and advice about the successful enactment of State laws can be found in several sources (Hanauer et al. 1986; Feldman et al. 1978; Walsh and Gordon 1986).
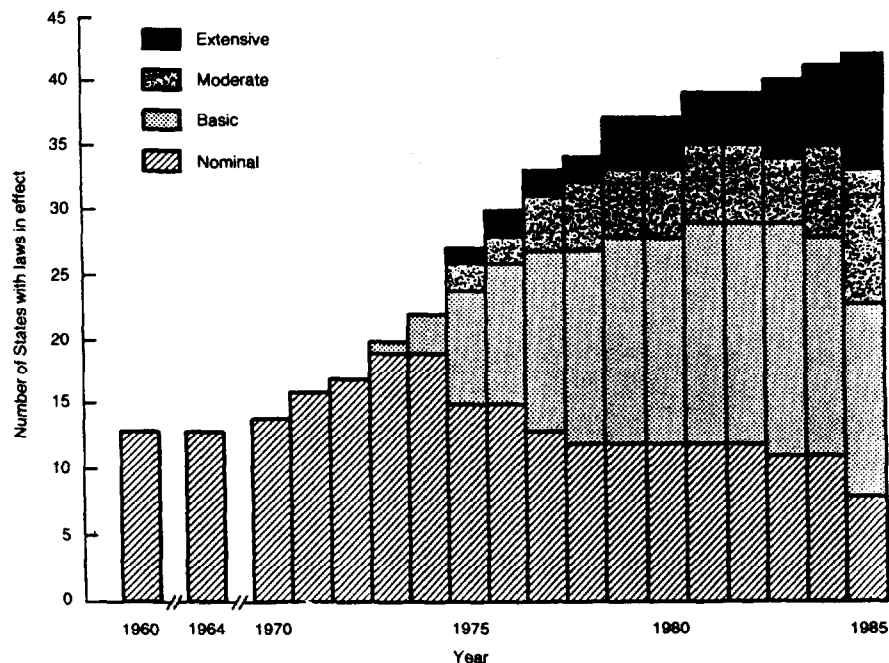
FIGURE 1.—Prevalence and restrictiveness of State laws
regulating smoking in public places, 1960–1985

NOTE: See appendix for definitions of restrictiveness of laws.

SOURCE: ASH (1986); OTA (1986); Tri-Agency Tobacco Free Project (1986); US DHHS (1985b).

The rate of enactment of State legislation increased throughout the seventies (Figure 1, Table 1). The pace of new legislation continues in the 1980s, with 23 new laws enacted by 16 States between 1980 and 1985 (Table 1). As of 1986, 41 States and the District of Columbia have enacted laws regulating smoking in at least one public place (Figure 1). Eighty percent of the U.S. population currently resides in States with some smoking restriction, compared with 8 percent in 1971 (Warner 1981b). Most of the nine States with no smoking legislation are concentrated in the southeast United States and include three of the six major tobacco-producing States (North Carolina, Virginia, and Tennessee) (Figure 2).

Current State legislation varies in comprehensiveness and language. The number of public places in which smoking is regulated by State law ranges from 1 (Delaware, Mississippi, and South Carolina regulate smoking on public transportation only) to 16 (Minnesota and Florida) (US DHHS 1985b, Tri-Agency Tobacco Free Project

268

TABLE 1.—State laws restricting smoking, 1970-1985

Year	Number of newly enacted laws	Cumulative number of States with laws in effect	Restrictiveness of newly enacted laws [1]	Average restrictiveness of laws in effect
1892-1969	—	14	—	.250
1970	0	14	—	.250
1971	2	16	.250	.250
1972	1	17	.250	.250
1973	3	20	.330	.263
1974	3	22	.417	.296
1975	12	27	.479	.389
1976	5	30	.563	.425
1977	6	33	.542	.462
1978	2	34	.625	.478
1979	4	37	.688	.507
1980	1	37	—[2]	.507
1981	6	39	.500	.513
1982	1	39	—[2]	.513
1983	4	40	.688	.538
1984	3	41	.667	.549
1985	8	42	.719	.619

[1] Index of Restrictiveness

0 = None; no statewide restrictions.

0.25 = Nominal; State regulates smoking in one to three public places, excluding restaurants and private worksites.

0.50 = Basic; State regulates smoking in four or more public places, excluding restaurants and private worksites.

0.75 = Moderate; State regulates smoking in restaurants but not private worksites.

1.00 = Extensive; State regulates smoking in private worksites.

[2] New California laws in 1980 and 1982 extended smoking restrictions to additional public places, but did not alter the restrictiveness of the State law (moderate).

1986). State laws most often restrict smoking in public transportation (35 States), hospitals (33 States), elevators (31 States), indoor cultural or recreational facilities (29 States), schools (27 States), public meeting rooms (21 States), and libraries (19 States) (Table 2). Other public places specifically mentioned in State smoking legislation are public restrooms and waiting rooms, jury rooms, polling places, prisons, hallways, stairwells, and stables. Most laws restrict smoking in these places to designated areas, thereby making nonsmoking the norm; in a few States smoking is banned entirely in these places. For example, smoking on public transportation is banned entirely in four States (Florida, Georgia, Massachusetts, and Washington) and one (Washington) bans smoking in theaters, museums, auditoriums, and indoor sports arenas. Smoking restric-
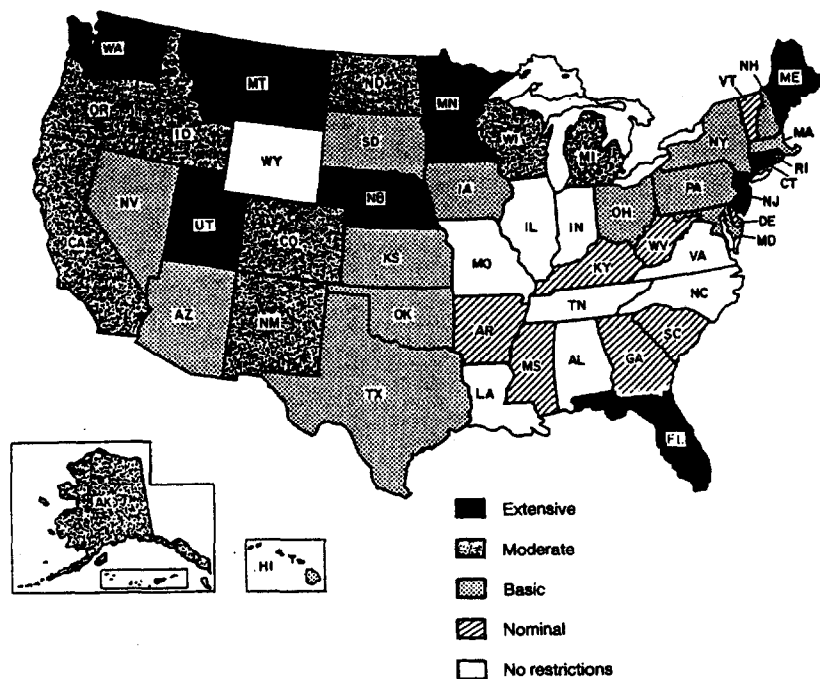
FIGURE 2.—Geographic variability of State laws regulating smoking in public places, 1986

NOTE: See appendix for definitions of restrictiveness of laws.
SOURCE: ASH (1986); OTA (1986); Tri-Agency Tobacco Free Project (1986); US DHHS (1985b).

tions extend to restaurants and retail stores, which are largely privately owned, in 18 States.

Smoking at the workplace is restricted for public sector employees in 22 States and for private sector employees in 9 States. The provisions of worksite smoking legislation vary widely, making direct comparisons of their comprehensiveness difficult.

Currently enacted workplace smoking laws contain provisions to (1) require a written policy (5 States); (2) limit smoking to designated areas (8 States); (3) require the posting of signs (10 States); and (4) give preference to nonsmokers in resolving conflicts over the designation of a work area (2 States) (OTA 1986). Public or private worksites are included in the definition of public places in some States where worksites are subject to the general provisions for public places. Other States have written separate guidelines for the worksite, which are usually more stringent. Laws in four States apply only to State and local government employees; restrictions apply to the private worksite in an additional nine States.

270

State	AL	AK	AZ	AR	CA	CO	CT	DE	DC	FL	GA	HI	ID	IL	IN	IA	KS	KY
Year(s) legislation enacted	—	1975 1984	1973 1981	1977 1985	1971,76 1980,81 1982	1977 1985[1]	1973 1974 1983	1960	1979	1983 1985	1975	1976	1925 1975 1985	—		1978	1975	1972

PUBLIC PLACES WHERE SMOKING IS PROHIBITED (EXCEPT IN DESIGNATED AREAS)

	AL	AK	AZ	AR	CA	CO	CT	DE	DC	FL	GA	HI	ID	IL	IN	IA	KS	KY
Public transportation		X	X	(X)[2]	X[3,4]	X	X[3]	X	X	X[3,5]	X[5]		X			X	X	X
Elevators		X[5]	X			X	X[5]		X	X[5]	X[5]	X	X			X	X	
Indoor recreational or cultural facilities[6]		X	X		X	X				X		X	X			X	X	
Retail stores		(X)[7]			(X)[7]	X	X		X	X			X					
Restaurants		X[8]			X[9]	X	X[10]			X[8]			X					
Schools		X	X	X	X	X	X		X	X			X					X
Health care facilities																		
Hospitals		X	X	X	X	X	X		X	X		X	X			X	X	
Nursing homes		X			X	X	X		X	X			X			X	X	
Public meeting rooms		X			X		X		X	X		X	X			X	X	
Libraries		X	X							X						X	X	
Restrooms		X[5]	X			X	X			X								
Waiting rooms		X	X			X	X			X						X		
Other		X[26,27]	X[27]							X[26,27,30]								

WORKSITE SMOKING RESTRICTIONS[16]

	AL	AK	AZ	AR	CA	CO	CT	DE	DC	FL	GA	HI	ID	IL	IN	IA	KS	KY
Public worksites		D[17]			B	D[1]	B		B	B,D[18]		B[1]	B			D		
Private worksites		A				B				B,D								

IMPLEMENTATION PROVISIONS

	AL	AK	AZ	AR	CA	CO	CT	DE	DC	FL	GA	HI	ID	IL	IN	IA	KS	KY
Nonsmokers prevail in disputes		X																
No discrimination against nonsmokers																		

ENFORCEMENT

	AL	AK	AZ	AR	CA	CO	CT	DE	DC	FL	GA	HI	ID	IL	IN	IA	KS	KY
Penalties for violations		X	X	X	X		X	X	X	X	X	X	X			X	X	X
Smoking		X[23d]	X[23p]	X[23e]	X[23e]		X[23c]	X[23c]	X[23e]	X[23i]	X[23e]	X[23e]	X[23d]			X[23e]	Z[23c]	X[23a]
Failure to post signs		X[24h]							X[24h]									

	AL	AK	AZ	AR	CA	CO	CT	DE	DC	FL	GA	HI	ID	IL	IN	IA	KS	KY
Overall State law restrictiveness:[25]	0	3	2	1	3	3	4	1	2	4	1	2	3	0	0	2	2	1

TABLE 2.—Continued

State	LA	ME	MD	MA	MI	MN	MS	MO	MT	NE	NV	NH	NJ	NM	NY	NC	ND	OH
		1954		1924	1967								1955		1921			
Year(s) legislation		1981,83	1957	1947	1968	1971					1911		1979		1975			1981
enacted	—	1985	1975	1975	1978	1975	1942	—	1979	1979	1975	1981	1985	1985	1976	—	1977	1984
PUBLIC PLACES WHERE SMOKING IS PROHIBITED (EXCEPT IN DESIGNATED AREAS)																		
Public transportation		X	X	X[a]	(X)[3]	X	X		X	X	X	X	X	X	X		X	X
Elevators			X	X[5]	X	X			X	X	X	X	X	X			X	X
Indoor recreational or cultural facilities[6]				X		X			X	X	X	X	X	X	X		X	X
Retail stores		X		(X)[7]	X	X			X	X		X	X					
Restaurants					X	X[11]			X	X			X[12]	X[13]			X	
Schools						X			X	X	X	X	X	X			X	X
Health care facilities																		
Hospitals		X	X	X	X	X			X	X	X	X	X	X			X	X
Nursing homes		X	X	X	X	X			X	X	X	X	X	X			X	X
Public meeting rooms						X			X	X	X	X	X	X			X	X
Libraries				X		X				X	X		X	X	X		X	
Restrooms		X				X				X							X	X
Waiting rooms		X				X				X	X	X					X	X
Other		X[25]		X[26]		X[26,27]				X[27]		X[28]			X[29]			
WORKSITE SMOKING RESTRICTIONS[16]																		
Public worksites	B,D					D[17]			D[18]	D[17]		D[20]	B,C[17]	B,C[20]			C	C
Private worksites	B,D					D[17,21]			D[19]	D[17,21]	A[22]		B,C[17]		A[22]			
IMPLEMENTATION PROVISIONS																		
Nonsmokers prevail in disputes						X								X				
No discrimination against nonsmokers	X																	

ENFORCEMENT

PUBLIC PLACES WHERE SMOKING IS PROHIBITED (EXCEPT IN DESIGNATED AREAS) / WORKSITE SMOKING RESTRICTIONS / IMPLEMENTATION PROVISIONS / ENFORCEMENT

State	OK	OR	PA	RI	SC	SD	TN	TX	UT	VT	VA	WA	WV	WI	WY	Total N (%)
Year(s) legislation enacted	1975	1973, 75, 1977, 1981	1927, 1947, 1977	1976, 1977	1937	1974	—	1975	1976, 1979	1892	—	1983	1913, 1919, 1985	1984	—	51 (100)
PUBLIC PLACES WHERE SMOKING IS PROHIBITED (EXCEPT IN DESIGNATED AREAS)																
Public transportation	X		X		(X)[2]	X		X	X			X[5]	X	X		35 (68.6)
Elevators	X	X	X			X		X	X			X[5]		X		31 (60.8)
Indoor recreational or cultural facilities[6]	X	X	X	X		X		X	X			X[5]		X		29 (59.6)
Retail stores		X	X	X					X			X[5]		X		18 (35.3)
Restaurants		X		X					X			X		X		18 (35.3)
Schools		X		X		X		X	X			X[5]	X	X		27 (52.9)
Health care facilities																
Hospitals		X	X	X		X		X	X			X		X		33 (64.7)
Nursing homes		X	X	X				X	X			X		X		29 (56.9)
Public meeting rooms		X							X			X[5]				21 (41.2)
Libraries	X			X		X		X	X			X				19 (37.2)
Restrooms												X				11 (21.6)
Waiting rooms		X										X		X		16 (31.4)
Other			X[30]	X[28]								X[15]				12 (23.5)
WORKSITE SMOKING RESTRICTIONS[16]																
Public worksites		D							D[17]			D		D[18]		22 (43.1)
Private worksites									D[17,22]	A[22]	A[22]	D				9 (17.6)
IMPLEMENTATION PROVISIONS																
Nonsmokers prevail in disputes									X							4 (7.8)
No discrimination against nonsmokers									X							2 (3.9)
ENFORCEMENT																
Penalties for violations	X	X	X	X		X		X	X	X		X	X	X		40 (78.4)
Smoking	X[23e]	X[23b]	X[23c]	X[23e]		X[23p]		X[23o]	X[23o]	X[23a]		X[23f]	X[23a]	X[23k]		39 (76.5)
Failure to post signs		X[24e]		X[24e]									X[24e]			9 (17.6)
Overall State law restrictiveness[25]	2	3	2	3	1	2	0	2	4	1	0	4	1	3	0	

TABLE 2.—Continued (Footnotes)

[1] Executive order.

[2] School buses only.

[3] Including school buses.

[4] California stipulates that at least 50 percent of all passenger seats must be in nonsmoking areas on trains, airplanes, and street railroad cars departing from the State.

[5] Smoking never permitted in this area.

[6] Indoor recreational and cultural facilities: museums, auditoriums, theaters, and sports arenas.

[7] Grocery stores only.

[8] Restaurants seating 50 or more persons must have a no-smoking section.

[9] Restaurants seating 50 or more persons must have a no-smoking section if the restaurant is in a publicly owned building.

[10] Restaurants seating 75 or more persons must have a no-smoking section.

[11] Restaurants must designate at least 30 percent of their seats as a no-smoking area.

[12] Restaurants are encouraged to establish no-smoking areas.

[13] Restaurants must designate at least 50 percent of their seats as a no-smoking area.

[14] (Deleted).

[15] No place other than a bar may be designated a smoking area in its entirety.

[16] Worksite (only B, C, and D count as having a worksite policy in caculation of totals): A – Employer must post a sign prohibiting smoking at the worksite; B – Employer must have a (written) smoking policy; C – Employer must have policy that provides a nonsmoking area; D – No smoking except in designated areas.

[17] Employer must post signs designating smoking and no-smoking areas.

[18] Employer must post signs in smoking areas.

[19] Employer must post either smoking or no-smoking signs, depending upon their policy.

[20] Employer must post signs in no-smoking areas.

[21] State does not restrict smoking in factories, warehouses, and similar places of work not usually frequented by the general public.

[22] Prohibits smoking in any mill or factory in which a no-smoking sign is posted.

[23] Persons who smoke in a prohibited area are subject to a fine or a penalty. Maximum fines or penalties, where applicable, are listed below: a = $5; b = $10; c = $25; d = $50; e = $100; f = $100/day; g = $200; h = $300; i = $500; j = $50 or up to 10 days in jail or both; k = $50 or 90 days imprisonment; l = civil action; m = minor misdemeanor; n = petty misdemeanor; o = misdemeanor; p = petty offense.

[24] Persons who are required to and fail to post smoking and/or no-smoking signs are subjected to a penalty. Maximum fines, where applicable, are listed in footnote 23.

[25] Restrictiveness key: 0 = None, no statewide restrictions; 1 = Nominal, State regulates smoking in one to three public places, excluding restaurants and private worksites; 2 = Basic, State regulates smoking in four or more public places, excluding restaurants and private worksites; 3 = Moderate, State regulates smoking in restaurants but not private worksites; 4 = Extensive, State regulates smoking in private worksites.

[26] Jury rooms.

[27] Halls and stairs.

[28] Stables.

[29] Polling places.

[30] Prisons, at prison officials' discretion.

The least restrictive workplace laws simply empower the employer to restrict smoking in factories by posting signs. These statutes were enacted in the early 1900s. The weakest recent laws simply require an employer to issue a written smoking policy and to post signs. More restrictive laws require that employers designate no-smoking areas at work, implying that smoking is the norm. The most comprehensive laws prohibit smoking except in designated areas, making nonsmoking the norm. Seven States (Florida, Maine, Minnesota, Montana, Nebraska, Utah, and Washington) have this type of law. In several States, some worksites or some parts of a worksite (usually private offices) are exempted from the regulations. To prevent employers from complying with the letter but not the intent of the law, some States prohibit a workplace from being designated as entirely smoking.

State laws vary in their provisions for implementation and enforcement. In most States, the State health department is responsible for policy enforcement. Nearly all (39 of 42) States with laws provide penalties for smokers who violate restrictions; the maximum penalty is $500. In two States violators can be jailed. Employers or others who fail to designate smoking areas can be fined in nine States.

The comprehensiveness of State laws, as defined by the number and nature of places where smoking is restricted or prohibited, has increased since 1970. In 1981, Warner (1981b) classified State laws according to their comprehensiveness (restrictiveness) and documented an increase in the average restrictiveness from 1971 to 1978. An updated and modified index of the comprehensiveness of State laws (described in the appendix) demonstrates that the phenomenon reported by Warner has continued into the mid-eighties. The comprehensiveness of newly enacted laws increased markedly during the mid-seventies, and the average restrictiveness of State laws in effect has increased more than twofold between 1972 and 1985 (Table 1, Figure 3). As shown in Figure 1 and Table 1, the increase in comprehensiveness of State laws occurred in two ways. The average comprehensiveness of first laws in additional States increased, and existing State smoking laws were replaced with more comprehensive legislation.

Warner also documented that both the prevalence and comprehensiveness of State laws enacted through 1978 varied by geographic region (Warner 1982). This has not changed (Table 3, Figure 2). Over 90 percent of the States in the Northeast and West have enacted at least one law regulating smoking, as have three-fourths of the North Central States. Southern States have fewer laws than other regions, and the laws they have are less comprehensive than laws in other regions. The six major tobacco-producing States, all located in the South, have less restrictive laws than do the other six Southern
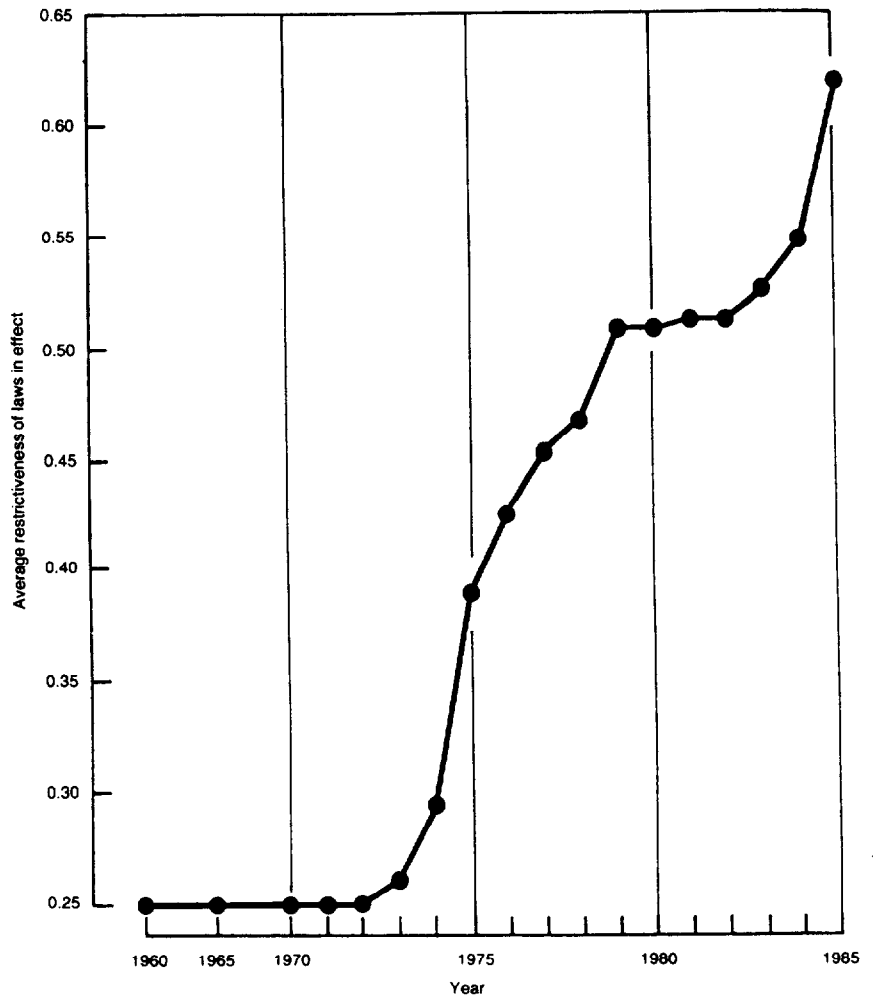
FIGURE 3.—Average restrictiveness of State laws in effect, 1960–1985

NOTE: Coding of restrictiveness of law; Extensive = 1.00; Moderate = 0.75; Basic = 0.50; Nominal = 0.25. (See appendix for definitions of restrictiveness of laws.)

SOURCE: ASH (1986); OTA (1986); Tri-Agency Tobacco Free Project (1986); US DHHS (1985b).

States. Compared with other States, major tobacco States are less likely to have enacted smoking legislation and more likely to have enacted less stringent laws.

TABLE 3.—Regional variation in State laws restricting smoking

Region	Total States N	States with laws[1] N	(%)	Average effective date of first law	Average restrictiveness of laws in effect in 1985[2,3]
Northeast	11	11	(100)	1944	.614
North Central	12	9	(75)	1976	.694
West	15	14	(93)	1968	.714
South	12	7	(58)	1955	.357
Major tobacco-producing States[4]	6	3	(50)	1961	.250
Other southern States	6	4	(67)	1951	.438

[1] Differences in prevalence of laws among four regions: chi square; (3 df) = 8.67, p = 0.03; difference in prevalence of laws, South vs. all others: chi square (1 df) = 5.99, p = 0.04.
[2] Includes only States with laws in effect (see Table 1 for Index of Restrictiveness).
[3] Difference in restrictiveness, South vs. all others: t = 2.76, p = 0.03.
[4] North Carolina, South Carolina, Virginia, Kentucky, Tennessee, Georgia.

Local Legislation

In the 1980s, the momentum of nonsmokers' rights legislation spread from the State to the local level, spearheaded by actions in California (Warner et al. 1986). Although not the first local action, the successful passage of San Francisco's Proposition P in 1983 in spite of heavily subsidized tobacco industry opposition attracted widespread publicity and was followed by the passage of comprehensive legislation in a number of other local communities (Doyle 1984).

Many local ordinances extend existing State policies to restaurants and worksites. According to a March 1986 survey, 74 California cities and counties have passed smoking ordinances, including 62 requiring no-smoking sections in restaurants and 54 restricting smoking in retail stores (Americans for Nonsmokers' Rights Foundation 1986). In the survey, 66 of these cities and counties require private employers to have a smoking policy or to identify no-smoking areas. As a result, 44 percent of California's population lives in communities that have enacted workplace smoking ordinances even though California has no State legislation covering the private workplace.

According to the Tobacco Institute, by the end of 1985, 89 cities and counties nationwide had restricted smoking in the private workplace. As stated above, three-fourths of these were in California (BNA 1986). Workplace smoking ordinances have also been passed in Cincinnati (Ohio), Kansas City (Missouri), Tucson (Arizona), Aspen

(Colorado), San Antonio, Austin, and Fort Worth (Texas), Newton (Massachusetts), and Suffolk County (New York). In New York City, a bill to prohibit smoking in all enclosed public places has been proposed by the mayor (New York Times 7/6/86).

Regulatory Approaches

Administrative agencies have become involved in smoking regulation in two ways: (1) the enforcement of smoking legislation enacted by State and local government is commonly delegated to a specific agency, usually the public health department; or (2) an agency may initiate smoking regulation as part of the activities it has been authorized to supervise (Feldman et al. 1978). Agency regulations have been the major mode of regulation at the Federal level, where smoking by Government employees and by passengers in interstate transportation vehicles have been addressed. Smoking by State and local employees has also been addressed by the actions of administrators; e.g., smoking by municipal employees and in public areas of municipal buildings was banned by a recent mayoral order in New York City (New York Times 6/26/86).

Smoking Regulation in Specific Public Places

Public Transportation

Because high concentrations of environmental tobacco smoke can accumulate inside public transport vehicles, smoking is often restricted or banned in public transportation. Smoking is likely to be banned entirely in vehicles where smokers spend relatively little time (e.g., city buses), and confined to designated areas in situations where smokers spend several hours (e.g., intercity buses, trains, and airplanes). Such restrictions are relatively well accepted.

Smoking on interstate transportation vehicles is regulated by Federal agencies. The Civil Aeronautics Board, under its jurisdiction to "ensure safe and adequate service, equipment, and facilities," initially regulated smoking on airplanes, requiring, since 1972, that every commercial air flight provide a no-smoking section for all passengers requesting such seating (Feldman et al. 1978; Walsh and Gordon 1986). Airline control is currently part of the authority of the U.S. Department of Transportation. Likewise, the Interstate Commerce Commission has restricted smoking on buses and trains to designated areas since the early 1970s (Feldman et al. 1978; Walsh 1984).

Additionally, States and local governments have regulated smoking in public transportation vehicles. Thirty-one States have enacted legislation to restrict smoking to designated areas in public transit vehicles; an additional four (Florida, Georgia, Massachusetts, and

278

Washington) ban smoking entirely on these vehicles (Table 2). Local ordinances also frequently address public transportation.

Retail Stores

In general, State and local legislation prohibiting smoking in retail stores is well accepted. Eighteen States currently prohibit smoking in retail stores (Table 2). Proprietors and their trade associations have generally supported smoking restrictions out of concern for the costs of cigarette burns to merchandise and facilities and for the image presented to customers by employees. Furthermore, their business is less likely to be affected than, for instance, the restaurant trade because smoking is not as closely associated with shopping as it is with eating and drinking.

Restaurants

The average American, who according to National Restaurant Association (NRA) statistics eats out 3.7 times per week, has the potential for repeated environmental tobacco smoke (ETS) exposure (NRA 1986). This is a problem particularly in small restaurants, where ventilation may not be able to remove smoke and room size precludes a meaningful separation of smokers and nonsmokers. Public opinion polls document support for restaurant smoking restrictions among nonsmokers *and* smokers. Ninety-one percent of nonsmokers and 86 percent of smokers responding to a 1983 Gallup poll favored either restricting or banning restaurant smoking, with most preferring restriction (Gallup 1983). Similar results were reported by two regional polls in 1984 (UC SRC 1984, Hollander-Cohen Associates 1984). Roper polls in 1976 and 1978 demonstrated the growth in this sentiment during the mid-seventies; the proportion of respondents supporting restrictions grew from 57 percent to 73 percent in 2 years (Roper 1978). Yet little is known about how restrictions affect decisions to dine out or the choice of restaurant. A 1981 telephone survey of 949 individuals conducted by the NRA (1982) found that the existence of a no-smoking section was near the bottom of a list of 13 attributes influencing an individual's choice of restaurant. On the other hand, 47 percent of 1,038 adults answering a 1984 Gallup Monthly Report on Eating Out stated that one reason they did not eat out more was that they were bothered by smoke (Gallup 1984).

As in other privately owned facilities, smoking regulations in restaurants have come about through private initiative *and* public mandate. Private initiatives have sometimes occurred in anticipation of a local ordinance, but the number of restaurants that have voluntarily established no-smoking sections is not known. The

279

Ontario Restaurant and Food Services Association (1985) published a handbook of guidelines for establishing no-smoking sections.

In 1974, Connecticut became the first State to require restaurants to have no-smoking sections. By 1980, eight other States also regulated restaurant smoking. At present, laws in 18 States and an unknown number of localities regulate smoking in restaurants. Although a nationwide accounting of local regulations is not available, data are available for several States (Table 2). Most State and local ordinances specify (1) the minimum number of seats that must be included in a no-smoking section, (2) the smallest restaurant for which rules apply, and (3) the manner in which customers are to be informed about no-smoking sections. Bars that do not serve meals are uniformly excluded from restrictions. Most current State legislation specifies that a minimum of 30 percent of seats be designated as no-smoking and exempts facilities with fewer than 50 seats. Local ordinances are generally more restrictive, specifying that a higher percentage of seats be designated no-smoking and extending coverage to smaller establishments. Model ordinances (Hanauer et al. 1986) suggest that a minimum of 50 percent of seats be designated as no-smoking, require the posting of signs inside and outside the facility, and specify that owners ask patrons about smoking preference rather than respond only to customer requests.

There has been more opposition to smoking restrictions in restaurants than in other privately owned public places (Hanauer et al. 1986). Opposition has come primarily from restaurant associations and centers on three concerns: (1) government intrusion into business practice, (2) practical problems in coordinating seating of smokers and nonsmokers, and (3) losing the business of smokers who chose to leave a facility rather than to dine in a no-smoking section or wait for an available table in a smoking section. These concerns assume that the supply of no-smoking tables will exceed demand. While the proportion of tables allocated by most laws to no-smoking sections greatly underrepresents the proportion of nonsmokers, mixed parties of smokers and nonsmokers would have to decide which section to sit in. Restaurant owners appear to perceive little customer demand for no-smoking areas, or are unaware of the very high percentage of smokers and nonsmokers responding to public opinion polls who support smoking restrictions.

In anecdotal reports, the experience of restaurant owners who have implemented restrictions is that they are well accepted by customers and less difficult to implement than expected (Lehman 1984). There is little information on the extent of restaurant compliance with State and local laws. In Park City, Utah, the Chamber of Commerce polled its 32 member restaurants, and only 25 percent had complied with State law to set up no-smoking areas (Park Record 6/13/85). However, a random survey of Minneapolis

280

restaurants in 1976, 1 year after enactment of the comprehensive Minnesota Clean Indoor Air Act, found near-total compliance with the State's smoking regulations (Sandell 1984). In a 1978 Minnesota survey, 66 percent of nonsmokers and 81 percent of smokers felt that there were adequate no-smoking areas in that State's restaurants (Minneapolis Tribune 1978).

Hotels and Motels

Over the past decade, hotel and motel operators have begun to offer guest rooms in which smoking is prohibited. In some facilities, no-smoking areas in lobbies and restaurants are also provided. Hotels are unique among public places in the manner and ease with which smoking has been addressed. Unlike the situation in restaurants, among hotels the no-smoking room policy is uniformly a private initiative, introduced by management in response to perceived customer demand (Linnell 1986). Hotel and motel rooms are not covered by State and local regulations and have not been addressed by nonsmokers' rights advocates.

Designating guestrooms as no-smoking began in the early 1970s in smaller hotel and motel chains. In the 1980s, the concept has spread to larger chains, including Hyatt Hotels in 1984 and Hilton Hotels in 1986 (Los Angeles Times 1986). According to a 1985 survey of 98 hotel and motel chains, 37 of 41 respondents provided no-smoking rooms, 23 by chainwide policy. The four respondents who did not offer no-smoking rooms were considering doing so (Linnell 1986). The percentage of rooms allocated as no-smoking varied from 5 to 30 percent, far less than the prevalence of nonsmokers in the adult population (70 percent). As a result, demand often exceeds supply, leading several chains to increase the percentage of no-smoking rooms (Linnell 1986; Vettel 1986). The only entirely no-smoking facility is the Non-Smokers Inn, a 134-room motel in Dallas, Texas, which has been open since 1982 and reports a 96 percent occupancy rate (Vettel 1986). Although there are anecdotal reports of problems with compliance, hotels do not have penalties for violators. The exception is the Non-Smokers Inn, where at check-in guests sign an agreement to abide by the rule; if the management detects smoking by occupants, $250 is charged to cover the costs of cleaning.

Whether no-smoking guestrooms offer significant protection from sidestream smoke exposure is not clear. It is not known whether nonsmokers are exposed to significant quantities of ETS by staying in hotel rooms previously, but not currently, occupied by smokers. Rooms designated as no-smoking may primarily allow nonsmokers to avoid stale tobacco odors.

The regulation of smoking in hotels and motels is supported by public opinion. Fifty to sixty percent of respondents to recent opinion polls favor restrictions on smoking in hotel rooms, and an additional

7 to 18 percent favor outright bans on smoking (Gallup 1983, UC SRC 1984, Hollander-Cohen Associates 1984). In the 1983 Gallup poll, 60 percent of nonsmokers and 49 percent of smokers supported smoking restrictions in hotels, with an additional 15 percent of smokers and 7 percent of nonsmokers favoring outright smoking bans.

Hotel management regards such policy as a marketing tool. Cost savings do not appear to be a motivating force in the trend, in spite of anecdotal reports of reduced cleaning and maintenance costs in no-smoking rooms (Linnell 1986). Preparing no-smoking rooms requires an up-front cost for the thorough cleaning of furnishings and often the repainting of walls. For instance, Quality Inns estimated that it spent $138 per room when it allocated 10 percent of its rooms as no-smoking in 1984 (Vettel 1986).

Schools

Smoking by students in schools has been the subject of State legislation, State and local school board regulations, and individual school policies. Colleges and universities are not discussed in this section. In 27 States, schools are among the public places where smoking is restricted to designated areas (Table 2). School board policies often combine restrictions on tobacco use in schools with educational programs about the hazards of tobacco use. Smoking by teachers, for whom school is the workplace, is also regulated by many school boards.

Smoking has traditionally been regulated in schools for reasons other than concern about sidestream smoke exposure. The two rationales have been to comply with State law and to prevent the initiation of smoking by adolescents. The sale or use of tobacco by minors is prohibited in 35 States (Breslow 1982). Many of these laws are rendered ineffective by the availability of cigarettes in vending machines and by cultural norms that discourage the laws' enforcement (US DHEW 1969). Nonetheless, the laws do provide a legal incentive for schools to regulate student smoking. The second reason for restricting smoking in schools is that adolescents are making decisions about whether to begin smoking and the influence of peers as well as of adult role models who smoke is recognized to be important (US DHHS 1980, 1982).

Recognition of the health effects of involuntary smoking provides an additional reason to address smoking in schools and a reason to expand attention from students to faculty. For teachers and staff, the school is the worksite, a location with the potential for substantial ETS exposure (Repace and Lowrey 1985). For students, school is the site where they spend the most time outside of the home.

282

A total prohibition of smoking on school grounds provides the greatest protection from sidestream smoke exposure and unwanted role modeling effects. In practice, however, this policy has often proved difficult to enforce effectively (Rashak et al. 1986). In some cases it has created major discipline problems and required substantial time and personnel for enforcement. School officials, faced with the management of other social problems, may not wish to devote much of their resources to enforcement of a strict smoking ban. Consequently, many schools have established student smoking areas inside or outside the school building. Use of these areas often requires parental permission. Smoking areas for students are not popular with parents or teachers, according to survey data. Over three-fourths of 603 adults responding to a 1977 Minnesota poll opposed allowing school boards to establish smoking areas for students. Only 13 percent of 1,577 public school teachers responding to a 1976 nationwide survey thought students should be able to smoke on school grounds.

The nature and extent of school smoking policies nationwide is not known. Results of the few statewide surveys vary considerably. A Connecticut survey reported that 75 percent of the State's public high schools permitted smoking (Bailey 1983). In contrast, in Arizona, where State law requires schools to restrict smoking on school grounds, 92 percent of the State's 169 public and private secondary schools surveyed had written smoking policies for students, and most policies prohibited all tobacco use by students (Rashak et al. 1986).

Smoking by teachers at schools is generally prohibited in the classroom, but is often permitted in a lounge where students are not allowed. Ninety percent of Arizona schools permit smoking in teachers' lounges, 40 percent in private offices, and 19 percent in meetings (Rashak et al. 1986). Such policies attempt to avoid negative role modeling effects; however, they create a double standard that may be a barrier to student compliance with smoking bans. There has been little concern for protecting teachers from involuntary smoke exposure at the worksite. Since smoking is prohibited in the classroom, their exposure is limited to offices and lounges.

Health Care Facilities

There are strong reasons for health care facilities to have particularly stringent restrictions on smoking. Many patients treated in these facilities suffer from illnesses whose symptoms can be worsened by acute exposure to tobacco smoke. Hospitals also convey messages about health to patients and visitors; permitting smoking on the premises may undermine the messages delivered to many patients about the importance of not smoking (Kottke et al. 1986).

Stringent restrictions on smoking in hospitals have been endorsed by the American Academy of Pediatrics (1986), the American Medical Association (1984), and the American College of Physicians (1986). Hospital smoking policies have been opposed by some who are concerned about inconveniencing smokers at times of illness and stress. Proponents of hospital no-smoking policies, on the other hand, are concerned about inconveniencing the *nonsmoking* patient or visitor at these stressful times.

Public opinion supports smoking restrictions in health care facilities. In the 1978 Roper survey, 69 percent of respondents favored a ban on smoking in doctors' and dentists' offices and waiting rooms (AMA 1984). Of the more than 3,000 individuals interviewed in hospitals and restaurants, 66 percent favored restricting or banning smoking in these areas (Barr and Lambert 1982). Over 80 percent of patients and faculty and 68 percent of employees agreed that "a smoke-free hospital would be an improvement in patient care" at the University of 1 linnesota hospital (Kottke et al. 1986).

Smoking in health care facilities has been addressed through State and local legislation, Federal regulation, and private initiative. In most States, hospitals and nursing homes are included among public places where smoking is restricted to designated areas (Table 2). In many cases, these legislative efforts have not led to strong protection of patients from involuntary smoke exposure because patient care areas may be included among the designated areas where smoking is permitted. Federally run hospitals have adopted increasingly stringent restrictions on smoking. For instance, Veterans' Administration hospitals and clinics adopted a new smoking policy in 1986, and a large number of Indian Health Service hospitals are now entirely smoke free (OTA 1986; Rhoades and Fairbanks 1985). Health care facilities run by some States, such as Massachusetts, have also adopted no-smoking policies (Naimark 1986). In nongovernment hospitals, most smoking restriction has been the result of private initiative, often spearheaded by the medical staff. Much of this action has taken place in the 1980s.

Hospital smoking policies can be complex. Within a single institution, smoking may be handled differently in inpatient, outpatient, and administrative areas. Patients, visitors, and employees may be subject to different sets of restrictions. Consequently, smoking policies vary widely among hospitals (Ernster and Wilner 1985). The least stringent policy prohibits smoking only where it is a safety hazard, such as near oxygen, and may permit the sale of cigarettes on the premises. Mild policies often assign patients to beds by smoking status, prohibit staff from smoking in patient care areas, and provide areas in cafeterias and waiting rooms for nonsmokers. Moderately stringent policies prohibit smoking in shared patient

284

rooms or in all patient rooms. Some hospitals permit patients to smoke with a doctor's written order. The most stringent policies, the so-called smoke-free hospitals, prohibit smoking throughout the facility or limit smoking to a single room away from patient care areas (Kottke et al. 1986). Enforcement of a smoking policy is usually the responsibility of the nursing staff. Guidelines for implementing hospital smoking policies have been formulated (Kottke et al. 1986; Ernster and Wilner 1985; AHA 1982).

In spite of anecdotal reports of the adoption of stringent smoking policies in individual hospitals (Andrews 1983), survey data indicate that smoking is still widely permitted in patient care areas. A survey of 360 randomly selected U.S. hospitals published in 1979 found few restrictions on smoking; fewer than half elicited the patients' smoking preference on admission or had no-smoking areas in cafeterias, waiting rooms, or lobbies, and smoking was permitted on 76 percent of the wards (Kelly and Cohen 1979). A 1981 survey of 1,168 community hospitals (Jones 1981) documented some change in policy prevalence. More than 90 percent of the hospitals had a written smoking policy, which restricted smoking to designated areas in 97 percent of cases. Over 85 percent of the hospitals offered no-smoking patient rooms, subject to availability (Jones 1981). A recent survey of 185 hospital administrators in Georgia reported that 70 percent continue to allow smoking in patient rooms, although only 6 percent permit it at nurses' stations (Berman et al. 1985). The proportion of hospitals allowing cigarette sales on the premises has declined from 56 to 58 percent in the late seventies (Kelly and Cohen 1979; Seffrin et al. 1978) to less than 30 percent in the eighties (Ernster and Wilner 1985; Jones 1981; Berman et al. 1985; Bertelsen and Stolberg 1981). While there are little data on the prevalence of smoking policies in private physicians' offices, guidelines for physicians wanting to provide assistance in smoking cessation are well developed (Lichtenstein and Danaher 1978; Shipley and Orleans 1982; US DHHS 1984).

Current Status of Smoking Regulations in the Workplace

Policies regulating smoking at the workplace for the protection of employees' health are a trend of the 1980s. As of 1986, smoking is restricted or banned in 35 to 40 percent of private sector businesses (HRPC 1985; BNA 1986; US DHHS 1986) and in an increasing number of Federal, State, and local government offices (OTA 1986). Private sector workplace smoking is regulated by law in 9 States and over 70 communities (OTA 1986; US DHHS 1985b; ASH 1986). Actions to restrict or ban smoking at the workplace are supported by a large majority of both smokers and nonsmokers (Gallup 1985).

285

The workplace has become the focus of particular attention as evidence about the health hazards of involuntary smoking has accumulated. Urban adults spend more time at work than at any other location except home (Repace and Lowrey 1985). For adults living in a household where no one smokes (Harris 1985), the workplace is the greatest source of ETS exposure. Consequently, an individual's workplace ETS exposure can be substantial in duration and intensity. This is of particular concern for individuals also exposed to industrial toxins whose effects may be synergistic with tobacco smoke (US DHHS 1985c). Furthermore, individuals have less choice about their ETS exposure at work than they do in other places, such as restaurants or auditoriums.

The nonsmoker's right to clean air on the job has been supported by common law precedent (US DHHS 1985a; Walsh and Gordon 1986). Assuring clean air at work has received the growing attention of policymakers and nonsmokers' rights advocates. The worksite has also received attention because of its naturally occurring interpersonal networks and intrinsic social norms. Behavioral scientists have attempted to take advantage of the social milieu of the workplace to increase the success of smoking cessation programs (US DHHS 1985c). Smoking policies have the potential to alter worksite norms about smoking and thereby to contribute to reductions in employee smoking rates or the prevention of smoking onset. A substantial fraction of blue-collar workers who smoke report the initiation of smoking at ages coincident with their entry into the workforce (US DHHS 1985c).

Smoking Policies

Legislation mandating smoking policies in the private sector workplace has been more controversial and less widespread than legislation covering public places. Because a worker's behavior off the job has traditionally been viewed as beyond the employer's legitimate concern, private employers have been reluctant to impose rules on behavior not directly related to employment (Walsh 1984; Fielding 1986). The concept of workplace smoking restriction has become more acceptable to employers and legislators as the hazards of involuntary smoking have become better known and as public attitudes about smoking have shifted. The rationale for policies has been reframed as guaranteeing an employee's right to a healthy work environment.

Prevalence of Smoking Policies

Notwithstanding the recent attention, regulating smoking at work is not a new idea. There is a long and noncontroversial tradition of smoking restrictions to insure the safety of the worker, workplace, and product (OTA 1986). Employers have restricted smoking to

286

prevent fires or explosions around flammable materials or to prevent product contamination. The policies were supported by State legislation dating back to 1892, when Vermont authorized employers to ban smoking in factories so long as a sign was posted (Warner 1982; US DHHS 1985b). New York, Nevada, and West Virginia had enacted similar legislation by 1921, and in 1924 Massachusetts banned smoking in stables because of the fire hazard (US DHHS 1985b).

Smoking restrictions remained uncommon throughout the 1960s. During the 1970s, workplace smoking regulations were included in the comprehensive clean indoor air legislation being proposed at the State level. In 1975, Minnesota became the first State to enact regulations for private worksites for the purpose of protecting employee health. Since then, eight other States have passed laws covering private sector workplace smoking (Tri-Agency Tobacco Free Project 1986; OTA 1986; ASH 1986; US DHHS 1985b). Fifteen percent of the U.S. population lives in these nine States. The scope of this legislative effort widened in the 1980s to include local government. It has been strongest in California, where ordinances in 66 communities cover 44 percent of the State's population (Americans for Nonsmokers' Rights Foundation 1986).

In spite of this legislative activity, surveys of employers through the 1970s reveal that worksite smoking regulations remained limited overall (Table 4). Those in place applied primarily to blue-collar areas and were motivated by safety concerns (NICSH 1980a,b; Bennett and Levy 1980). Policies were more common in industries with product safety concerns (food, pharmaceuticals) or explosion hazards (chemicals) (HRPC 1985). Safety was the prime reason for smoking policies in a survey of 128 large Massachusetts employers in 1978–1979. The potential for an adverse impact on clients, especially in service industries, was also cited (Bennett and Levy 1980). Concerns about the impact of smoking on the health of employees or costs to employers—the focus of the current workplace smoking action—were not mentioned. Fewer than 1 percent of 855 employers answering a nationwide survey in 1979 had calculated the costs of employee smoking (NICSH 1980a,b).

Five surveys of employers conducted between 1977 and 1980 document the situation just prior to the proliferation of workplace smoking policies. Estimates of the prevalence of smoking policies ranged from 14 to 64 percent, reflecting differences in types of businesses sampled and response rates (Table 4). A survey conducted by the National Interagency Council on Smoking and Health in 1979 had the largest sample size and the only random sample, but had a low response rate (29 percent) (NICSH 1980a). Their estimate of a 50 percent prevalence of smoking policies is probably biased upward by the likelihood that companies with policies were more likely to

TABLE 4.—Surveys of worksite smoking policies

Survey name (pub. date)	Survey year	Business surveyed			Sampling method	Interview		Response rate N (%)	Restrict smoking (%)	Worksite cessation program (%)	Incentives for nonsmoking (%)
		Number	Workforce size	Location		Method	Who?				
Dartnell's Business (1980)	1977	250	Large	U.S. and Canada	?		Office administrators	?	30	11	3
Bennett and Levy (1980)	1978-79	128	Large (>1000)	Mass.	All Mass. business with >1000 employees	Mail		88 (66)	64	12	
National Inter-agency Council on Smoking and Health (1980)	1979	3000	Three strata of 1000: small (50-499), medium (500-2200), large (Fortune Double 500)	U.S.	Random sample stratified by size	Mail and phone	Top level management and health officials	855 (29); same for each strata	50	15	1
Dartnell's Business (1980)	1980	325	Large	U.S.	?		Administrative managers	?	23	9	3
Administrative Management Society (Thomas 1980)	1980	500	?	U.S. and Canada	Nonrandom; representatives of AMS chapters	Mail	Members of AMS	302 (60)	14		
Human Resources Policy Corp. (1985)	1984-85	1100	Large: Fortune 1000 and Inc.'s 100 fastest growing companies	U.S.	All members of two selected groups	Mail	CEO or VP for Human Resources	445 (40)	32	43	8.5

TABLE 4.—Continued

| Survey name (pub. date) | Survey year | Business surveyed | | | Sampling method | Interview | | Response rate N (%) | Restrict smoking (%) | Worksite cessation program (%) | Incentives for nonsmoking (%) |
		Number	Workforce size	Location		Method	Who?				
U.S. Department of Health and Human Services (1986)	1985	1600	Two strata: small (50–99), medium-large (>100)	U.S.	Random sample stratified by size, location, and industry type	Phone		1358 (85)	38	19	
Bureau of National Affairs, Inc. (1986)	1986	1967	Predominantly small-medium 80%-<1000	U.S.	Random sample, selected group: Am. Soc. Pers. Admin. members	Mail	Personnel executives	662 (34)	36	41	4
Petersen and Massengill (1986)	1986	1100	Predominantly small-medium: 62% - <500; 16% - 500-1000, 22% - >1000	U.S., Canada, and Puerto Rico	?	Mail	?	577 (53)	56	50	5

TABLE 4.—Continued

| Survey name (pub. date) | Correlates of having a smoking policy | | | | Type of smoking policy (B = ban, R = restrict | Reason for policy | Duration of policy | Comments |
	Workplace size	Location	Business type	Other				
Dartnell's Business (1980)							42% ≤5 years	Employees raised smoking issue in 25%
Bennett and Levy (1980)	No	No	No	No		Protect products, equipment (91%), worker safety (37%), customer contact (17%), worker health (0%)		Cigarettes sold on premises of 95%
National Inter-agency Council on Smoking and Health (1980)	Large >small (54% vs 46%)			Blue-collar > white-collar areas	Blue-collar areas 42%R/28%B, white-collar areas 15%R/11%B, cafeterias 19%R/2%B, conference rooms 6%R/7%B, medical facilities 15%R/25%B	(<1% calculate costs due to smoking	64% adopted since 1964	Management-initiated policies with rare union role; 54% with policies impose penalties

TABLE 4.—Continued

Survey name (pub. date)	Correlates of having a smoking policy				Type of smoking policy (B = ban, R = restrict	Reason for policy	Duration of policy	Comments
	Workplace size	Location	Business type	Other				
Dartnell's Business (1980)					18% R to designated areas (usually open offices and public contact areas), 8% R in cafeterias, 5% limit smoking to breaks		69% ≤5 years	Employees raised smoking issue in 30%, 5% more than in 1977 survey
Administrative Management Society (1980)					Office areas 12%R/2%B B: reception areas (46%), security areas (35%), open offices (27%), hallways (16%), conference rooms (8%)			White-collar area survey only; 37% without policy had employee complaints

TABLE 4.—Continued

Survey name (pub. date)	Correlates of having a smoking policy				Type of smoking policy (B = ban, R = restrict	Reason for policy	Duration of policy	Comments
	Workplace size	Location	Business type	Other				
Human Resources Policy Corp. (1985)		West - 45%, NE - 36%, NC - 28%, South - 22%	>50%: insurance, pharmaceuticals, finance, publishing; <20%: mining, consumer goods	Located where workplace smoking law in effect	3% B while working or on premises, 35% B by some employees, 5% do not hire smokers	Safety (25%), health (20%), comply with laws (16%), employee preference (16%) save money (3%), increase productivity (2%) Reasons reject policy: unacceptable to employees, employees settle own problem, implementation too difficult	51% ≤5 years	Sponsored by Tobacco Institute; management initiated policies; 70% encourage employees to settle own disputes
U.S. Department of Health and Human Services (1986)	Large >small		Services > other industry types	Not unionized or blue-collar %		Comply with regs (39%), protect nonsmokers (39%), protect equipment (14%), protect high risk employees (8%)		Data analysis still in progress

TABLE 4.—Continued

| Survey name (pub. date) | Correlates of having a smoking policy | | | | Type of smoking policy (B = ban, R = restrict | Reason for policy | Duration of policy | Comments |
	Workplace size	Location	Business type	Other				
Bureau of National Affairs, Inc. (1986)	Large >small (45% vs 33%)	West - 52%, EN - 42%, NC - 29%, South - 28%	Nonbusiness or nonmanufacturing >manufacturing	Located where workplace smoking law in effect	Open work areas 19%R/41%B; halls, conference rooms, restrooms, customer areas 56%–66%B; cafeterias 58% partial B; total worksite 2%B; 1% hire only nonsmokers, 5% prefer nonsmokers	Comply with laws (28%), employee health, comfort (22%), employee complaints (21%), mandate by president (3%)	85% <5 years 85%; 10% before 1982	2% to adopt policy in 1986; 21% considering policy; 23% penalties set; 32% procedures to resolve disputes
Petersen and Massengill (1986)	Only 33% of smallest (<50 employees) have policy		Health care (93%), retailing (83%), finance (61%), manufacturing (57%), transportation (50%), service (49%), insurance (18%)	Located where workplace smoking law in effect	Designated areas only 38%, client-contact area 13%B, 1%B entirely, 2% hire only nonsmokers	Employee pressure (21%), comply with laws (19%), protect employee health (19%), reduce insurance costs (9%)	43% <3 years, 53% <6 years	6% made structural changes; 27% use barriers or air purifiers; 45% discipline violators

respond. An even higher prevalence of smoking policies (64 percent) reported in a survey of large Massachusetts businesses may reflect similar biases or regional variation or both. Smoking policies were reported in only 14 percent of white-collar offices in a nonrandom survey (Thomas 1980) and in 23 to 30 percent of large corporations responding to two nonrandom surveys by the same group (Petersen and Massengill 1986).

These surveys found that smoking restrictions were moderate, worksite smoking cessation programs uncommon (9 to 15 percent), and incentives for nonsmoking rare (<3 percent). Outright smoking bans and preferential employment of nonsmokers were not mentioned. However, employee complaints about smoking were reported by one-third of the businesses in two surveys (Petersen and Massengill 1986; Thomas 1980), suggesting a growing pressure on employers for change. Smoking policies were stricter for blue-collar workers and larger worksites (NICSH 1980b; Bennett and Levy 1980).

A second set of business surveys, conducted only 5 years later (1984–1986), shows a different picture (Table 4). Three large surveys, two based on random samples, reported a remarkably similar prevalence of workplace smoking restrictions, ranging from 32 to 38 percent (HRPC 1985; US DHHS 1986; BNA 1986). A fourth study reported that 56 percent of small and medium sized businesses had smoking policies, but only 38 percent of businesses restricted smoking to designated areas (Petersen and Massengill 1986).

Because of uncertainty in the earlier (1977–1980) estimates, it is difficult to conclude that the most recent estimates of policy prevalence represent an increase. However, there is suggestive evidence on this point: half or more of policies reported in the 1984–1986 surveys were adopted within 5 years, indicating that the policies are largely products of the 1980s; a sizable number of companies without policies are considering them; in addition to the 36 percent of companies reporting policies in one 1986 report, 2 percent were planning to implement a smoking policy in 1986 and another 21 percent were considering adopting a policy (BNA 1986). Finally, companies that adopt policies rarely reverse them: in the BNA 1986 survey, only 1 percent of companies without policies had ever had one and rescinded it. These data support a contention that workplace smoking policies are a growing trend.

The nature and scope of smoking restrictions also changed during the 1980s. The most common policy still restricted smoking to designated areas, but those areas appeared to be shrinking. Despite several well-publicized examples (Pacific Northwest Bell, Group Health Cooperative of Puget Sound), total workplace smoking bans were still rare (1 to 3 percent). An even more stringent smoking policy now being adopted, giving preference to nonsmokers in hiring or refusing to hire smokers, was not even considered less than a

294

decade before (BNA 1986; HRPC 1985; Petersen and Massengill 1986). Fewer than 5 percent of businesses have currently adopted such a policy. Workplace smoking cessation programs were more common, but incentives for nonsmoking remained rare.

The 1984–1986 surveys suggest that the diffusion of workplace smoking policies throughout the private sector is occurring in a nonuniform fashion. Companies with policies differ from those without policies in workforce size, geographic location, and type of industry. Smoking policies are slightly more prevalent in large companies than in small businesses (45 versus 33 percent) (Petersen and Massengill 1986; BNA 1986). Policies also differ by company location, being more common in the West and Northeast than in the North Central region or the South (BNA 1986; HRPC 1985). This geographic disparity is similar to the pattern of State smoking legislation, and may in part be explained by it. Businesses in States with workplace smoking laws are more likely to have adopted smoking policies than are companies located elsewhere (HRPC 1985; BNA 1986). Industries are adopting smoking policies at different rates, with more policies and more recent policies in nonmanufacturing industries (finance, insurance, health care, pharmaceuticals) (HRPC 1985; Petersen and Massengill 1986; BNA 1986). This represents a shift from the earlier blue-collar predominance of smoking restrictions and reflects the change in policy orientation from workplace safety to employee health.

Two factors may explain the growth of workplace smoking policies in the 1980s. Recently enacted State and local workplace smoking legislation is one factor influencing the private sector. Legal mandates are cited as a major reason for adopting policies, and as noted above, the prevalence of private sector smoking policies is higher in regions with legislation in place. Laws may encourage more rapid private action by putting smoking on the corporate agenda. A second factor is public support. Support for an employer's right to restrict smoking to a designated area at work grew from 52 percent to 61 percent during the 1970s (Roper 1978) and continued to increase in the 1980s (Gallup 1983, 1985). In 1985, 79 percent of U.S. adults, including 76 percent of smokers, favored restricting smoking at work to designated areas. Only 8 percent favored a total workplace smoking ban (Gallup 1985). These attitudes may also be manifest as employee pressures to restrict smoking (Petersen and Massengill 1986; BNA 1986; HRPC 1985).

Reasons for Adopting Smoking Policies

It is not always easy to identify the motivations and goals for a specific workplace policy (OTA 1986). Explicit reasons for implementing policies, according to the most recent employer surveys, are (1) to protect the health of the employee—especially the nonsmok-

er—and assure a safe working environment, (2) to comply with State and local statutes mandating worksite smoking policies, and (3) to anticipate or handle demands from nonsmoking employees for a smoke-free working environment. Other reasons may be the fear of possible legal liability for illnesses caused by sidestream smoke exposure in the workplace (Fielding 1982; Walsh 1984), an opportunity to symbolize a company's concern for employee welfare (Walsh 1984; Eriksen, in press), as part of a general health promotion and wellness program, and the goal of saving the company money.

Although it is generally agreed that employees who smoke cost their employers more than do nonsmoking employees, there is as yet little evidence that implementing policies will reduce the extra smoking-related costs (OTA 1986; Fielding 1986; Eriksen, in press). Corporations are keenly interested in stemming the rapid rise in health insurance costs, but may not see smoking policies as a means to that end. The top management at Xerox, for example, rejected a proposed smoking policy because of concerns about the potentially adverse economic impact of excess smoking breaks on productivity (Walsh 1984). Actually, economic considerations do not appear to be a major reason why businesses adopt smoking policies, according to three recent surveys (HRPC 1985; BNA 1986; Petersen and Massengill 1986).

Barriers to Adopting Smoking Policies

Both survey data and case reports give insights into reasons why employers have elected not to implement worksite smoking policies. According to a Tobacco Institute-sponsored survey, the 24 percent of large employers who had considered and rejected a smoking policy gave these reasons: policy not acceptable to employees (59 percent), employees can handle the problem on their own (58 percent), implementation too difficult (39 percent) or too costly (5 percent), policy not acceptable to clients (10 percent), and no employee complaints about smoking (29 percent) (HRPC 1985).

Fear of worker discontent or union opposition is the major reason cited by employers who have considered and rejected a workplace smoking policy. Surveys consistently indicate that smoking policies are initiated by management, and are often adopted with little or no employee or union input (HRPC 1985; BNA 1986; NICSH 1980a,b). Although most businesses that have surveyed their employees have found strong support for smoking restrictions (Pacific Telephone 1983; Robert Finnigan Associates 1985; Addison 1984; Ziady 1986; Marvit et al. 1980), some unions have actively opposed employer-mandated policies, both in individual cases and at the national level. In 1986 the AFL–CIO Executive Council stated its opposition to unilateral policies and called for the case-by-case handling of workplace disputes between smokers and nonsmokers (BNA 1986).

296

Both employee organizations and employers find it difficult to simultaneously balance the wishes of all their constituents.

Another reason for reluctance to adopt smoking policies is concern about implementation (HRPC 1985). In some cases, this means concerns about how to enforce the policy (BNA 1986) or whether it is enforceable (Eriksen, in press). Other reasons cited by companies were questions about the legality of limiting employee smoking (BNA 1986) and the nonsupport of top management who are smokers (BNA 1986). Some companies are dependent on business relationships with tobacco companies and businesses with tobacco-related interests, which they do not want to jeopardize (Kristein 1984; Walsh 1984).

Types of Smoking Policies

Private sector businesses have addressed the issue of employee smoking in a variety of ways. In addition to smoking policies, the umbrella concept of "worksite smoking control" can include educational campaigns to motivate workers to quit, self-help and organized smoking treatment programs, medical advice, and incentives to encourage nonsmoking (Orleans and Shipley 1982; Windsor and Bartlett 1984). Smoking programs are sometimes subsumed as part of broader corporate wellness programs. Worksite smoking cessation programs were reviewed in the 1985 Report on the Health Consequences of Smoking (US DHHS 1985c).

Businesses have taken a variety of approaches to a worksite smoking policy. The choices reflect the individual company's motive in adopting a policy and assessment of the potential for implementation and enforcement. When protection from fire or explosion was the primary motive, policies primarily applied to blue-collar areas; when the goal was to avoid antagonizing customers, smoking bans applied only to client-contact areas (Bennett and Levy 1980). A company's solution also reflects its particular social environment. Recent study indicates considerable variability among individual worksites in attitudes and norms about smoking cessation (Sorensen et al. 1986).

Because smoke travels, the desires of smokers and nonsmokers will inevitably come into conflict in common areas, and it is difficult to simultaneously maximize the goals of smoke-free air, minimum employee disruption, and minimum cost. A business adopting a policy primarily to avoid employee conflicts is likely to pay greater heed to smokers' wishes at the expense of smoke-free air, and may consider solving the problem with increased ventilation (to avoid the necessity of behavioral change) or may separate smokers and nonsmokers. A business whose primary goal is to reduce involuntary smoking hazards will be more willing to sacrifice smokers' convenience and may consider a total smoking ban. A business that aims

to reduce costs may choose a minimum of structural changes and a maximum likelihood that the policy will result in employee smoking cessation; a total ban on workplace smoking or the hiring of only nonsmokers would be more likely to achieve these goals. Alternatively, adopting *no* policy may also be *inexpensive*, so long as there are no employee conflicts over smoking.

The myriad of current smoking policies have been categorized in several ways (US DHHS 1985a; BNA 1986; OTA 1986; ALA 1985a,b). The range, in ascending order of protection for the nonsmoker, includes these:

   (1) No explicit policy (the "individual solution" approach)
   (2) Environmental alterations (separating smokers with physical barriers, using air filters, or altering ventilation)
   (3) Restricting employee smoking, a range with these extremes:
      (a) smoking permitted except in designated no-smoking areas
      (b) smoking prohibited except in designated areas
   (4) Banning employee smoking at the worksite
   (5) Preferential hiring of nonsmokers.

Options (1) through (3a) effectively state that smoking at work is acceptable behavior; options (3b) through (5) indicate to employees that nonsmoking is the company norm. Several groups have developed model policies of varying degrees of comprehensiveness to assist employers (ALA 1985a,b; GASP 1985; BNA 1986; Hanauer et al. 1986).

The "Individual Solution" Approach

According to surveys, having no explicit policy is still the most prevalent approach to smoking in the workplace (HRPC 1985; BNA 1986; US DHHS 1986). Smokers and nonsmokers work out differences on their own, using so-called common courtesy or finding an individual solution. According to a 1984 Tobacco Institute-sponsored survey, 70 percent of large employers encourage employees to work out differences on their own (HRPC 1985). When there is no explicit policy, there is the implicit message that environmental tobacco smoke does not represent a hazard. So long as there are few disputes and they are easily settled, this approach is expedient. However, it is not likely to be a successful long-term policy. Nonsmokers in the late 1970s may have been reticent to assert their rights and perceived a burden of confrontation (Roper 1978; Shor and Williams 1978), but there is a growing consensus, even among smokers, that supports abstention in the presence of nonsmokers and smoking restrictions at worksites (Gallup 1983, 1985).

298

Environmental Alterations

Environmental alterations range from simply separating smokers and nonsmokers to different areas of a room to installing improved ventilation systems to remove environmental tobacco smoke. The advantage of this approach is that it requires no behavioral change of smokers and satisfies some of the wishes of nonsmokers. However, because tobacco smoke easily diffuses beyond physical boundaries, simple barriers provide at best a slight reduction in involuntary smoke exposure (see chapters 3 and 4) (Olshansky 1982). More sophisticated ventilation systems can be prohibitively expensive, and even the best may not be able to clean the air adequately (Repace and Lowrey 1985; Lefcoe et al. 1983). Workplace modification has sometimes been utilized as a company's first step in the development of a more restrictive policy, as happened at the Control Data Corporation in Minneapolis (OTA 1986).

Restrictions on Employee Smoking

The most common workplace smoking policy is to restrict where employees may smoke (BNA 1986). This policy has broad public support; in a 1985 Gallup poll it was the approach favored by 79 percent of U.S. adults, including 76 percent of smokers (Gallup 1985). Policies differ in (1) the proportion of the workplace in which smoking is permitted, (2) whether the default condition is smoking, nonsmoking, or unspecified, (3) who has the authority to designate the smoking status of an area, and (4) whose wishes prevail when smokers and nonsmokers disagree. Policies often categorize the worksite into four areas that are subject to different rules: (1) private offices, (2) shared offices or work areas, (3) small common use areas (elevators, bathrooms), and (4) large common use areas (conference and meeting rooms, auditoriums, cafeterias).

The least restrictive policies permit smoking except in designated no-smoking areas, indicating that smoking is the company norm. Who has the authority to designate an area's smoking status and whether smokers' or nonsmokers' wishes prevail may not be explicit. The usual pattern is for common use areas to be designated either totally no-smoking (elevators, bathrooms, conference rooms) or partly no-smoking (cafeterias, auditoriums). Private offices are left to the discretion of the occupant, who is often given the authority to declare it no-smoking. In shared office areas, where the wishes of smokers and nonsmokers may conflict, each individual may be given the authority to designate his or her own immediate work area, or the policy may stipulate that a compromise be reached. However, this cannot ensure that an employee's self-designated no-smoking area is free of sidestream smoke. Because the majority of an employee's time is spent in the immediate work area rather than in

the no-smoking common use areas, a policy that does not specify no-smoking in shared work areas may not substantially reduce an employee's environmental tobacco smoke exposure. However, these policies may satisfy some nonsmokers' wishes with minimal disruption to smokers. In some cases, companies seeking to limit smoking have adopted this type of policy as a first step to more stringent restrictions or a total ban (e.g., Boeing, cited in OTA 1986).

The most restrictive policies specify that "smoking is prohibited except in designated areas," establishing nonsmoking as the workplace norm. In the strictest policies, smoking is prohibited in shared work areas (unless all occupants agree to designate an area "smoking permitted") and in most common use areas. Policies may limit the areas that can be designated "smoking permitted" and predetermine that the wishes of nonsmokers prevail when conflict occurs. Even stricter regulations stipulate not only the location in which but also the time when smoking is allowed (e.g., work breaks only). So long as the smoking areas do not contaminate the air of work areas, these policies provide greater protection of employees from sidestream smoke at the cost of greater inconvenience to smokers, who may perceive the restrictions as coercive. The productivity of smokers may suffer if they are permitted to take extra smoking breaks or if smoking areas are located too far from the work station.

The variability of smoking restrictions in common work areas was demonstrated in a 1985 survey conducted by the Bureau of National Affairs, Inc. (BNA). Of the 239 companies with smoking policies, 41 percent banned smoking in open work areas, and an additional 20 percent banned it if employees or supervisors wished. Only 8 percent permitted smoking in all open work areas, and 19 percent divided areas into smoking and no-smoking sections. There was more uniformity in treatment of common use areas. Over 50 percent of the companies banned smoking in hallways, conference rooms, rest-rooms, and customer contact areas, and smoking was partially banned in 58 percent of cafeterias (BNA 1986).

In contrast to shared work areas, smoking was permitted in 56 percent of the private offices in that survey, with occupants often given the authority to designate the office as smoking or no-smoking. This has the potential for charges of unequal treatment and problems with employee morale (BNA 1986).

Banning Smoking at the Workplace

Some businesses—including large corporations, among them Pacific Northwest Bell and the Group Health Cooperative of Seattle—have recently opted for total bans on smoking at work (US DHHS 1985a; Ziady 1986). Bans may be preceded over several years by progressively stricter smoking regulations. Notwithstanding these

well-publicized successful examples, smoking bans are rare and not widely supported by public opinion. Only 6 percent of companies with smoking policies (2 percent of all respondents) in a 1986 survey totally banned smoking (BNA 1986). Only 12 percent of adults (4 percent of smokers) agreed that "companies should totally ban smoking at work" in a 1985 Gallup poll. In spite of this hesitancy, smoking bans are gaining momentum among large employers such as Boeing, who recently announced an upcoming ban that will cover its 90,000 employees (Iglehart 1986).

Smoking bans provide the maximum protection for nonsmokers, at the cost of greater inconvenience for smokers. They send a clear message that nonsmoking is the company norm. They can reduce ventilation needs and maintenance costs due to smoking, but pose potential problems with enforcement and loss of employees who smoke. Thus, how a ban is planned, prefaced and introduced, and implemented and enforced is very important. Through a concern for employee well-being, assistance for smokers who wish to quit should be implemented along with bans (Orleans and Pinney 1984).

Preferential Hiring of Nonsmokers

The most restrictive workplace smoking policy, preferential hiring of nonsmokers, was not even discussed several years ago. Explicit policies favoring nonsmokers are still uncommon. According to the 1986 report of the Bureau of National Affairs, Inc., 1 percent of businesses hire only nonsmokers, 5 percent give nonsmokers preference, and 10 percent permit supervisors to exercise a nonsmoking preference (BNA 1986). The majority either have no policy (43 percent) or do not permit such a preference (39 percent). On the other hand, data from small surveys indicate that personnel managers, the majority of whom are themselves nonsmokers, may preferentially hire nonsmokers (Weis 1981; Iglehart 1986). In a unionized setting, selective hiring of nonsmokers may need to be the subject of collective bargaining (Eriksen, in press).

Hiring only nonsmokers ensures a smoke-free work environment without conflicts over smoking and makes it clear that nonsmoking is the company norm. Since the nonsmoking workforce should be healthier, lower health insurance premiums may also result. On the other hand, such a policy limits the potential pool of new employees, raises the issue of what to do about currently employed smokers, and may present problems with verification of smoking status. Employers may be reluctant to adopt a policy in which off-the-job activity is a condition of employment (Walsh 1984).

Assuring compliance with workplace smoking policies is complex. Model policies usually include three enforcement provisions: (1) identifying who is responsible for policy enforcement, (2) designating penalties for noncompliance, and (3) ensuring the protection of an

employee bringing a complaint. These provisions are often not included in practice. Only 23 percent of the policies stipulated penalties for noncompliance and only 32 percent specified procedures for resolving disputes in the 1986 BNA survey. Approximately half of the policies outlined in two other business surveys had provisions for disciplining violators (Petersen and Massengill 1986; NICSH 1980a,b).

Implementation of Smoking Policies

Worksites that have adopted smoking policies have differed in the ease with which policy was implemented. To aid employers, the American Lung Association and the Office of Disease Prevention and Health Promotion of the U.S. Department of Health and Human Services have developed guides with specific recommendations on how to adopt and implement worksite smoking policies (ALA 1985b; US DHHS 1985a). These are based on the experience of companies and can be extremely helpful even though they are not based on research.

The experiences of 12 corporations that considered smoking policies are described in a report of the Bureau of National Affairs, Inc. (1986). Case reports are also included in the guide from the Office of Disease Prevention and Health Promotion (US DHHS 1985a). According to these case reports, strong support from top management and having an advisory committee composed of a wide variety of employees (including both smokers and nonsmokers, managers, and employee representatives) are common to successful policies. Surveys of employees can assess distress caused by involuntary smoking and support for policy changes. As a rule, such surveys have generally documented widespread support for smoking restrictions from employees, the majority of whom are nonsmokers.

Another correlate of success is a well thought out and clearly articulated communication of the policy. A written document should give the rationale for the policy implementation, specify where smoking will be allowed or prohibited, and define responsibility and procedures for policy enforcement and penalties for violation. Successful policies avoid criticizing smokers or setting up an antagonistic situation between smokers and nonsmokers. They make it clear that the company is not requiring that employees quit smoking and will help smokers in adjusting to the new regulations. Giving smokers advance notice of the policy and providing help for those who want to quit smoking can help gain their support.

Careful plans for implementation are recommended. Allowing several months between the announcement of the policy and its effective date gives smokers time to prepare for the change and to attend smoking cessation programs if they wish to quit. This also provides time for the posting of adequate numbers of signs and for

302

'making any structural alterations that may be necessary. After policy implementation, an advisory committee should monitor its effectiveness and enforcement. A followup survey is helpful to determine what, if any, adjustments need to be made.

Impact of Policies Restricting Smoking in Public Places and in the Workplace

Policies that regulate where smoking is permitted may have a number of direct and indirect effects. In the short term, a policy that is adequately implemented and enforced will alter the behavior of smokers in areas where smoking is prohibited and should result in a reduced concentration of tobacco smoke in that area. Beyond these direct effects, there is the potential for smoking restrictions to have broader, indirect effects on smoking behavior and on public attitudes about tobacco use. This section outlines the possible impacts of smoking policies, addresses methodologic considerations, and reviews existing data that bear on these hypotheses.

Potential Impacts of Smoking Policies

Policy Implementation and Approval

The degree to which a smoking policy or law has been implemented as written is an essential consideration in evaluating its effects on attitudes, behavior, and air quality. Successful *implementation* involves public awareness of the policy, compliance with its regulations, and enforcement of violations. Compliance requires not only that smokers refrain from smoking where prohibited from doing so, but also that appropriate decisionmakers develop written policies, designate areas as no-smoking, and post signs as stipulated. Enforcement requires that policy violations be dealt with, either by peer action or by penalties defined by the policy. Because smoking policies and laws are approved by the majority of individuals whose behavior they affect, they are generally held to be self-enforcing, obviating the need for active policing (Hanauer et al. 1986). When enforcement is needed, smoking policies and legislation rely primarily on peers, assuming that the nonsmoking majority of the population will enforce the policy or statute because it is in their best interest.

Nonsmokers can be expected to favor smoking restrictions, which offer the benefits of cleaner air and reduced health risks and require no change in their behavior. The opinions of smokers are expected to be less favorable because they stand to be inconvenienced. Some smokers may support the policy to assure themselves of having a location where smoking is clearly permitted, because of a desire to quit smoking, or because of concerns about the health hazards of involuntary smoking. The degree of smokers' support for a policy

may also depend on other factors, such as the degree of smoking restriction or the adequacy of policy implementation.

Direct Effects: Air Quality and Smoking Behavior

The evaluation of a specific policy or piece of legislation must address whether the policy achieved its stated goals and must also screen for other effects. The primary goal of policies regulating smoking in public places or in the workplace is the reduction of individuals' *exposure to environmental tobacco smoke.* Measures of air quality directly assess how well a policy meets this goal. Air quality also indirectly reflects the behavior of smokers and the degree of policy compliance.

Smoking policies may have both direct and indirect effects on smoking behavior. The direct effect of adequately implemented smoking restrictions is to limit where smoking is permitted, altering the behavior of smokers in those settings. Smoking policies may have indirect effects on smoking behavior if they influence the behavior of smokers outside these settings.

Indirect Effects: Knowledge, Attitudes, Social Norms, and Smoking Behavior

Policies that restrict or ban smoking in public places or the worksite convey potentially powerful messages about the role of cigarettes in society and help to reinforce nonsmoking as the normative behavior. Restricting smoking to protect nonsmokers may increase public *knowledge* of the health risks of smoking and of involuntary smoking. Smoking restrictions may also alter *attitudes* about the social desirability of smoking and the acceptability of smoking in public. Changes in the knowledge or acceptance of health risks combined with attitude shifts contribute to changing *social norms* about where smoking should and should not occur, as well as whether it is an acceptable social behavior.

Changes in social norms may influence *smoking behavior* by reducing pressures to smoke and increasing social support for nonsmoking and cessation. The combination of altered social norms and reduced opportunities to smoke may encourage smokers to quit and discourage experimentation among nonsmoking youth. Changing social norms may have their greatest impact on teenagers and young adults, who might be less inclined to experiment with a socially undesirable substance. Current smokers are likely to be prompted by changing social norms to move further through the stages of self-change that precede cessation (Prochaska et al. 1985).

Smoking restrictions may influence smoking behavior apart from their influence on social norms. By reducing opportunities for smoking, restrictions may decrease a smoker's daily cigarette

304

consumption. By reducing the range of settings where smoking occurs, they reduce the cues and alter the stimulus–response patterns that help to maintain smoking behavior and that contribute to relapse among ex-smokers (Orleans 1986). This could increase the success of quit attempts. Smoking restrictions, especially those at the workplace, may also help smokers to discover alternatives to smoking as a stress reduction tool. Likewise, new entrants into the workforce may not as easily learn to rely on cigarettes to cope with work-related stressors. This might blunt the increase in smoking prevalence that occurs at the time of workforce entry, especially among blue-collar workers (O'Malley et al. 1984; US DHHS 1985c).

Thus, the widespread adoption of smoking restrictions may have a profound impact on smoking behavior at many points in its natural history. Hypothesized consequences include reduced cigarette consumption, increased motivation and progress through the stages of self-change, increased rates of smoking cessation, and decreased rates of smoking initiation.

Smoking policies may have additional impacts beyond their effects on attitudes and smoking behavior, such as positive economic effects for employers by reversing the excess costs associated with employees who smoke. It is generally agreed that employees who smoke cost their employers more than nonsmoking employees because of excess absenteeism, increased health care utilization, and reduced productivity (OTA 1986; Fielding 1986; Eriksen, in press). This leads to greater use of sickness, disability, and health care benefits and ultimately, higher health insurance costs to business. Productivity losses to business are attributed not only to the individual smoker's time lost owing to on-the-job smoking, but also to increased maintenance costs due to cigarette-related damage and refuse. Estimates of the excess annual cost per smoking employee vary by an order of magnitude, but even conservative estimates are substantial: $300 to $600 (Kristein 1983, 1984; Solomon 1983; Weis 1981).

Reductions in health care costs are partly dependent on whether policies lead smokers to quit smoking. Even if smokers quit, the reduction in health care costs may not be seen in the short term. Some employers have been concerned that strict smoking bans may unfavorably alter employee turnover patterns or productivity. Smokers' productivity could decrease if, for example, they are permitted to take extra breaks away from their work stations in order to smoke (OTA 1986; Michigan Tobacco and Candy Distributors and Vendor Association 1986). Costs involved in adopting a smoking policy should also be considered. Assessment of these endpoints is useful because employers may consider them in deciding whether to implement smoking policies.

Methodologic Considerations in Policy Evaluation

Study Design

Evaluating a new smoking policy in a defined population is similar to evaluating a smoking cessation intervention, with the addition of nonsmokers. Impacts on beliefs and attitudes, as well as on behavior, can be assessed in the population at baseline and at intervals after implementation. Because smoking policies may influence smoking behavior gradually, designs must be able to measure delayed effects.

Simultaneous assessment of outcomes in a control population strengthens confidence in the validity of conclusions. With uncontrolled pretest/posttest designs, there is the possibility that changes in smoking behavior and attitudes are confounded by outside influences. Worksites, for example, may have concurrent smoking cessation programs that can affect attitudes and behavior. Populationwide trends in smoking behavior are another source of confounding. In practice, random assignment of whole populations will rarely be feasible, since researchers are rarely in a position to "assign" the intervention and must rely on natural experiments. Quasi-experimental designs, which include natural comparison groups, are the best alternative. Identifying and accessing such appropriate comparison populations may be difficult in practice.

Either longitudinal or cross-sectional sampling can be employed. Longitudinal designs, in which the same individuals are interviewed at two or more points in time, provide the best measure of changes in outcome measures, but depend on high rates of followup, which may be practically difficult. Furthermore, individuals' behavior or attitudes may be influenced by repeated assessments in such studies. On the other hand, when attitudes and behavior are evaluated by repeated assessments of independently chosen cross-sectional samples, the possibility exists that smokers and nonsmokers will enter or leave the population at different rates as a consequence of smoking restrictions. Turnover needs to be followed to assure that changes in behavior or attitudes are a result of changes in individual behavior and not changes in the composition of the population.

One-time comparisons of populations with and without policies can provide suggestive but not conclusive data about impact. The validity of differences detected in attitudes and behavior is dependent on the degree of similarity between the policy group and the control group. Uncontrolled one-time assessments done before or after policy adoption do not permit conclusions about the policy effects, although they may provide hypotheses for further work. Postimplementation surveys of a population can, however, provide useful information about the degree of policy approval, awareness, compliance, and enforcement.

Assessment of the impact of legislation on smoking behavior is more difficult because the unit of study is larger and more diverse.

306

Consequently, detailed behavioral or attitudinal data and repeated assessments are more difficult to obtain. Evaluations are often limited to analyses of aggregate measures such as smoking prevalence and tobacco consumption, which are collected for other purposes. This approach does not control for potentially confounding influences on tobacco use or smoking behavior, such as price fluctuations. Identifying and assessing control groups not subject to smoking legislation or regulation can strengthen the confidence in conclusions for the same reasons as above, but is often difficult to achieve in practice.

Assessing the Effects of Smoking Policies

Ideally, *air quality* should be measured objectively, but current technology for measuring the concentration of tobacco smoke in indoor air is expensive and cumbersome. There is also uncertainty about which constituent of smoke is best to measure (See chapters 3 and 4 of this volume). Air quality can also be assessed subjectively. Ratings made by occupants of smoke-free areas can be compared with those of a control area or to ratings made prior to the ban. Measurement of an individual nonsmoker's actual exposure *to* secondhand smoke, using biochemical measures, is not a specific measure of the concentration of this smoke in a single area because an individual may have other sources of smoke exposure. Such measures might be useful for assessing the concentration of smoke in areas, like the worksite, that represent a primary source of exposure. They cannot be used to measure air quality in other places, like an auditorium, where an individual spends only a few hours.

Many markers of *smoking behavior* need to be examined in order to understand the multiple effects of smoking restrictions on behavior. In a defined population, a new policy may increase smokers' motivation to quit, confidence in their ability to quit, or the number, duration, and success of quit attempts. It may also reduce cigarette consumption among continuing smokers. Workplace policies may have different impacts on cigarette consumption at work and outside work. These variables should be separately assessed. As in other research in smoking behavior, biochemical verification of self-reported smoking status is desirable.

Public *knowledge* about the health risks of involuntary smoking and *attitudes* about smoking can be assessed by surveys. Data on *social norms* can be construed from survey items such as those measuring the social acceptability of smoking in public places or in the presence of nonsmokers, the rights of nonsmokers to smoke-free air, the perceived prevalence of smoking in the environment, and the perceived social support for cessation or nonsmoking.

The adequacy of a policy's *implementation* can be assessed by surveys that measure individuals' knowledge and compliance with a

policy. The degree of noncompliance and enforcement can also be assessed by observations of behavior in public places subject to smoking restrictions.

Review of Current Evidence on Impact

Workplace Smoking Policies

In 1982, Orleans and Shipley concluded that the evaluation of worksite smoking policies was limited to a few public opinion polls. Since then, many policies have been adopted, but evaluation remains rare. Most common are baseline surveys done by companies considering smoking policies. The best surveys utilize random or probability samples and achieve high rates of completion; they provide useful one-time data on attitudes and behavior prior to policy implementation. Unfortunately, few companies adopting smoking policies have done postimplementation surveys to assess impact. To date, the best evaluations of worksite smoking policies have been done in the health care setting. There are two controlled and two uncontrolled studies assessing the effects on employees of adopting a smoking policy for a hospital (Rigotti et al. 1986; Biener et al. 1986; Andrews 1983; Rosenstock et al. 1986).

One uncontrolled study was reported by Andrews (1983). He described the process by which the New England Deaconness Hospital in Boston adopted a restrictive smoking policy in 1977. Patients and employees were surveyed prior to the policy. Employees were surveyed again 20 months after the policy took effect. The survey method and response rate were not specified; presumably it was not a random sample. Policy approval and smoking behavior were assessed.

The second uncontrolled study (Rosenstock et al. 1986) evaluated the impact of a near-total smoking ban adopted in April 1984 by the Group Health Cooperative of Puget Sound, Washington, the fourth largest health maintenance organization in the Nation. Four months after the policy was adopted, they surveyed a systematic probability sample of 687 employees, assessing smoking behavior, attitudes toward the policy, and its effect on work performance. Employees were asked retrospectively about attitudes and behavior prior to the policy. The response rate was 65 percent.

The two controlled studies of the impact of adopting a restrictive hospital smoking policy are similar in design. Both involve prepolicy and postpolicy measurements of intervention and control groups and assess similar outcomes. Rigotti and colleagues (1986) studied the impact of a total ban on smoking adopted in November 1984 by the pediatric service at Massachusetts General Hospital in Boston. All nurses employed by the service were surveyed at baseline and at 4 and 12 months. Nurses working on the hospital's medical service, where no policy change occurred, were surveyed concurrently as

308

controls. Response rates to the surveys ranged from 55 to 75 percent; the prevalence of smoking among respondents and nonrespondents did not differ. Surveys assessed smoking behavior, attitudes about smoking, and perceived air quality in both groups. The pediatric nurses answered additional questions about approval, compliance, and awareness of the policy. Employment records were reviewed to assess employee turnover before and after the policy.

Biener and colleagues (1986) studied employees at two Providence, Rhode Island, hospitals where self-help smoking cessation programs were being introduced. At one, the Miriam Hospital, there was a concurrent change in smoking policy. Smoking was prohibited hospitalwide except in three locations as of August 1985. Separate random probability samples of 85 employees at each hospital were surveyed by telephone at baseline (2 to 4 weeks before the policy) and at 1, 6, and 12 months after the policy. Data were collected in both hospitals on smoking behavior, attitudes about smoking, and air quality. Information on policy awareness, compliance, and approval was obtained at the intervention hospital.

Results of these studies are included in the subsequent sections, which address the outcomes of workplace smoking policies.

Policy Implementation

According to case reports, organizations that have adopted smoking control policies generally develop careful plans to introduce the policy, but rarely evaluate how effectively the policy has been implemented. The findings of Rosenstock and colleagues (1986) indicate that even careful implementation plans may fall short of their goals. In their survey of the Group Health Cooperative employees, only half of the respondents knew of the existence of the advisory group whose role was to provide information to employees. Only 36 percent of the smokers and 76 percent of the nonsmokers felt that they had had an adequate opportunity to express their views. Not all smokers knew that the decision to prohibit smoking was an irrevocable one.

Rigotti and colleagues (1986) found that awareness of the smoking ban on the pediatric service was high; at 4- and 12-month followups, over 90 percent of employees knew where smoking was not permitted. Employees noted smoky air or smoking in restricted areas on approximately 20 percent of days worked. Two-thirds of the employees who smoked admitted at least one personal episode of noncompliance during the year after the policy took effect. Although nonsmokers perceived themselves to be more assertive in enforcing smoking rules after the smoking ban, many were reluctant to confront a smoker, especially if the smoker was a coworker.

Biener and colleagues (1986) found a similar high level of policy awareness and better compliance among the employees of Miriam

Hospital in Providence. Six months after the adoption of a policy prohibiting smoking in all but three areas, 95 percent of the employees were aware of the policy and half had noted no evidence of noncompliance. There was no evidence that smokers perceived more pressure to abstain in the form of increased assertiveness by nonsmokers; the policy may have reduced the need for assertive behavior. Rigotti and colleagues (1986) reported that nurses in the control group described themselves as having to be more assertive about asking people not to smoke than nurses in the policy group.

Dawley and colleagues (Dawley et al. 1980; Dawley, Carrol et al. 1981; Dawley, Morrison et al. 1981; Dawley and Baldwin 1983; Dawley and Burton 1985) addressed the question of compliance with smoking restrictions at the New Orleans Veterans' Administration Medical Center. Their technique was to unobtrusively observe the smoking behavior of individuals occupying areas designated as smoking or no-smoking. In a series of 10-minute periods, an observer noted the proportion of people smoking among all individuals occupying a no-smoking area, which served as the measure of noncompliance. Posting no-smoking signs in a hospital lobby reduced the prevalence of smoking to one-third of its previous level (from 29 percent to 5 to 11 percent, $p < 0.01$). There was a nonsignificant trend for better compliance with positively worded signs (e.g., "Please do not smoke") compared with negatively worded signs (e.g., "No smoking—Offenders subject to fine") (Dawley, Morrison et al. 1981). Posting signs designating a no-smoking area in a cafeteria resulted in a similar decline in smoking prevalence in the area. The combination of signs and enforcement (polite reminders from staff to noncompliant patients) achieved greater reductions in smoking prevalence than were achieved with signs alone; however, the incremental value of enforcement was not directly assessed in the study (Dawley and Baldwin 1983). Following a change to a more restrictive smoking policy (smoking prohibited except in designated areas, with provisions for enforcement), the noncompliance rate dropped to under 2 percent (Dawley and Burton 1985). Another study demonstrated that smoking models reduce compliance with smoking restrictions. The noncompliance rate doubled when a smoker was experimentally introduced into the no-smoking area (Dawley, Carrol et al. 1981).

These studies indicate that there has been good employee compliance with smoking policies in health care facilities, even though there may be some reluctance by employees to enforce restrictions. The implementation of smoking policies in other types of worksites has not been systematically evaluated. Descriptions of the adoption of policies in a number of worksites do not report major problems with compliance (BNA 1986).

310

Air Quality

Three studies assessed air quality before and after hospitals adopted restrictive smoking policies. Both Rigotti and colleagues (1986) and Biener and colleagues (1986) used a subjective measure, the frequency that an employee was bothered by smoke at work. In the Rigotti group's study, perceived air quality was similar in the intervention group and the control group at baseline. It improved significantly at 4- and 12-month followup on floors where smoking was banned and did not change on control floors. At 12 months, 79 percent of the nurses on floors with the smoking ban reported noticing less smoke, and none noted an increase; in contrast, 87 percent of control nurses noted no change in air quality. Biener and colleagues found a similar pattern; there was a significant difference in employee assessments of perceived air quality between hospitals with and hospitals without a smoking policy.

At the New England Baptist Hospital in Boston, the distribution of respiratory particulates (RSP) was measured before and 1 year after the adoption of a restrictive smoking policy (Bearg 1984). At followup, RSP were lower in many hospital areas where smoking was restricted, most notably in patient care areas and an employee lounge, but remained high in the cafeteria. Because same-day measurements of outside air revealed low ambient RSP levels, Bearg concluded that the high levels inside the building were attributable to smoking rather than air pollution.

These studies suggest that hospital policies result in less smoking in work areas designated no-smoking, but that no-smoking areas in cafeterias may provide little protection from secondhand smoke exposure because of ventilation problems and the increased smoking in the few smoking-permitted areas.

Policy Approval

A number of private and public sector organizations considering a smoking policy have assessed employee attitudes prior to implementation. Pacific Northwest Bell, Pacific Telephone, New England Telephone, Texas Instruments, and StrideRite are among businesses that have done employee surveys (R. Addison, personal communication, July 21, 1986; Pacific Telephone 1983; Robert Finnegan Associates 1985; BNA 1986; Ziady 1986). Public sector employers include the Hawaii and Massachusetts Departments of Public Health (Marvit et al. 1980; Naimark 1986). The findings of these surveys are remarkably similar. Over 60 percent of employees report being at least occasionally bothered by smoke at work (Robert Finnegan Associates 1985; Pacific Telephone 1983; Ziady 1986; R. Addison, personal communication, July 21, 1986). There is broad support for adopting a smoking policy, even among smokers (Pacific

Telephone 1983; Robert Finnegan Associates 1985; Marvit et al. 1980, Sorensen and Pechacek 1986).

Assessment of employees' approval of policies after implementation have been done primarily in health care settings. High rates of approval are the uniform finding, with smoker–nonsmoker differences. In the Rigotti group's study (1986), the overall approval of a smoking ban increased from 72 percent at baseline to 85 percent at 4 and 12 months. Most of the increase was a result of the improved opinions of the smokers. Only 35 percent of smokers supported the ban at baseline, but by 1 year this nearly doubled, to 67 percent. High rates of policy approval at followup by both smokers and nonsmokers were also reported by Biener and colleagues (1986) (69 percent smokers, 89 percent nonsmokers) and Andrews (1983) (83 percent smokers, 93 percent nonsmokers). Rosenstock and colleagues (1986) found high overall policy approval at 4 months (85 percent), but less support by smokers (36 percent). These data indicate that smoking policies in hospitals are well accepted by employees, and that smokers' initial reluctance diminishes as they gain experience with the policy. Generalization from these studies is limited by the nature of the population studied—health care workers. Followup surveys in industrial setting would be valuable.

Sorensen and Pechacek (1986) have examined correlates of smokers' approval of smoking restrictions. They surveyed smokers in eight Minnesota businesses without smoking policies, sampling a broad cross-section of employees, from blue-collar workers to professionals. Over three-fourths of the 378 respondents agreed that employers should establish separate smoking and no-smoking areas at work. Smokers who favored worksite smoking policies had greater interest in quitting and more concern for the health risks of smoking and saw their social environment as supportive of nonsmoking, as measured by a higher perceived coworker support for quitting and a greater perceived prevalence of nonsmokers.

Smoking Behavior

Many smokers anticipate that their smoking behavior will change after a smoking policy is adopted at their worksite. At Pacific Telephone, 51 percent of the smokers expected that the policy would lead them to alter their smoking habits, either by cutting down (38 percent) or quitting (13 percent) (Pacific Telephone 1983). In the Rigotti group's study (1986) of a hospital smoking ban, 72 percent of the smokers expected the policy to change their habits. All expected to smoke less at work and most to smoke less outside work.

A successfully implemented smoking policy will provide a smoker fewer opportunities to smoke. Of course, the smoker may compensate for reduced smoking opportunities at work by more intense smoking (number of cigarettes, inhalation, puff topography) on

312

breaks or with increased smoking outside work to maintain a constant overall daily consumption. This is consistent with the addictive model of smoking behavior (Gritz 1980; US DHEW 1979). But if compensation does not occur, the smoker's lower rate at work would reduce overall daily smoking. Studies at present differ on which of these alternatives occurs. The results reported below are entirely self-reports; thus, they suffer from a lack of biochemical validation of smoking status as well as from an inability to detect compensation through altered smoking topography (US DHHS 1985c).

Compensation did not appear to occur in the Biener group's hospital study (1986). Among smokers in the "policy" hospital, the number of cigarettes smoked daily while at work fell from a baseline of 8.1 to 4.5 at 1 month and 4.0 at 6 months. Over the same time period, the at-work cigarette consumption in the control hospital rose slightly (7.6 to 8.1 cigarettes). The difference in smoking rates between baseline and 1-month followup in the "policy" group was significant (p=0.02). At 6 months, the difference in smoking rates at work between hospitals (8.2 vs. 4.0) was also significant (p=0.01). There were no significant changes in the smoking rate outside work. Smokers in the hospital study by Rosenstock and colleagues (1986) reported smoking a mean of 15.6 cigarettes daily, 2 fewer than before the policy (p<0.003). These data suggest that smokers did not compensate for reduced smoking opportunities at work by increasing their smoking at home.

Rigotti and colleagues (1986) found indirect evidence for compensation. The nurses' self-reported cigarette consumption at work decreased in the policy group, but did not change in the control group. However, overall cigarette consumption in the policy group did not change. Both the degree of change and the number of smokers in the study were small.

In an earlier study, Meade and Wald (1977) compared the smoking behavior of three British employee groups. Smoking was prohibited at work for two groups. Smokers who were allowed to smoke at work had a somewhat higher self-reported average daily cigarette consumption. The maximum rate of smoking occurred at work in the afternoon, but for workers prohibited from smoking at work, the maximum rate occurred in the interval between leaving work and retiring at night.

There has been much speculation that smoking policies will increase the smoker's motivation and success in quitting. In the study by Biener and colleagues (1986), the percentage of smokers considering quitting in the next 6 months increased from 71 percent at baseline to 91 percent at followup, but there was no change in motivation in the control hospital group. Two-thirds of the smokers in Rosenstock and colleagues' uncontrolled study (1986) had a

definite desire to quit. However, Rigotti and colleagues (1986) found no difference in the motivation of nurses between the control group and the policy group.

Smokers' use of worksite smoking cessation programs before and after policies go into effect have been used as an index of their motivation to quit smoking. The results are mixed. In the 6 months after Pacific Northwest Bell adopted a smoking ban in October 1985, 1,044 employees, representing 25 percent of all smokers, enrolled in programs reimbursed by the company. This compared with 331 who attended free onsite programs in the previous 26 months. The cost to the company per smoker was $142 (Martin 1986; K. Rowland, memorandum for Len Beil, April 25, 1986). At Texas Instruments (R. Addison, personal communication, July 21, 1986), 486 smokers enrolled in cessation classes within the first year after the announcement of a smoking policy; this compares with only 11 in 1982, the last year for which statistics were kept. In both cases, this enthusiastic response may in part be due to the employers' new willingness to pay for the classes, as well as to the incentive provided by a new policy. For example, only 8 of 148 smokers at the New England Deaconness Hospital who said they were interested in a smoking cessation program on their own time actually showed up (Andrews 1983). Even company sponsorship is not a guarantee of popularity. At the Group Health Cooperative, only two smokers aware of the company-sponsored cessation programs had participated within 4 months of policy adoption (Rosenstock et al. 1986). The signup rate for worksite-based self-help smoking cessation programs was no greater at a Rhode Island hospital with a new smoking policy than at one without (Biener et al. 1986).

It is not known whether the cessation rate of smokers who enroll in worksite programs is affected by the presence of a smoking policy at the worksite. Only uncontrolled studies with self-report measures are currently available. At Texas Instruments (R. Addison, personal communication, July 21, 1986), 34 percent of 354 employees enrolled in the first round of company-sponsored cessation classes quit smoking by the end of the program; in the second round of classes, 17 percent of 132 enrollees quit. At Pacific Northwest Bell, 44 percent of 639 respondents quit smoking in a survey of the 1,200 participants in a company-sponsored program. If nonrespondents are included as smokers, the cessation rate was 23 percent (Shannon 1986).

There is as yet no conclusive evidence that smoking policies are associated with increases in smoking cessation attempts or reductions in smoking prevalence. All reports are based on self-reported smoking behavior. There are anecdotal reports of smokers quitting in case reports of company policies (StrideRite, cited in BNA 1986) and in uncontrolled surveys (Rosenstock et al. 1986; Andrews 1983). Supporting evidence comes from the New England Deaconness

314

Hospital, where a two-part survey, before and 20 months after the adoption of a strict smoking policy, demonstrated a reduction in the prevalence of smoking among employees from 32 to 24 percent, along with an increase in the prevalence of ex-smokers (27 to 34 percent) (Andrews 1983). However, methodologic problems prevent an unequivocal conclusion. The first survey included both employees and patients, but the followup covered only employees; smoking rates for employees only are not provided. The survey method was not specified, but it did not appear to be a probability sample, thereby limiting generalizability of the finding to the entire group. Finally, because the same group of employees was not surveyed at followup, an alternate interpretation for the change in smoking prevalence is that the policy influenced employee turnover rates so that smokers left and were replaced by ex-smokers. The study did not assess employee turnover.

Controlled studies by Biener and colleagues (1986) and Rigotti and colleagues (1986) did not detect an increase in smoking cessation by employees of hospitals that adopted smoking policies. In the study by Rigotti and colleagues, nurses in the policy group did not differ from controls in their motivation to quit, or their expectation of doing so, or in the number or success of quit attempts. The prevalence of smoking in the policy group and in the control group was similar at baseline and did not change in the year after policy adoption. Similarly, employees in a Rhode Island hospital with a smoking policy were no more likely to try to quit or to succeed in quitting than were employees in a control hospital (Biener et al. 1986). The number of smokers in these two studies was small, and it is possible that the studies lacked adequate power to detect changes in behavior. Followup periods of greater than 1 year may also be required.

Attitudes About Smoking

There has been little assessment of the impact of worksite smoking policies on attitudes about smoking. The two controlled studies of hospital smoking policies assessed attitudes about the health risks of smoking and about involuntary smoking (Biener et al. 1986; Rigotti et al. 1986). There was no significant change in the smokers' beliefs about the health risks of smoking or about environmental tobacco smoke exposure.

Management Issues

There is only sketchy evidence about the impact of worksite smoking policies on absenteeism, health care costs, productivity, or employee turnover. No systematic analysis of economic impact has been done. There is an anecdotal report of cost saving by the Merle

315

Norman Cosmetics Company, which reported lower absenteeism and housekeeping costs and increased productivity in the year after it adopted a ban on smoking (ALA of San Diego 1984). In the 6 months after Pacific Northwest Bell adopted a total smoking ban, no employees left because of it (Martin 1986). Rigotti and colleagues (1986) reported no change in employee turnover in the year after the adoption of a hospital smoking ban. Rosenstock and colleagues (1986) found that self-reported work performance was unaffected in 75 percent of employees and improved in 21 percent. Costs involved in implementing a smoking policy have not been systematically measured, but appear from case reports to have been small (BNA 1986). Adverse impacts of worksite smoking policies have not been reported.

Legislation Restricting Smoking in Public Places

Legislation restricting smoking in public places has been less well evaluated than worksite smoking policies. Opinion polls in States and communities that have passed smoking control regulations provide some information on attitudes about smoking and smoking policies. There are no controlled studies of the impact of legislation on smoking behavior or attitudes.

Policy Implementation and Enforcement

Evaluation of the implementation of State or local smoking control statutes has been limited. In general, enforcement is delegated to a State or local agency, such as the department of public health. Enforcement is handled passively rather than actively; the responsible agency responds to complaints, but does not actively monitor policy compliance by surveying worksites, restaurants, or public places. Nonsmokers rights groups and individual activists are a major force for informing the public and aiding enforcement by bringing complaints (Sandell 1984).

The experience of cities like San Francisco and States like Minnesota contradicts tobacco industry estimates of the expense and intrusiveness required to enforce a smoking law (Martin 1986, New York Times 4/13/86; Sandell 1984). In the first year after San Francisco implemented a strict workplace smoking law in March 1984, only 124 complaints were processed and 1 citation was issued; there were no legal actions. No new employees were hired and no additional funds were required for enforcement. Policy enforcement required progressively less of a single employee's time over a 1-year period (Martin 1986). Minnesota enforces its 1975 State smoking law in a fashion similar to San Francisco's. State public health department officials estimate that they handle 1,200 to 1,400 complaints per year, with costs of enforcement estimated to be under $5,000 per

316

year (Sandell 1984). A survey of 10 California cities with workplace smoking laws documented that complaint rates were low and enforcement of these laws was a low priority for all city governments. Officials indicated that they would spend any additional funds available for enforcement on a public education campaign to increase awareness of the law rather than initiate active surveillance (Linson 1986).

Because active monitoring of policy compliance is not done, a low complaint rate is often taken as evidence of a high compliance rate. Data from Minnesota suggest that this is not always true. In 1976, 1 year after the comprehensive Clean Indoor Air Act was enacted, 43 percent of respondents to a statewide poll felt that the law was not very effective in reducing smoking in public places; 38 percent found it somewhat effective and 12 percent, very effective (Minneapolis Tribune 1976). Six years after the law took effect, a survey of Minnesota businesses with 200 or more employees documented that only 46 percent of businesses had such a policy. Restaurants, however, had nearly uniformly conformed to the law within a year of implementation (Sandell 1984). A statewide opinion poll in 1978 demonstrated that over 70 percent of both smokers and nonsmokers felt that the Clean Indoor Air Act should be strictly enforced (Minneapolis Tribune 1978). Two years later, Minnesotans were of mixed opinion about the law's enforcement: fewer than half (43 percent) considered it very well enforced, 42 percent felt it was not so well enforced, and 10 percent said it was not enforced at all (Minneapolis Tribune 1980).

Randolph (1982) studied factors associated with compliance and enforcement of local ordinances regulating smoking. She assessed the implementation of a recently enacted San Rafael, California, smoking ordinance by interviewing proprietors of randomly selected businesses. Less than 1 year after the ordinance went into effect, 68 percent of 25 proprietors were aware of the policy, but only 44 percent of 30 businesses had complied with the requirement to post no-smoking signs. The major variable associated with compliance by businessmen was the type of business; restaurants, retail food stores, drug stores, banks, and movie theaters were generally posting signs as required, but department stores and small retail stores were not. City residents were less well informed. Fewer than half (45 percent) of 200 randomly selected residents surveyed by telephone were aware of the ordinance, and only 11 percent could describe its provisions.

Randolph's study (1982) of implementation also included a 1980 telephone survey of 600 randomly selected residents of three northern California cities, two with smoking ordinances and one without. Smokers were classified as compliers or noncompliers according to whether they refrained from smoking in supermarkets,

which was required by State law. Characteristics of smokers who complied were (1) lower daily cigarette consumption, (2) less perceived need to smoke, (3) greater perception of others' disapproval for tobacco smoking in public, (4) and greater support for policies restricting smoking in public places. Smokers' perception of pressures to refrain from smoking in public, awareness of the presence of a local smoking law, and the duration of the ordinance were not associated with compliance. Enforcement of smoking laws was studied in nonsmokers. The best predictor of enforcement behavior was a nonsmoker's degree of annoyance with tobacco smoke. Other characteristics associated with enforcement behavior were more negative attitudes about smoking in public places, greater intolerance of noncompliance, and higher educational level.

Policy Approval

National and regional polls have surveyed public opinion about where smoking should be restricted or banned. Regional polls have often been taken when legislation is being considered. There are little data about public opinion on legislation after its enactment.

Nationwide public opinion about smoking in public places was assessed by Roper polls in 1976 and 1978 (1978), two Gallup polls (1978, 1983), and the Harris Prevention Index 85 (Harris 1985). The Roper polls asked separate questions about preferences for a smoking restriction or a total ban; the Gallup and Harris polls offered a choice between the two in the same question. In both Roper polls, a majority of respondents favored restricting smoking in all places mentioned: transportation vehicles (airplanes, buses, and trains), restaurants, workplaces, and indoor arenas. By 1978 three-fourths of the respondents favored restrictions in all places except the worksite. Total smoking bans were less popular but still the choice of at least one-fourth of the respondents.

The 1983 Gallup poll documented increased public support for smoking restrictions, particularly in restaurants. More than 80 percent of smokers and 90 percent of nonsmokers favored either banning or restricting smoking in airplanes, buses, and trains and restaurants. Over half of both smokers and nonsmokers favored restrictions in motels and at the worksite. Although bans were less popular than restrictions, they were twice as popular with nonsmokers as with smokers. In 1985, 80 percent of the respondents to the Harris poll supported restrictions or bans in public places in general. Regional polls generally support the conclusions of nationwide surveys.

Minnesota is one State where public opinion of existing legislation has been measured. Five years after enactment, public opinion of Minnesota's 1975 Clean Indoor Air Act remained high. Ninety-two percent of the 1,200 respondents to a statewide poll favored the act,

318

including 87 percent of heavy smokers (two packs per day) and a larger fraction of lighter smokers (Minneapolis Tribune 1980).

During the first year of the San Rafael, California, smoking ordinance, nearly 70 percent of 200 randomly selected residents agreed that there should be laws about smoking in public places and 77 percent said they would have voted for the ordinance had they had the opportunity (Randolph 1982). The reaction of local businesses was less favorable. Over half (52 percent) did not like the ordinance, but only 41 percent favored rescinding it. The most common reason for support was concern for smoking-related damage to property. Concerns about invading personal rights and fear of losing business were the major reasons for opposition.

Attitudes and Social Norms

It has been suggested that smoking restrictions will alter public attitudes and norms about smoking behavior. There are few data addressing this hypothesis.

Randolph (1982) reported on attitudinal differences between residents of California communities with and without smoking ordinances. Smokers in two cities with laws had more negative attitudes about smoking in public places and were more likely to feel that there should be laws regarding tobacco smoking in public. However, there was no difference in smokers' perceptions of social pressures to refrain from smoking. Nonsmokers in cities with laws were more likely to believe that tobacco smoke should be regulated in public, but they were no more annoyed by tobacco smoke, intolerant of noncompliance, or disapproving of smoking in public places than residents of the city without a law. Although residents of communities with and without smoking ordinances did not differ in their personal support of smoking laws, residents of communities with laws perceived greater support for these laws by other residents of their communities. This cross-sectional study cannot differentiate whether these attitudinal variations were a cause or consequence of differences in community smoking ordinances.

Data from opinion polls demonstrate that negative attitudes about smoking generally preceded rather than followed legislation to restrict smoking in public places. The four Adult Use of Tobacco Surveys, a series of nationwide surveys conducted between 1964 and 1975, measured attitudes in the decade after the health hazards of smoking were first widely appreciated (US DHEW 1969, 1973, 1976). As early as the first survey in 1964, a majority of nonsmokers agreed with these statements: "It is annoying to be near a person who is smoking cigarettes" and "Smoking should be allowed in fewer places than it is now." By 1970, a majority of all respondents agreed with these statements. By 1975, a majority of smokers agreed with the idea of further restricting smoking, suggesting that there was wide

public support for restricting smoking well before the first comprehensive Clean Indoor Air Act was passed in Minnesota in 1975. As early as 1973, 73 percent of the nonsmokers in a Minnesota poll felt that they had the right to a smoke-free environment, and 65 percent wanted to ask others not to smoke (Minneapolis Tribune 1973). More recent opinion polls document that negative attitudes about smoking in public continue to grow. In a 1985 Gallup poll, 75 percent of the respondents (including 62 percent of the smokers) felt that smokers should refrain from smoking in the presence of nonsmokers.

However, nonsmokers' attitudes do not translate directly into action. A smaller proportion of nonsmokers are willing to confront a smoker whose smoke is bothersome. In three successive Roper polls between 1974 and 1978, fewer than 10 percent of the nonsmokers indicated that they would ask an individual smoking indoors to stop (Roper 1978). Only 32 percent of the nonsmokers in a 1974 Minnesota poll would complain when bothered by another person's smoking, although an additional 31 percent would take nonconfrontational action such as moving away or opening windows (Minneapolis Tribune 1974). These data suggest that in the mid-1970s, despite strong preferences, many nonsmokers did not perceive that asking a smoker to stop was socially sanctioned behavior.

Smokers, on the other hand, report an awareness of nonsmokers' concerns and a willingness to comply with restrictions. Over 90 percent of the smokers in a 1981 Iowa poll (Des Moines Register 1981) extinguished tobacco when they saw a no-smoking sign. Sixty percent of the smokers in a 1973 Minnesota poll (Minneapolis Tribune 1973) had at least some misgivings about smoking in the presence of nonsmokers, and 90 percent would not have been offended if asked not to smoke. Only 29 to 36 percent of smokers in three Roper polls (1974–1978) lit a cigarette without looking around, asking others, or refraining from smoking (Roper 1978).

There may be, therefore, an interaction between attitudes and policy development. These survey data suggest that attitudes about smoking in public preceded and may have contributed to the development of a public policy (Breslow 1982). At the same time, publicity surrounding campaigns for legislation may increase public awareness of an issue such as the hazards of involuntary smoking and therefore contribute to further changing attitudes.

Smoking Behavior

The impact of legislation on smoking behavior has received little formal attention. There are no controlled studies in which smoking behavior has been tracked over time in the States or communities that have enacted smoking legislation. In Randolph's one-time assessment (1982) of smoking behavior in California communities with and without smoking control ordinances, there was no differ-

ence in smoking prevalence or mean daily cigarette consumption between the residents of a city with a recent ordinance and one without. A lower prevalence of smoking in one community with a longstanding ordinance was probably explained by demographic differences between that community and the other areas.

Uncontrolled reports of declining smoking prevalence or cigarette consumption in a State or community with a smoking law cannot establish a causal relationship. This was particularly the case during the 1970s, when both smoking prevalence and per capita cigarette consumption were declining nationally. Warner (1981a; Warner and Murt 1982) conducted a series of analyses of this decline. In separate analyses, he estimated the levels of smoking prevalence and cigarette consumption that would have been achieved if previous trends in these indicators had continued unabated through the 1960s and 1970s. Cigarette consumption in 1978, for example, would have been 36 to 41 percent higher had previous patterns continued. He ascribed the difference between observed and modeled values to the impact of the so-called antismoking campaign, defined as the combination of public events, legislative activity, and Federal regulations that affected cigarette price, counter-advertising, and the circumstances in which smoking was allowed.

To assess the relative contributions of components of the antismoking campaign to the decline in adult per capita cigarette consumption, Warner (1981a) developed a multivariate analysis that included independent variables to account for price fluctuations, adverse publicity about smoking, antismoking activities, and the effectiveness of the nonsmokers' rights movement. The percentage of adults residing in States restricting smoking in public places was used as an index of the strength of the nonsmokers' rights movement. This variable was strongly associated ($p < 0.0001$) with decreases in consumption from 1973 to 1978.

In Warner's view, the temporal relationship between the growth in legislation restricting smoking in public places and the decline in cigarette consumption is so close that a causal relationship is unlikely. He attributed the decline in consumption to the changes in attitudes and social norms about smoking that were an earlier consequence of the entire antismoking campaign. He regarded the legislation as another reflection of changing social norms rather than the creator of them (Warner 1981b).

Recommendations for Research

Policies restricting the circumstances in which smoking is permitted have been adopted by a broad range of institutions, mostly in the last decade. Smoking regulations affect the daily lives of a large and growing number of Americans. Consequently, these policies are of

interest to many individuals and groups. For instance, public health officials are concerned about the health effects of both active and involuntary smoking; they are most interested in whether these policies actually reduce a population's exposure to environmental tobacco smoke and whether they will alter the prevalence of smoking. Behavioral scientists, primarily concerned with smoking behavior and attitudes, are chiefly interested in how smoking policies alter these variables and how this knowledge can increase our understanding of the dynamics of smoking behavior. Businesses, unions, and government policymakers have different perspectives. They are faced with deciding whether to adopt smoking restrictions and how to improve the implementation and acceptability of existing ones. Information about the determinants of policy approval and compliance will be of most interest to them. Businesses may also be concerned about the economic and managerial impacts of smoking restrictions.

Understanding the effect of policies on smoking behavior is of widest interest and deserves attention. Policies may affect the natural history of smoking behavior at several points, and detailed behavioral information should be collected to distinguish among effects on rates of initiation, cessation, and relapse. Studying how smokers cope with enforced abstinence may provide additional insights into the maintenance of smoking behavior. Detailed studies of the influence of policy may advance the state of knowledge about the determinants of smoking behavior in general. The relationship between interventions at the social and individual levels is also of interest. Researchers should consider whether the effectiveness of individual treatment is enhanced by the presence of a smoking policy, and whether the impact of a policy is enhanced by the availability of individual treatment. Concurrent collection of information on attitudes about smoking may help to clarify the nature of the relationships among attitudes, smoking behavior, and smoking policies.

In addition to considering a variety of outcome measures, researchers should address the determinants of these outcomes. Characteristics of the policy, the institution, and the population should be considered. The components of a smoking policy and its implementation (such as restrictiveness, degree of advance notice, degree of support for the policy by affected groups, access to smoking cessation programs) that contribute to its effect—be it on behavior, attitudes, air quality, acceptability, or compliance—have generally not been analyzed. Because smoking policies vary widely in their provisions and implementation, they cannot be evaluated as a unitary intervention; i.e., better operationalization of "policy" interventions is needed. The relative strength of policy components on each outcome measure should be assessed in order to make informed

322

policy recommendations. For example, the degree of protection from involuntary smoke exposure afforded by policies of different degrees of stringency in not empirically known. To acquire this knowledge, researchers will need to develop and validate measures of such concepts as restrictiveness. The index described in the appendix to this chapter is a preliminary attempt to do that. The components of a policy that are most powerful in reducing cigarette consumption, inducing cessation attempts, preventing relapse, or reducing smoking initiation need to be identified.

Similarly, the components of a policy associated with maximal acceptability and compliance have been addressed only cursorily. Dawley and colleagues (Dawley, Morrison et al. 1981; Dawley and Burton 1985), for example, have examined variables such as the wording of signs or the presence of active enforcement. Guidelines for the implementation of smoking policies have not been experimentally derived. Research could empirically support or refute recommendations on the basis of experience. Interventions such as the training of managers to handle implementation problems might then be developed to increase policy acceptability and compliance.

Different types of organizations have presented different climates for the adoption of smoking regulations. In assessing policy impact, there may also be substantial interactions between the policy and type of facility in which it is adopted. Even within a single type of facility, there may be considerable variability in social norms, social supports, and characteristics of the population using it. Sorensen and colleagues (1986) have pointed out these differences among worksites. Policy evaluations should consider these variables.

Because smoking policies represent a recent social phenomenon, there is at present relatively little information about their impact. New policies are being adopted at a growing rate, providing researchers with the opportunity to study natural experiments that, up to now, have largely gone unevaluated. The variety of potential outcomes, number of interested parties, and current lack of information make efforts to collect systematic data on new public and private sector smoking policies a high priority for research. Controlled studies are desirable and permit the firmest conclusions, but with the current knowledge base, even limited efforts may yield valuable information. Uncontrolled case studies, for example, can provide suggestive data and generate hypotheses for further testing. In some cases, data are already partially collected. For example, many businesses considering smoking policies survey employees at baseline, but few repeat the survey after policy adoption. At the aggregate level, it may be possible to estimate the impact of legislation on smoking prevalence or cigarette consumption by relating national survey data on smoking behavior to smoking restrictions in geographic areas.

Conclusions

1. Beginning in the 1970s, an increasing number of public and private sector institutions have adopted policies to protect individuals from environmental tobacco smoke exposure by restricting the circumstances under which smoking is permitted.

2. Smoking in public places has been regulated primarily by government actions, which have occurred at Federal, State, and local levels. All but nine States have enacted laws regulating smoking in at least one public place. Since the mid-1970s, there has been an increase in the rate of enactment and in the comprehensiveness of State legislation. Local governments have enacted smoking ordinances at an increasing rate since 1980; more than 80 cities and counties have smoking laws in effect.

3. Smoking at the workplace is regulated by a combination of government action and private initiative. Legislation in 12 States regulates smoking by government employees, and 9 States and over 70 communities regulate smoking in the private sector workplace. Approximately 35 percent of businesses have adopted smoking policies. The increase in workplace smoking policies has been a trend of the 1980s.

4. Smoking policies may have multiple effects. In addition to reducing environmental tobacco smoke exposure, they may alter smoking behavior and public attitudes about tobacco use. Over time, this may contribute to a reduction of smoking in the United States. To the present, there has been relatively little systematic evaluation of policies restricting smoking in public places or at the workplace.

5. On the basis of case reports and a small number of systematic studies, it appears that workplace smoking policies improve air quality, are met with good compliance, and are well accepted by both smokers and nonsmokers. Policies appear to be followed by a decrease in smokers' cigarette consumption at work and an increase in enrollment in company-sponsored smoking cessation programs.

6. Laws restricting smoking in public places have been implemented with few problems and at little cost to State and local government. Their impact on smoking behavior and attitudes has not yet been evaluated.

7. Public opinion polls document strong and growing support for restricting or banning smoking in a wide range of public places. Changes in attitudes about smoking in public appear to have preceded legislation, but the interrelationship of smoking attitudes, behavior, and legislation are complex.

324

APPENDIX

APPENDIX

The Comprehensiveness Index of State Laws

To permit comparisons over time, an index of the comprehensiveness of each State's smoking law was created. Laws were classified on the basis of the number and nature of places where smoking was restricted or prohibited. The overall principle was that stronger measures are those that reduce exposure to ETS to the greatest degree. More comprehensive laws were considered to be those that restrict smoking in a larger number of public places, extend to privately owned facilities, and cover places where individuals spend a large amount of time.

Laws regulating smoking in private worksites were considered to be the the most comprehensive, and States with such laws were assigned the extensive category. Because individuals spend more time at work than in any other place outside the home, worksite legislation has the potential for marked reductions in public exposure to involuntary smoking. Worksite laws also represent an extension of legislation to the private sector, considered a further evidence of their comprehensiveness. Nine States are categorized as having extensive restrictions; the average number of public places covered by their legislation was 11.0.

The next most stringent category, moderate, was assigned to States that regulated smoking in restaurants. Restaurants were chosen because they represent privately owned public places and because laws covering them have been controversial to enact. It was felt that States regulating restaurants but not the private workplace had moderately comprehensive restrictions. The 10 States in this category also regulated smoking in a large number of public places (9.5).

The last two categories, nominal and basic, were defined for States that did not regulate smoking in restaurants or in the private workplace. They differed in the number of public places covered. States restricting smoking in one to three public places were considered to have nominal restrictions. Those restricting smoking in four or more public places were classified as basic.

327

This number of public places covered by smoking restrictions increases with increasing comprehensiveness of categories.

Category	Number of States	Mean number of public places covered
Extensive	9	11.0
Moderate	10	9.5
Basic	15	6.6
Nominal	8	1.4
No policy	9	0

For the calculation of the comprehensiveness index, categories were weighted as follows:

Category	Weight
Extensive	1.00
Moderate	.75
Basic	.50
Nominal	.25
No policy	.00

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330

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334

INDEX

Environmental Tobacco Smoke is abbreviated as ETS throughout this index.

INDEX

INDEX

339

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

INDEX

RESPIRATORY SYSTEM—Contd.
  sidestream smoke particle deposition, 186–189
  smoke particle size as factor in regional deposition, 189, 191–192

RESPIRATORY TRACT CANCER
  animals exposed to cigarette smoke, 248

RESPIRATORY TRACT DISEASES
  acute illness in children, parental smoking as risk factor, 38, 42–44
  asthma in children, maternal smoking as risk factor, 55–58
  children, case–control studies of paternal smoking as risk factor, 43–44
  children, nonuniform deposition of smoke particles as risk factor, 192
  children, parental smoking as factor, 13
  children, parental smoking as risk factor, 38–59
  early childhood, involuntary smoking relationship (table), 39–41
  involuntary smoking as risk factor, 10
  nonsmoking adults and children, involuntary smoking as factor, 37–66
  pneumonia in children of smokers, conclusions about risk, 107
  population characteristics as factor in ETS risk, 28
  smoking as major risk factor, 6

RESPIRATORY TRACT INFECTIONS
  children of smokers, conclusions about risk, 107
  infants, ETS exposure as risk factor, 31

SALIVA
  cotinine level as marker for ETS exposure in nonsmokers, 36
  cotinine levels in ETS-exposed nonsmokers vs. active smokers (table), 211–214
  nicotine and cotinine levels to quantify ETS exposure, 208, 215
  nicotine levels as sidestream smoke exposure indicator, 204–205

SALIVA—Contd.
  nicotine levels in ETS-exposed nonsmokers vs. active smokers (table), 209–210
  nicotine levels in nonsmokers vs. smokers, 216

SIDESTREAM SMOKE
  (See also CIGARETTE SMOKE;
  MAINSTREAM SMOKE;
  SMOKE STREAMS; TOBACCO
  SMOKE)
  bioassays needed to determine genotoxicity, 252
  carbon monoxide and carbon dioxide levels vs. mainstream smoke, 129
  carcinogen levels vs. mainstream smoke, 24
  carcinogenic potential, effect of levels of oxides of nitrogen, 129
  carcinogenicity vs. mainstream smoke in animal models, 252
  chemical analysis, 127–129, 132
  chemical composition as factor in estimating exposure using "cigarette equivalents", 199
  component levels, combustion temperature effect vs. mainstream smoke, 128–129
  constituent formation vs. mainstream smoke, 7–8
  definition, 7
  experimental and mathematical models show deposition in airways, 217
  formaldehyde and acrolein concentrations above occupational limits, 230
  formation and physiochemical nature, 127
  inhalation effects in laboratory animals not reported, toxicity factor, 249
  irritation in nonsmokers vs. gas phase sidestream smoke vs. acrolein, 236–237
  irritation of nonsmokers in laboratory, ventilation as factor, 234–235
  laboratory collection devices, 125–126
  major source of ETS, 125

353

INDEX

INDEX

INDEX