VOLUME 18, NUMBER 1, 1992

ISSN 0160-4120

ENVIRONMENT INTERNATIONAL

A Journal of Science, Technology, Health, Monitoring and Policy

окружающая среда

L'ENVIRONNEMENT

環境

OKOLINA
UMHVERFI
OMEGN
MAZINGIRA

περιβαλλου

DIE UMWELT

환경

البيئة

環境

ÇEVRE
APVIDUS
KÖRNYEZET
MILIEU

AMBIENTE

Pergamon Press
New York Oxford Seoul Tokyo

ENVIRONMENT INTERNATIONAL

A Journal of Science, Technology, Health, Monitoring and Policy

---

Editorial Office: *Environment International,* P. O. Box 7166, Alexandria, Virginia 22307, USA.

Publishing, Subscription and Advertising Offices: Pergamon Press, Inc., 395 Saw Mill River Rd., Elmsford, New York 10523, USA, INTERNET "PPI@PERGAMON.COM"; and Pergamon Press plc, Headington Hill Hall, Oxford, OX3 0BW, England.

Published Bimonthly. Annual institutional subscription rate (1992): £260.00 ($415.00); Two-year institutional subscription rate (1992/93): £494.00 ($788.50). Personal subscription rate for those whose library subscribes at the regular rate (1992): £95.00 ($152.00). Sterling prices are definitive. US dollar prices are quoted for convenience only. Prices are subject to change without notice. Notify 8 weeks in advance of address change with a copy of the subscription mailing label. Back issues of all previously published volumes, in both hard copy and on microform, are available direct from Pergamon Press Offices. Subscription rates for Japan include despatch by air and prices are available on request.

The Item-Fee Code for this publication is 0160-4120/92 $5.00 + .00

Printed in the USA

(∞)™ The paper used in this publication meets the minimum requirements of American National Standard for Information Sciences - Permanence of Paper for Printed Library Materials, ANSI Z39.48-1984.

Environment International, Vol. 18, pp. 1 - 2, 1992

0160-4120/92 $5.00 +.00

EDITORIAL

POLITICALLY PROCESSED SCIENCE

After the second world war, the scientific community increased its awareness of its responsibility to society. The dominant role of science in the development of atomic weapons, the production of combat airplanes with jet engines, and the deployment of rockets capable of delivering warheads are examples of the contribution of scientists to war efforts. Understandably, the scientific community argued that in the second half of the twentieth century, it was no longer possible to wage war without the contribution of science and that scientists should make a concerted effort to avoid wars. These noble thoughts were advocated by a large number of exceptionally distinguished scientists. In effect, the scientific community informed political decision makers that it was no longer willing to follow the political leadership blindly. The social consciousness of science became an accepted norm.

Based on such an assessment, one could conclude that during the period preceding the sixties, the scientific community had no role in societal decisions. In fact, during that period the scientific community was the sole decision maker for what is now called environmental and occupational protection. Permissible exposure standards for chemicals and radiation, design standards for equipment, fire safety standards, and a large number of other standards were entirely the domain of the scientific community.

During the sixties and seventies, a large number of advocacy groups were formed and existing groups were strengthened. These interest groups wanted to influence societal decisions in favor of their views. They chose a logical route by using the emerging social consciousness of science to question the validity of existing standards. The method chosen frequently was to question the validity of the science upon which the standards were based. Because their area of action was the political arena, discussion of scientific issues occurred in public instead of traditional scientific avenues such as meetings and scientific publications. These advocacy groups argued that they lacked the resources to combat the "establishment", and thus although their science may be poor, their goals were noble. The public, including some segments of the scientific community, accepted this argument.

Based on their success, these groups saw no need to change their method; although their influence and their resources grew so rapidly that they became a part of the "establishment", and their resources became comparable or superior to their opponents'. These groups published reports and other materials comparable in frequency and extent to any other established organization. Because of their interest in societal goals, as a general rule, they chose to politically process scientific information.

Politically processed science is now a common occurrence. Nowhere is politically processed science as prevalent as in the environmental area. Virtually every environmental advocacy group evaluates scientific information, chooses data supporting its political views, and discards data that may not support its goals. Misquotations and misrepresentations are commonplace. Repeatedly, minor differences among scientific findings are magnified to indicate a lack of consensus; this leads to the conclusion that their (political) view and their "scientists" are right, and that others have a "conflict".

There is an old saying that those who do not learn from history are bound to repeat past mistakes. There are numerous historical examples indicating the dangers of politically processed science; the two most recent examples are Aryan physics and Lysenko's genetics.

During the second world war, two German physicists with very distinguished scientific accomplishments formed a school of physics known as Aryan physics. Nobel Laureates Philipp Lenard and Johannes Stark contended that there was a conspiracy to promote scientific findings of Jewish scientists, notably Einstein and they found one hundred scientists supporting their cause. According to Lenard and Stark, it was acceptable to reject scientific findings of Einstein and other Jewish scientists in the interest of society, because their writings were inseparable from their Jewish heritage. The end of the war put an end to the political processed science of Aryan physics.

Lysenko was a plant geneticist who eventually became the Director of the Institute of Genetics of the Academy of Sciences in the Soviet Union. The scientific accomplishments of Lysenko are subject to considerable dispute. However, his influence in shaping genetics in the Soviet Union is beyond question. Because of this influence, he was able to discredit leading Russian geneticists and destroyed the existing level of the science of genetics in the Soviet Union.

In a democratic society, all societal goals, including the support of science, are determined through the electoral process. The political process determines which branch of science is to be supported and what goals are to be pursued. The scientific community, the scientists, and the scholarly organizations must participate in the process and convince the system of their desire like any other group.

In contrast to funding and setting scientific goals, scientific results are not the purview of the political process. Politically processed science inevitably leads to excesses, such as Aryan physics and Lysenko's genetics. Those who believe that politically processing science justifies their goal should learn from history. Aryan physics and Lysenko's genetics are undesirable; they should not be repeated.

A. Alan Moghissi

Environment International, Vol. 18, pp. 3 - 9, 1992
Printed in the U.S.A.

0160-4120/92 $5.00 +.00

FROM DATA WAREHOUSE TO INFORMATION CRAFT SHOP: THE CHANGING SHAPE OF INFORMATION SUPPORT FOR ENVIRONMENTAL PROTECTION

Malcolm K. Sparrow
Kennedy School of Government, Harvard University, Cambridge, MA 02138

EI 9102-117M (Received 7 February 1991; accepted 17 July 1991)

Strategies of environmental protection in the U.S. are undergoing significant change. Emphasis is shifting from measures of productivity to measures of environmental quality; from pollution abatement to pollution prevention; from a traditional enforcement mentality to a more creative risk-identification and problem-solving orientation. These shifts in the organizational culture and strategies of U.S. environmental protection agencies have profound effects on the nature of the relationships between federal and state agencies, and upon the kind of information support required. This study examines the State/EPA Data Management Program, a major and nationwide initiative to transform the style of information management within the environmental community. In particular, this study tests the extent to which this initiative serves the emerging strategies, and its effect on interagency cooperation.

INTRODUCTION

When William Ruckelshaus became the first Administrator of the U.S. Environmental Protection Agency in 1970, he selected the phrase "Pollution Abatement" as his mission statement (Wiehl 1974).

In 1990 the language of senior EPA officials includes, instead, "pollution prevention", "risk management", "cross-media integration," and "managing for environmental results" (Grizzle 1989; Reilly 1989; Reilly 1990a,b,c). To many these phrases signal important new ideas about the business of environmental protection and about its ends and about its means; they signal a shift in the strategy of environmental protection (USEPA 1989b).

New strategies require new institutional structures and processes to support them. In particular, they require new uses of information and of information technology.

The task for this paper is to examine the new ways in which information technology is being used within Federal and State environmental protection agencies and to determine the extent to which they fit new or emerging strategies. The focus of the paper is the nationwide effort to coordinate and integrate data collection—The State/EPA Data Management Program.

PIONEERS IN GEORGIA

In 1985 Georgia's Environmental Protection Division (EPD) of the Georgia Department of Natural Resources established a "Comprehensive Data Management Program", introducing on-line State access to EPA databases. The federal databases were physically resident on EPA's mainframe computers at Research Triangle Park (RTP) in North Carolina. There were several motivations for the changes.

In terms of mandated provision of data, the U.S. EPA had viewed the Georgia agency as one of the worst in the country (GDNR 1984). Georgia's EPD had been seriously embarrassed at data discrepancies brought to light during Congressional hearings. State and federal officials, called to testify, both talked about the same facilities in Georgia, but they had two completely different sets of data, with two different sets of opinions and conclusions (Sparrow 1990a).

Also Georgia's EPD, faced with increasing demands and diminishing resources, was learning the importance of accurate data as the proper basis for intelligent priority setting.

Third, the agency was having some highly information-intensive tasks added to its work load. A new state law required EPD to regulate agricultural users of ground water (GDNR 1988d), and another required regulation of underground storage tanks (GDNR 1988c). Georgia had over 10 000 farmers using ground water (whereas they were previously monitoring only a hundred or so industrial users) and roughly 50 000 tanks. Hence, the agency faced a massive explosion in the regulated community, quite apart from the continuing rapid expansion of the population of Georgia with its expanding industrial base.

Fourth, the Georgia agency faced serious difficulties with the computer support that EPD received from the State's central data processing facility (GDNR 1984; Sparrow 1990a)

EPA offered assistance to Georgia's EPD in the form of a Prime 2550 minicomputer, which could act as a front-end interface to the national databases. The Prime would be directly connected through a high-speed data link, and would be able to handle all of the state's local requirements not met by the available federal databases.

The promise of the scheme, for EPA, was the prospect of obtaining reasonable quality data from Georgia—hitherto one of the most seriously delinquent states in that regard—since EPD would rely upon the data in EPA's databases for its own operational purposes. The advantages for EPD included cost savings and resolution of their immediate problems.

Phase I: Data sharing

There were two distinct aspects to the program. The first established on-line connections from EPD to seven EPA databases at Research Triangle Park, North Carolina:

(1) NEDS — National Emissions Data System: provides data on air emissions from industrial facilities;

(2) SAROAD — System for the Storage and Retrieval of Aerometric Data: provides ambient air quality data from air quality monitoring sites;

(3) CDS — Compliance Data System: provides air compliance data. (Superseded, along with NEDS and SAROAD, in 1989 by AIRS, the Aerometric Information and Referral System);

(4) GICS — Grants Information and Control System: keeps track of municipal sewage treatment plant construction projects when supported by federal grants.

(5) STORET — Water Quality Storage and Retrieval System: provides water quality data from monitoring sites;

(6) PCS — Permit Compliance System: provides compliance data and effluent data for facilities having surface water discharge permits; and

(7) HWDMS — Hazardous Waste Data Management System: provides information about hazardous waste sites.

A Memorandum of Understanding stipulated that EPA would not alter the State's data. Previously EPA would quite happily have altered data they mistrusted or did not like. A formal management procedure was established for resolving any disputes about accuracy, and EPD became solely responsible for the quality of its data.

The Phase I objective was met, in Georgia, by the end of 1986, although some of the benefits of the data-sharing scheme were apparent long before that. So much so, in fact, that the EPA headquarters in Washington, D.C. was beginning to pay close attention to what was happening in Georgia. Lee Thomas, EPA's administrator, took a close personal interest, and staff at EPA Headquarters' Office of Information Resources and Management began to see the potential impact of the data-sharing approach if extended to other states (ASIWPCA 1986; Sparrow 1990b). The phenomenon was simply that Georgia's EPD had turned around from being one of the worst providers of data to one of the best, in less than two years.

Phase II: Decision making for environmental results

Phase II of Georgia's program, partially supported by a grant from EPA, related more to the uses to which the data would be put, than to the mechanisms through which it would be collected. The explicit goal of Phase II was "the use of automated systems to better support decision making for environmental results" (GDNR 1988a). Under that rubric, three specific objectives were highlighted:

(1) Data integration to support decision making;

(2) Use of Geographic Information Systems (GIS) to relate and analyze data from the different media (air/water/land etc.); and

(3) Support of the toxic substances and risk management programs. This was a state initiative to help coordinate emergency response to toxic spills, and to make rapidly available the necessary chemical information for dealing with such an emergency.

It was the use of Geographic Information Systems that most dramatically demonstrated the value of cross-media integration of data (GDNR 1988a). The EPD in Georgia had five early successes. They are worth examining in some detail as they shed some light on the philosophy and strategy of this state agency.

Example 1: Siting sanitary landfills. Traditionally municipal applicants for permits to construct sanitary landfills had to face rejection of their proposals by the Georgia EPD in at least 50% of cases. Applicants tended to choose rocky, swampy, or steeply sloping sites because these were unsuitable for other development and consequently low priced. They also had high environmental impacts, being groundwater recharge areas, or wetlands, or upstream of drinking water sources.

To make relationships with applicants more productive, the EPD used GIS to construct a map, for public release, which showed vast areas of Georgia that were unsuitable for siting sanitary landfills. The map itself resulted from the overlay of nine separate digitized databases. The map increased the productivity of both the EPD in processing applications and the local governments in their selection of possible sites. It also produced a more cooperative relationship between them.

Example 2: Prioritizing hazardous waste sites. There are 3230 facilities in Georgia which generate, treat, store, transport, or dispose of hazardous waste. Georgia's EPD could not pay attention to them all, so they plotted their locations in relation to significant ground water recharge areas. A crude scoring system, incorporating proximity to recharge areas, together with the toxicity and the subjectively assessed risk of a release, enabled EPD to rank the sites in order of environmental impact. The product of the GIS application in this case was a list of priorities, not a map.

Example 3: Impact of agricultural chemicals. Georgia recognized the risk posed by overuse of agricultural chemicals. By superimposing the ground water recharge areas on the agricultural land-use areas, EPD highlighted particular agricultural areas as targets for educating farmers on management practices that would minimize the risk.

Example 4: Siting regional water supply reservoirs. Georgia's drought problem required intelligent siting of new reservoirs for drinking water. EPD used GIS to help identify appropriate sites by integrating information about measured stream flows (during recent drought periods), local population density, local land uses, acceptability of dam sites, and stream classification (i.e., they had to avoid building dams on trout streams etc.)

Example 5: Communicating the risks of radon exposure. The Georgia General Assembly requested an assessment of the risks posed by radon in the state. EPD used GIS to superimpose zip-code areas on a geologic map of rock formations with high natural concentrations of radioactive minerals.

Other methods of data integration

The EPD's local Prime 2550 computer became host to new integrated databases, designed and implemented by EPD in high level database programming languages. These local databases served specific local management needs, but drew their information from EPA's databases, combining data elements from two or more of those databases and presenting it in an integrated format.

The first was the Facility Identification Module, which stored basic information about the states' regulated facilities—their name, location (coordinates), address, and contact names, together with a unique EPA identification number—irrespective of which program was obliged to regulate them.

The second was the Permit Application Tracking Module, which was designed to provide a management overview on EPD's accomplishments, backlogs, and productivity with respect to processing permit applications.

A third was the Compliance Management and Enforcement module, designed to facilitate inter-program coordination on routine facility inspections and on enforcement actions. It enabled, for example, the water branch to examine the status of the air permits and vice versa. It also provided the basis for scheduling the multi-media inspections that EPD ran from its four Regional Offices. The data it drew from program-specific EPA databases included the results of inspections, details of notices of violation, consent orders, and dates upon which facilities returned to compliance. It provided a quick and comprehensive view of any one facility's compliance record and status, thus more clearly revealing which were the good guys and which were the bad guys.

EPA HEADQUARTER'S PERSPECTIVE

EPA also made data management a priority, and established its Office of Information Resources and Management in 1985. That Office, with strong support from its administrator Lee Thomas, formally established the State/EPA Data Management Program as a nationwide umbrella for the further development of information management. It was modelled on the experience of Georgia's EPD and was similarly divided into two phases (USEPA 1989a).

Phase I (Data Sharing) concentrated on the establishment of the physical network infrastructure and cooperative relationships and understandings necessary to ensure provision of "complete, accurate and timely data". Phase II (Data Integration) was more concerned with making intelligent use of the data once they were available. The explicit goals of the two phases were as follows:

Phase I

Obtain and enter complete, timely, and accurate information in all EPA enforcement, monitoring, and compliance data bases.

Provide states with high-speed, on-line access to all EPA data bases.

Ensure the integrity of state data in EPA data bases and due process for states in resolving data disputes with EPA.

Phase II

Provide EPA and the states the data, methods, and technology required to conduct integrated environmental analyses and to plan and manage cross-media programs.

Build effective, long-lasting arrangements for sharing data and technology between environmental agencies at all levels and with our colleagues in federal, state, and local agencies that are responsible for commerce, agriculture, science, and natural resources conservation.

In 1987, one state in each EPA region (and two from region IV) were selected as Regional pilot states for Phase I. In 1988, a further 19 states were added to the list. As of April 1991, high speed data links to all states except Hawaii (also to Puerto Rico) have been connected.

However, installation of the communications channels is no guarantee that the various programs within state agencies will adopt on-line access to EPA's databases. Nor is technical adoption of Phase I's data-sharing provisions any guarantee that states will grasp the fundamental purposes and significance of Phase II.

Many states have experienced substantial difficulties in linking the federal databases to their own existing computer systems (Sparrow 1990c). Even when the technical connections are completed, some states report that their staffs find EPA's databases unfamiliar and more difficult to use than their own (Sparrow 1990c; 1990e). Most states find that EPA databases do not meet all of their operational requirements (USEPA 1989b; Sparrow 1990a; 1990d; 1990e). And often the long term benefits of the Data Management Program are not sufficiently visible or not sufficiently understood to make the implementation obstacles worth overcoming.

STRATEGY AND CULTURE AT GEORGIA'S EPD

Therefore it is prudent to ask what was so special about the culture and philosophy of Georgia's EPD. Why did these new information management ideas fit there, when they do not fit so well in some other states and regions? (Sparrow 1990c; 1990e). Six features of Georgia EPD's philosophy are quite striking (Sparrow 1990a).

Cross program integration

For Georgia's EPD, cross-program integration was the routine way to use data. Data management was only one of ten functions within the Program Coordination Branch whose budget was roughly $5 million annually, representing between one third and one half of the EPD's program budget (GDNR 1988b).

One major program within that Branch was the administration of the multi-disciplinary inspection teams, based around the state in four regional offices. Fifty interdisciplinary field officers handled all of the inspections for 6000 of the state's 10 000 regulated facilities. The others, requiring specialist engineering or complex technical skills, were regulated by program specialists from the State central EPD office. The EPD moved to this multimedia approach over a decade ago, in 1976.

Cooperative attitude towards industry

EPD is almost service oriented, as opposed to viewing industry as the involuntary object of enforcement and regulation. And it views enforcement as only one means for compliance.

Another sign of the agency's commitment to working with, rather than against industry, is its New Industry Program, designed to smooth the whole process of site selection and permit issuance for industry contemplating moving into Georgia (Sparrow 1990a). This EPD scheme helps to attract industry to Georgia by eliminating unnecessary obstacles.

Selection of performance measures

EPD's performance measures are described by its staff as results oriented, not numbers oriented. They have rejected the traditional measures of output or productivity: the numbers of enforcement actions taken, the numbers of permits issued. Instead, they set goals such as to insure that dissolved oxygen in a given reach of a river achieves a particular level within six months. In other words, they measure their performance by environmental results.

Attitude towards public release of data

They view release of data and information to the public as lightening the agency's load, not increasing it. They see it as a method of empowering the public to participate in procuring a cleaner, safer environment.

Pioneering spirit

Georgia EPD also prides itself on being quick to adopt new ideas, new practices, and to experiment with new programs. Staff members are encouraged to publish papers, attend conferences, and to help out agencies in other states who want to learn from Georgia's experience.

Attitude towards other state agencies within Georgia

EPD consciously assumes a cooperative rather than an adversarial position. In particular, the interests of economic prosperity and environmental protection—so often in conflict—seem well integrated.

NEW STRATEGIES FOR ENVIRONMENTAL PROTECTION

The Georgia story provides some useful clues about the directions in which strategies of environmental protection might be moving. The signals about reorientation in philosophy emanating from federal EPA have been quite unmistakable, especially since the arrival of William Reilly as Administrator in February 1989 (Reilly 1989; Reilly 1990a,b,c). The initiatives being pursued by EPA's Office of Information Resources and Management properly reflect some of those strategic shifts.

Phase II of the Data Management Program is, in fact, predicated on the assumption that environmental agencies will have to change the way they do business in at least three important ways: first, there is the perceived need to break out of the strict programmatic straightjacket (water/air/hazardous waste etc.) in order to do cross-media risk analysis and problem solving; second, there is the push to focus on environmental impact rather than on the more traditional "bean-counting" output performance measures; and, third, there is a new emphasis on drawing the public into the decision-making process through provision of public access to data.

Cross program integration

The need for cross program integration is obvious. It is mandated by the advent of new environmental problems such as global warming.

When EPA was formed in 1970 from a number of disparate programs, the congressional oversight arrangements were never integrated. EPA Headquarters staff is primarily disaggregated along program lines.

These divisions within EPA Headquarters are mirrored by similar divisions within the EPA Regional Offices and within almost all state agencies. The strength of the programmatic divisions present a constant challenge for the proponents of the Data Management Program, in the details of Phase I as well as in the more philosophical concerns of Phase II.

Managing for environmental results

Equally obscure is the extent to which managing for environmental results can become a practical reality for EPA within the foreseeable future. The Program Staff at EPA recognizes William Reilly's commitment to it, but still feels the compulsion to maintain or increase the numbers of judicial referrals as a method of demonstrating their productivity. Some of the staff are still more conscious of the requirement to collect data, than the need to use it intelligently. For many the most obvious purpose for having national data collections is for congressional reporting, not for operational decision support. Their focus on getting the data from states, makes them natural fans of the Data Management Program, at least of Phase I. Anything that helps make it easier to get the states' data is a bonus. The need for Phase II seems much less immediate.

Looking further ahead, to measuring states' performance by the quality of their water rather than by the number of enforcement actions and the extent of permittee non-compliance, EPA officials point to the extreme difficulty of designing generally applicable water quality measures.

There seem to be two major obstacles facing any major shift towards managing for environmental results: first, the scientific problem of establishing meaningful measures of environmental quality; and, second, the necessity of re-educating not only agency staff, but the legislatures, the media, and the public as to appropriate new forms of accountability. The scientific debate about the first and the political debate about the second are active and vigorous.

Public access to data

While EPA continues the struggle to design more meaningful indicators of environmental quality and better measures of environmental impact, it simultaneously has to deal with ever increasing public interest in environmental affairs.

The Data Management Program has not yet included public release of data within its formal Phase I or Phase II goals. But senior EPA staff know that it has to come (Habicht 1989). They describe EPA's past attitude to data as being secretive and possessive. And they see the public availability of toxic discharge data as a small indication of what will come.

Since 1989, a National Library of Medicine computer provides on-line access to one of EPA's databases. Using a PC and modem, anyone can access the files on 17 000 different manufacturing facilities across the country. Included are emissions to each media on an annual basis. The Toxic Release Inventory, as it is called, contains data on over 300 different toxic chemicals, and has a total of 75 000 records, submitted by industry itself (USEPA 1986).

Officials of EPA's Office of Toxic Substances, responsible for directing this implementation, refused to protect the chemical industry from public misinterpretations of the data. The burden of educating the public had to be shared by the industry itself. The result, according to a senior EPA official, was that the industry began a meaningful dialogue with the public about the data, rather than stonewalling. "The result has been more two-way communication about toxics in the last year than we've ever seen before" (Sparrow 1990b).

FROM DATA WAREHOUSE TO INFORMATION CRAFT SHOP

These trends in environmental protection strategies require new forms of information support. Data collection cannot remain focused on levels of activity; regional and national aggregation cannot remain the dominant form of analysis. Four broad trends for information support will emerge.

First, the process of analysis of incidents comprising any one risk will require the facility to aggregate and disaggregate data along a number of different dimensions—geographic, temporal, type of pollution source, affected medium, causal mechanism for the pollution, offending chemical, or class of chemicals. That requires flexible database structures and versatile analytic capabilities.

Second, the information and analytic support for risk identification, risk selection, problem-solving, and resource allocation will be required at many different levels—ranging from support for isolated, street-level problems dealt with by a single Field Engineer, to major and protracted national priorities.

Third, agencies' information and analytic support has to be available for environmental problems whether they are covered by traditional enforcement programs or not. Public partnership may result in the nomination of new priorities.

Fourth, increasing attention should be paid to educating and thereby empowering the public regarding environmental matters. Release of appropriate information should be seen as a powerful tool, not a regrettable drain on resources.

The emerging strategies will therefore require the production of more appropriate information products, in addition to enhanced data collection. Good quality data only has to be accurate, up to date, and complete. Good quality information has to be relevant, useful, comprehensible, well designed and presented, and in the right hands. Environmental protection can no longer be adequately supported by a "data warehouse". It has to be supported by an "information craft shop".

It could be argued that Phase I of the State/EPA Data Management Program seeks to perfect the traditional national data warehousing system and that Phase II, with its emphasis on GIS units, introduces the information craft shop, elevating the status of data analysis.

CONCLUSION

It is not yet clear to what extent the Data Management Program itself will ultimately be successful in supporting strategic changes within the environmental protection community; nor is it clear to what extent the progress of the Data Management Program will be constrained and hampered by the traditional enforcement-oriented and programmatically divided status-quo.

But it seems an inescapable reality that environmental information is one of EPA's major assets; and that the agency's future credibility will depend to a considerable degree on how it manages, uses, and communicates that information. Collecting the data is a necessary prerequisite. But, the aggregate picture has to be presented in such a way and to such an audience that it serves some useful environmental purpose.

The implications for the State/EPA Data Management Program are clear. First, Phase I must never be regarded as an end in itself. The EPA national databases, however complete, accurate, and up-to-date, are of no use unless significant attention, resources, and creativity are applied to generating useful and usable information products from them.

Second, Phase II should never be made to wait for Phase I. The transformation of the strategy of environmental protection does not depend on perfecting the national information infrastructure. Many information products supporting intelligent environmental decision-making are now being generated without using data from the major national databases. Supporting a wider variety of risk-assessment and resource-allocation decisions utilizes a wider variety of data sources and demands many non-traditional forms of analysis.

REFERENCES

ASIWPCA (Association of State and Interstate Water Pollution Control Administrators). Comprehensive data management conference in cooperation with the USEPA; conference report. Georgia Department of Natural Resources, Atlanta, GA; 1986.

GDNR (Georgia Department of Natural Resources) Georgia data management recommendations; consultant's report. Environmental Protection Division of the Georgia Department of Natural Resources, Atlanta, GA; 1984.

GDNR (Georgia Department of Natural Resources). Use of integrated information system for environmental decision making. Report on Phase II of the Georgia/U.S. EPA Comprehensive Data Management Project. Environmental Protection Division of the Georgia Department of Natural Resources, Atlanta, GA; 1988.

GDNR (Georgia Department of Natural Resources). Annual Report. Georgia Department of Natural Resources, Atlanta, GA; 1988.

GDNR (Georgia Department of Natural Resources). Georgia Underground Storage Tank Act. Official Code of Georgia; Section 12-13-1. Georgia Department of Natural Resources, Atlanta, GA; 1988.

GDNR (Georgia Department of Natural Resources). Georgia Ground Water Use Act. Official Code of Georgia. Section 12-5-90. Georgia Department of Natural Resources, Atlanta, GA; 1972, Amended 1988.

Grizzle, C.L. Future directions: Managing environmental protection. Address by EPA Assistant Administrator before the Association of State and Interstate Water Pollution Control Administrators, Nashville, TN. August 1989. United States Environmental Protection Agency, Washington D.C.; 1989.

Habicht, F.H.(II). Environmental dispute resolution in the 1990's: How EPA is building consensus. Address by EPA Deputy Administrator to the Society of Professionals in Dispute Resolution. Washington, D.C. October 1989. United States Environmental Protection Agency, Washington D.C.; 1989.

PSCTPS (Program on Strategic Computing and Telecommunications in the Public Sector). Building partnerships for tomorrow's challenges: The Senior Executives Forum for the State/EPA Data Management Program. Report of Conference Proceedings. John F. Kennedy School of Government, Harvard University, Cambridge, MA; 1989.

Reilly, W.K. Measuring for Environmental Results, EPA J. May/June; 1989:2-4.

Reilly, W.K. Caring for creation: A moral imperative. Address: Inter-Continental Conference on Caring for Creation, Washington D.C., May 1990. United States Environmental Protection Agency, Washington, D.C.; 1990a.

Reilly, W.K. Remarks by William K. Reilly. Address: EPA Senior Executive Service Dinner, Washington D.C. September 25th 1990. United States Environmental Protection Agency, Washington, D.C.; 1990b.

Reilly, W.K. Aiming before we shoot: The quiet revolution in environmental policy. Address: National Press Club, Washington D.C. September 26th 1990. Reprinted in U.S. EPA, Communications and Public Affairs (A-107) United States Environmental Protection Agency, Washington, D.C.; 1990:1-6.

Sparrow, M.K. Pioneers in Georgia: The State/EPA Data Management Program: Case (A). Program on Strategic Computing and Telecommunications in the Public Sector, Kennedy School of Government—teaching case. Harvard University, Cambridge, MA; 1990a.

Sparrow, M.K. The evolving strategy of environmental protection: The State/EPA Data Management Program: Case (B). Harvard University, Cambridge, MA; 1990b.

Sparrow, M.K. Implementation in New England: The State/EPA Data Management Program: Case (C). Harvard University, Cambridge, MA; 1990c.

Sparrow, M.K. Missouri—Planning for the next century: The State/EPA Data Management Program: Case (D). Harvard University, Cambridge, MA; 1990d.

Sparrow, M.K. New Jersey—Redefining the importance of EPA: The State/EPA Data Management Program: Case (E). Harvard University, Cambridge, MA; 1990e.

USEPA (U.S. Environmental Protection Agency). Superfund Amendments and Reauthorization Act: Emergency Planning and Community Right-to-know. Section 313. Public Law 99-499; U.S. Environmental Protection Agency, Washington, D.C.; 1986.

USEPA (U.S. Environmental Protection Agency). Building environmental partnerships through information sharing. State/EPA Data-Management Program Progress Report. EPA: PM-211D. United States Environmental Protection Agency, Washington D.C.; 1989a.

USEPA (U.S. Environmental Protection Agency). Building environmental partnerships through information sharing. In: Proc. National Environmental Information Conference. United States Environmental Protection Agency, Region VII, Kansas City, MO. 1989.

Wiehl, P. William D. Ruckelshaus and the Environmental Protection Agency. Teaching Case no: C16-74-027. John F. Kennedy School of Government. Harvard University, Cambridge, MA; 1974.

Environment International, Vol. 18, pp. 11 - 17, 1992
Printed in the U.S.A.

0160-4120/92 $5.00 +.00

SICK BUILDING SYNDROME SYMPTOMS — DIFFERENT PREVALENCES BETWEEN MALES AND FEMALES

Kåre Lenvik
National Institute of Occupational Health, N-0033 Oslo 1, Norway

EI 9011-208M (Received 16 November 1990; accepted 20 May 1991)

The importance of gender to the prevalence of the "sick building syndrome" symptoms was investigated by questionnaire studies in three office buildings in Norway. The study included 710 persons. Of these, 590 (83%) completed the questionnaires. The most important factor related to the differences in symptom prevalences was found to be the sex. A greater percentage of females than males reported having symptoms. A relatively frequent occurrence of symptoms was reported by a greater percentage of females than males. The difference between males and females within each building was greater than the corresponding differences between females and males respectively in different buildings. The results show that gender is of importance to the prevalence of symptoms recorded in indoor air questionnaire studies. It must be taken into account when analyzing the results; otherwise, the sex can be a confounding factor. Possible reasons for the observed differences are discussed.

INTRODUCTION

From many countries during the last 10 to 15 years, there has been an increasing number of reports of discomfort and adverse health effects in the non-industrial sector of the population (Finnegan et al. 1984; Hedge et al. 1987; Skov and Valbjørn 1987). Although a broad range of symptoms is reported, many are common, such as irritative symptoms from the eyes, nose, throat, and lower airways; skin reactions; unspecific hypersensitivity reactions; mental fatigue; headache; nausea; and dizziness (WHO 1983). The frequent occurrence of the symptoms in any population makes it difficult to establish a relationship to indoor environment in particular cases.

The prevalence of symptoms of discomfort and illness in a building is taken as a measure of the health of the persons working in that building. However, there is no objective method for measuring the sick building syndrome (SBS) (Hedge 1990). Investigations are generally based on questionnaire studies, reflecting the employees' subjective feelings. The need for standardized questionnaires has been emphasized (Andersen 1984; Berglund et al. 1987; Valbjørn and Kousgård 1984), but to date no general design of questionnaire investigations for this aim has been outlined. In fact, reports differ greatly with regard to prevalence of SBS symptoms, and correlations between the occurrence symptoms and a wide range of attributes have been reported (Hedge 1984; Hodgson et al. 1987; Jaakkola et al. 1987; Lam et al. 1987; Morris and Hawkings 1987; Robertson et al. 1989; Woods et al. 1987). There appears to be much controversy concerning the primary cause and the mechanism of appearance of the symptoms (Hedge et al. 1987; Zweers et al. 1990; Menzies et al. 1990; Kirkbride et al. 1990; Miller J.D. 1990).

Investigations have indicated a higher frequency of occurrence of symptoms among females than among males (Hedge et al. 1987; Norbäck et al. 1987; Skov and Valbjørn 1987; Finnegan and Pickering 1987), but as yet no psychological or physical environmental factor which can generally explain the observations has been found. The "healthy worker effect" and atopy are considered in only a few studies, but they are not found to be crucial factors for the observed differences (Norbäck 1987; Arundel 1987). Recently, it has been suggested that it may be related to more body awareness in females than in males (Burge 1990).

However, statistically significant correlations do not necessarily mean profound associations. In a large group, for example, small variations can be detected as significant; whereas in a small group, large and important variations may go undetected. For many practical purposes, the magnitude of the variations remains the most relevant information. Further work and more thorough analyses are necessary in order to verify correlations among certain factors suggested by the sporadic studies to date and in order to determine the relative importance of various factors.

The study described below deals particularly with differences between the sexes with regard to the results of questionnaire studies of indoor environment. It is part of continuing investigations into the relationships between various factors and the prevalence of SBS symptoms.

MATERIALS AND METHODS

Buildings

Employees in three public office buildings, A, B, and C, were asked about their working situation and about SBS symptoms by questionnaires. The study was conducted at the request of health personnel in the buildings which means that the buildings were already suspected of being sick. The ages of the buildings A, B, and C were 16, 15, and 2 y, respectively. Buildings A and B were situated in urban areas and building C in a rural area. All three buildings were made of concrete and brick and had mechanical supply and exhaust ventilation.

Study population

The study included 710 employees, most engaged in clerical work. Of these, 590 (83%) returned the questionnaire. Sick leave, maternity leave, and vacation were stated as the reason for non-participation by ~85% of the non-respondents. For the rest, unwillingness to participate, short-term absence, etc. are assumed to be the reasons. No further analysis of the non-participants was done.

Mean age for males was 41.8 y and for females 39.2 y.

Of the females, 38% (101 persons) were smokers; and 27% (87 persons) of males were smokers.

In buildings A, B, and C, 30%, 7%, and 10%, respectively, of the employees worked in open areas.

Questionnaire

A self-administered questionnaire was used, with questions concerning the following four main groups of items: general items, health symptoms, environmental and climatic factors, and job-performance conditions.

The categories of answers for individual health symptoms and work-related complaints were "Very often", "Often", "Sometimes", and "Never". For statistical evaluation, "Very often" and "Often" were combined in one group as "Often".

According to the employees' own job descriptions, three categories of employment were used: 1) secretarial work; 2) executive work by highly skilled engineers, architects, economists, and management personnel; and 3) other work by caretakers, librarians, bookkeepers, craftsmen, etc.

The questionnaires were organized and distributed by the health personnel at the offices under investigation. The importance of high response rates and com-

Table 1. The number of respondents in each building (A, B, and C).

	FEMALES		MALES		Response rate
		Smokers		Smokers	
A	100	43 %	96	26 %	196 (83 %)
B	63	32 %	44	34 %	107 (74 %)
C	105	36 %	182	26 %	287 (87 %)
Total	107	38 %	287	27 %	590 (83 %)

plete answers from the employees was stressed. All staff members were encouraged to participate regardless of their rank.

Statistical analyses

Chi-square tests were used for the statistical analyses, using a level of significance of $p < 0.05$. Statistical comparisons were carried out for each of the symptoms.

RESULTS

The proportion of males and females who returned the questionnaire in the three offices is shown in Table 1. Table 2 shows the prevalence of symptoms

Table 2. The prevalence (%) of symptoms and significance levels (p) between the responses from females and males.
O - Often S - Sometimes N - Never

	Prevalence (%)						Significance (p)
	Female, n=268			Male, n=322			
Category of answer:	O	S	N	O	S	N	
Irritation - face							
Build. A	12	20	68	6.7	5.3	88	0.0089
" B	13	6.7	80	9.1	15	76	0.4323
" C	11	19	70	2.5	12	86	0.0037
Total (mean)	12	17	72	4.4	10	85	0.0007
Irritation - eyes							
Build. A	27	35	38	7.1	21	71	0.0000
" B	33	33	35	19	19	62	0.0457
" C	35	33	33	15	22	63	0.0000
Total (mean)	32	33	35	13	22	65	0.0000
Dry skin - face							
Build. A	46	26	27	7.7	19	73	0.0000
" B	60	13	27	18	21	61	0.0003
" C	45	24	31	13	16	71	0.0000
Total (mean)	49	22	29	12	17	70	0.0000
Dry skin - hands							
Build. A	59	22	20	15	16	69	0.0000
" B	69	9.3	22	16	22	62	0.0000
" C	42	26	32	14	7.8	78	0.0000
Total (mean)	55	21	25	15	12	73	0.0000
Headache							
Build. A	26	51	23	15	37	48	0.0044
" B	38	46	16	11	42	47	0.0012
" C	19	51	30	3.6	39	57	0.0000
Total (mean)	26	50	25	7.6	39	54	0.0000
Tiredness							
Build. A	33	49	18	19	51	31	0.0514
" B	57	36	6.9	22	51	27	0.0007
" C	37	45	18	16	54	29	0.0008
Total (mean)	41	44	15	18	53	29	0.0000
Lethargy							
Build. A	37	49	13	21	45	35	0.0015
" B	58	37	5.1	23	48	30	0.0002
" C	45	43	12	18	49	33	0.0000
Total (mean)	46	44	11	19	48	33	0.0000
Concentration problems							
Build. A	6.9	60	33	8.8	39	53	0.0336
" B	21	55	23	11	44	44	0.0888
" C	11	51	38	6.5	48	45	0.3695
Total (mean)	12	55	33	7.7	45	47	0.0055

in each building and combined for all three buildings.

For all three buildings combined, and for each of the sexes, the following calculation was done:

$$\frac{\text{Frequency ("Often")}}{\text{Frequency ("Often" + "Sometimes")}} \times 100\% \quad (1)$$

The results of this calculation are given in Fig. 1.

When asked if the problems had resulted in a visit to a medical doctor, 30% of the females and 16% of the males replied in the affirmative.

Distribution of symptoms

Table 2 shows that the prevalence of the symptoms varies greatly. In most instances, for each symptom and for each building, the differences in prevalence of symptoms between females and males have a level of significance of $p < 0.01$. The symptoms are much more widespread among females than among males. As shown in Fig. 1, a larger percentage of women than men answered "Often" to the question of the occurrence of symptoms, which suggests also that the symptoms recur more frequently among women than men.

The prevalence of symptoms in each of the three buildings was statistically compared for males and females separately. In 85% of the comparisons carried out, the differences in symptom prevalences between the buildings were found to be statistically insignificant for males and for females.

Investigations have indicated some complaints to be related to job category (Skov and Valbjørn 1987). Investigations of symptom prevalences related to job categories (Lenvik 1990) show that for each job category, the symptom prevalences were much higher among females than among males, and the differences were statistically significant in half of the cases. The prevalence of symptoms in each of the three job categories was compared for males and females separately, and in most cases no statistically significant differences were found for males or for females.

The prevalence of symptoms among smokers and non-smokers, among persons of age 40 y or less, and for persons more than 40 y old was compared for each of the sexes for the three offices together. The differences among these groups were found to be small and therefore are omitted in the further analyses.

Woods et al.(1987) found that poor air quality was reported by workers in open areas 1.5 times more often than those in closed areas. In the present study, significant differences were found in the occurrence of dryness of face, 47.1% and 28.4%, respectively; dryness of hands, 43.4% and 25.4%, respectively;

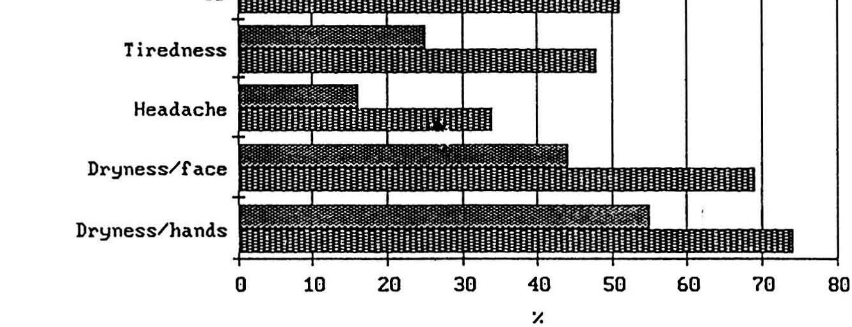


Fig. 1. Symptoms reported to occur "often" as a percentage of occurrence of all symptoms ("often" + "sometimes"), given for males and females and for different symptoms.

and of headache, 20.0% and 13.7%, respectively. Between female groups in open and closed areas, there was a statistically significant difference for only one symptom. The prevalence of symptoms was 1.5 to 3 times higher for males in open areas than for males in closed; and statistically significant different prevailed for four of the symptoms. The prevalence of symptoms among the males with the worst complaints, ie., those in open areas, was at the same level and lower than among the females with the least complaints.

DISCUSSION

The health of employees in a particular building is usually judged by the frequency of answers in the "Often" (or corresponding) category for single symptoms, discomfort, or complaints obtained by a questionnaire.

In this study, the simultaneous evaluation of several categories of answers has revealed more particular differences in responses by males and females. The study shows that symptoms are reported by a higher percentage of females than males, as was also found in earlier studies (Hedge et al. 1987; Norbäck et al. 1987; Skov and Valbjørn 1987). In addition, the calculations (Eq. 1) and Fig. 1 show that a relatively frequent occurrence of symptoms was reported by a higher percentage of females than of males. Thus, the symptoms are found to be both more widespread and recurring more frequently among females than among males.

More complaints were registered for workers in open areas than in closed; for males, the incidence of symptoms being 1.5 to 3 times higher. For females, the difference was small and statistically insignificant. As no environmental factor has been found as a plausible explanation for this inconsistency between the sexes, the question arises as to whether women and men respond in different ways to some environmental conditions.

The observed differences between the sexes could be due to differences in the nature of employment of men and of women. In this case, the difference between the sexes within the same job category would be reduced, while a crucial difference in the symptom prevalences between the job categories would be expected. However, the results showed statistically significant differences between the sexes regardless of job category. A more thorough analysis on this specific question has been carried out (Lenvik 1990), which shows that the differences between the sexes are considerable regardless of job category. Some studies have revealed (Valbjørn and Kousgård 1984) that females suffer from health problems and discomfort more than males outside the working environment as well, supporting the premise that factors other than job category must be of importance.

The way in which the questions are presented and the way in which they are interpreted, as well as the way in which the answers are evaluated may affect the end result. However, a number of questioning methods have been used in various studies which have shown different prevalences of symptoms between the sexes. It is unlikely that this is due to differences in interpretations in all cases. Furthermore, in questionnaire studies where answers were given as the number of times individual symptoms occurred (Valbjørn and Kousgård 1984), there was still a higher frequency among females than among males. The fact that relatively many more women than men, 30 and 16%, respectively, reported consulting a doctor for the problems associated with indoor environment, also indicates that the differences exist in reality and are not simply due to the questioning methods and interpretation.

The employees in building B were also questioned about asthma and allergies. No statistically significant differences were found between those who reported having allergies and those who reported not having allergies. Reports concerning asthma and allergies and the "healthy worker effect" show that observed differences in the occurrence of symptoms can only partly be explained by these factors (Norbäck 1987; Arundel 1987).

Although all three buildings investigated had similar ventilation systems, variations due to the operation of the systems, for example, cannot be excluded. However, this factor would have the same impact upon males and females in the same building, and does balance out for the comparisons performed. Especially for comparisons between the sexes inside each building, the ventilation conditions would be similar for both sexes.

The study shows greater variations in the occurrence of symptoms between females and males within a building than among groups in different buildings and indicates that environmental factors affect men and women differently. Variations observed among buildings can therefore be due to the composition of the study groups with regard to gender and not necessarily to different building factors, as is often suggested. It appears to be important to take the sex of the participants into account when considering results from questionnaire investigations. Unfortunately, in many studies possible differences between the sexes are not taken into consideration, and therefore there will be some uncertainties and limitations in using the results outside the specific work done. Lack of consistency in published data may, at least to some degree, be due to gender as a confounding factor.

It has not been the purpose of this paper to find out why the symptom prevalences are different for the sexes. However, as recently suggested (Burge 1990), the results support that perceptual or cultural differences between females and males may be a crucial factor. Selection bias between males and females in the study group can not be excluded, although as yet, there is no evidence of any crucial bias. More specific studies are required to clarify these questions.

CONCLUSION

The SBS symptoms are both more widespread and recur more frequently among females than among males. Differences in the prevalence of symptoms appear to be so profound that the composition of study groups with regard to sex can be a confounding factor unless taken into consideration when interpreting results of questionnaire investigations of indoor environment.

REFERENCES:

Andersen, I. Sick Buildings: Physical and psychological features, effect on humans and preventive measures. In: Berglund, B.; Lindvall, T.; Sundell, J., eds. Proc. 3th International Conference on Indoor Air Quality and Climate. Vol. 6. Stockholm: Swedish Council for Building Research; 1984:77-81.

Arundel, A.; Collett, C.; Sterling, E.; Steeves, J. Low relative humidity and eye, nose, throat and skin irritation. In: Seifert, B.; Esdorn, H.; Fischer, M.; Ruden, H.; Wegen, J., eds. Proc. 4th International Conference on Indoor Air Quality and Climate. Vol. 2. Berlin(West): Institute for Water, Soil and Air Hygiene; 1987:650-654.

Berglund, B.; Berglund, U.; Lindvall, T. Measurement and control of annoyance. Koelega, H.S., ed. In: Environmental Annoyance: Characterization, Measurement, and Control. Amsterdam: Elsevier Science Publisher B.V.; 1987:29-44.

Burge, P.S. Building sickness—a medical approach to the causes. In: Walkinshaw D.S., ed. Proc. 5th International Conference on Indoor Air Quality and Climate. Vol. 5. Ottawa Ontario: Canada Mortgage and Housing Corporation; 1990:3-14.

Finnegan, M.J.; Pickering, C.A.; Burge, P.S. The sick building syndrome: prevalence studies. Br. Med. J. 289:1573-1575; 1984.

Finnegan, M.J.; Pickering, C.A. Prevalence of symptoms of the sick building syndrome in buildings without expressed dissatisfaction. In: Seifert, B.; Esdorn, H.; Fischer, M.; Ruden, H.; Wegen, J., eds. Proc. 4th International Conference on Indoor Air Quality and Climate. Vol. 2. Berlin(West): Institute for Water, Soil and Air Hygiene; 1987:542-546.

Hedge, A. Suggestive evidence for a relationship between office design and self-reports of ill health among office workers in the United Kingdom. J. Architect. Planning Res. 1:163-174; 1984.

Hedge, A.; Wilson, S.; Burge, P.S.; Robertson, A.S.; Harris-Bass, S. Indoor climate and employee health in offices. In: Seifert, B.; Esdorn, H.; Fischer, M.; Ruden, H.; Wegen, J., eds. Proc. 4th International Conference on Indoor Air Quality and Climate. Vol. 2. Berlin(West): Institute for Water, Soil and Air Hygiene; 1987:492-496.

Hedge, A. Questionnaire design guidelines for investigations of "sick" buildings. In: Walkinshaw D.S., ed. Proc. the 5th International Conference on Indoor Air Quality and Climate. Vol. 1. Ottawa Ontario: Canada Mortgage and Housing Corporation; 1990:605-610.

Hodgson, M.J.; Permar, E.; Squire, G.; Cagney, W.; Allen, A.; Parkinson, D.K. Vibration as a cause of "Tight-building" symptoms. In: Seifert, B.; Esdorn, H.; Fischer, M.; Ruden, H.; Wegen, J., eds. Proc. 4th International Conference on Indoor Air Quality and Climate. Vol. 2. Berlin(West): Institute for Water, Soil and Air Hygiene; 1987:449-450.

Jaakkola, J.J.K.; Heinonen, O.P.; Seppännen, O. Mechanical ventilation in an office building and sick building syndrome. A short-term trial. In: Seifert, B.; Esdorn, H.; Fischer, M.; Ruden, H.; Wegen, J., eds. Proc. 4th International Conference on Indoor Air Quality and Climate. Vol. 2. Berlin(West): Institute for Water, Soil and Air Hygiene; 1987:454-458.

Kirkbride J.; Lee, H.K.; Moore C. Health and Welfare Canada's. Experience in indoor air quality investigation. In: Walkinshaw, D.S., ed. Proc. 5th International Conference on Indoor Air Quality and Climate. Vol. 5. Ottawa Ontario: Canada Mortgage and Housing Corporation; 1990:99-106.

Lam, T.H.; Lee, P.W.H.; Ong, S.G.; Wong, C.M.; Chow, W.K.; Kleevens, J.W.L. Mental health and work stress: A comparison of response patterns in executives and clerical workers in Hong Kong. J. Occup. Med. 29:892-897; 1987.

Lenvik, K. Comparisons of working conditions and "sick building syndrome" symptoms among employees with different job functions. In: Walkinshaw D.S., ed. Proc. 5th International Conference on Indoor Air Quality and Climate. Vol. 1. Ottawa Ontario: Canada Mortgage and Housing Corporation; 1990:507-512.

Menzies, R.I,; Tamblyn, R.M.; Tamblyn, R.T.; Farant, J.P.; Hanley, J.; Spitzer W.O. Sick building syndrome: The effect of changes in ventilation rates on symptom prevalence: The evaluation of a double blind experimental approach. In: Walkinshaw, D.S., ed. Proc. 5th International Conference on Indoor Air Quality and Climate. Vol. 1. Ottawa Ontario: Canada Mortgage and Housing Corporation; 1990:519-524.

Miller, J.D. Fungi as contaminants in indoor air. In: Walkinshaw D.S., ed. Proc. 5th International Conference on Indoor Air Quality and Climate. Vol. 5. Ottawa Ontario: Canada Mortgage and Housing Corporation; 1990:51-64.

Morris, L.; Hawkins, L. The role of stress in the sick building syndrome. In: Seifert, B.; Esdorn, H.; Fischer, M.; Ruden, H.; Wegen, J., eds. Proc. 4th International Conference on Indoor Air Quality and Climate. Vol. 2. Berlin(West): Institute for Water, Soil and Air Hygiene; 1987:566-571.

Norbäck, D.; Gertie, R.; Michel, I. Overfrequencies of skin and airways symptoms among personnel in sick buildings and polluted industrial environments in relation to exposure. In: Seifert, B.; Esdorn, H.; Fischer, M.; Ruden, H.; Wegen, J., eds. Proc. 4th International Conference on Indoor Air Quality and Climate. Vol. 2. Berlin(West): Institute for Water, Soil and Air Hygiene; 1987:515-519.

Robertson, A.S.; McInnes, M.; Glass, D.; Dalton, G.; Burge, P.S. Building sickness, are symptoms related to the office lighting? Ann. Occup. Hyg. 33:47-59; 1989.

Skov, R.; Valbjørn, O. The "sick" building syndrome in the office environment. The Danish town hall study. Environ. Int. 13:339-349; 1987.

Valbjørn, O.; Kousgård, N. Headache and mucous membrane irritation - An epidemiological study. In: Berglund, B.;

Lindvall, T.; Sundell, J., eds. Proc. 3rd International Conference on Indoor Air Quality and Climate. Vol.2. Stockholm: Swedish Council for Building Research; 1984: 249-254.

WHO (World Health Organization). Report on a WHO meeting. Indoor air pollutants: Exposure and health effects. Euro Reports and Studies No. 78. Copenhagen: WHO Regional Office of Europe; 1983.

Woods, J.E.; Drewry, G.M.; Morey, P.R. Office worker perceptions of indoor air quality effects on discomfort and performance. In: Seifert, B.; Esdorn, H.; Fischer, M.; Ruden, H.; Wegen, J., eds. Proc. 4th International Conference on Indoor Air Quality and Climate. Vol. 2. Berlin(West): Institute for Water, Soil and Air Hygiene; 1987:464-468.

Zweers, T.; Preller L.; Brunekreef, B.; Boleij J.S.M. Relationships between health & indoor climate complaints and building, workplace, job & personal characteristics. In: Walkinshaw, D.S., ed. Proc. 5th International Conference on Indoor Air Quality and Climate. Vol. 1. Ottawa Ontario: Canada Mortgage and Housing Corporation; 1990:495-500.

Environment International, Vol. 18, pp. 19 - 28, 1992
Printed in the U.S.A.

0160-4120/92 $5.00 +.00

THE MEASUREMENT OF ENVIRONMENTAL TOBACCO SMOKE IN 585 OFFICE ENVIRONMENTS

Simon Turner
Healthy Buildings International, Inc. (HBI), Fairfax, VA 22030 USA

Louis Cyr
Department of Biostatistics and Biomathematics, School of Medicine, University of Alabama Medical Center at Birmingham, Birmingham AL 35294 USA

Alan J. Gross
Department of Biostatistics, Epidemiology, and Systems Science (DBESS), Medical University of South Carolina, Charleston, SC 29425 USA

EI 9104-129M (Received 15 April 1991; accepted 19 July 1991)

In order to provide information on levels of environmental tobacco smoke (ETS) in office environments during 1989, a total of 585 offices was sampled for a number of factors, including respirable suspended particles (RSP), nicotine, carbon monoxide, carbon dioxide, room size, average number of room occupants, and number of cigarettes consumed. Each data set was collected over a one-hour sampling period. Discriminant analysis of the data collected showed a group of rooms used for light smoking (59.9% of total smoking rooms) was not significantly different from the nonsmoking rooms, in terms of the variables which contributed to the predictive ability of the model (RSP and nicotine). These light-smoking rooms overlapped somewhat with the heavy-smoking rooms, suggesting other variables not measured here might contribute to this model, such as air change rates or outside air intake volumes. This leads to the possibility that a range of smoker densities could be established inside which indoor air quality will not be significantly affected, thus reflecting the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 62-89, which shows that with good ventilation acceptable air quality can be maintained with moderate amounts of smoking. Statistical analysis also showed overall levels of ETS in offices to be considerably lower than estimated in work ten years previously, and that carbon monoxide is only weakly influenced by smoking activity. Carbon dioxide measurements taken in each room did not correlate significantly with RSP, nicotine, or carbon monoxide, and there were significant relationships between smoker density, RSP, and nicotine, respectively.

INTRODUCTION

Given the present-day concerns in the U.S. society about exposure to environmental tobacco smoke (ETS), it is important that measurements used to assess exposure to this substance are representative of conditions existing in modern office environments.

Numerous studies have measured levels of various components of ETS in both the home, workplace, and other public places. Repace and Lowrey (1980, 1982) presented results of field measurements made in non-office environments (bars, restaurants, bingo games, dinner dances, bowling alleys, sports arenas, waiting rooms, etc.), as well as experimental results in office type environments with high smoking rates (32 cigarettes smoked in 49 min). Respirable suspended particles (RSP) levels were found as high as 697 $\mu g/m^3$ in the non-office environments. In some office experimentation, an equilibrium of 1947 $\mu g/m^3$ of RSP was attained with a time constant (τ) of 14 min. They used data from these two papers to derive a mathematical model to estimate average RSP concentrations of 200 $\mu g/m^3$ in office environments where smoking was allowed (Repace and Lowrey 1987).

These papers are frequently referenced by other workers, and were extended by Repace and Lowrey to compute a "quantitative estimate of nonsmoker lung cancer risk from passive smoking" (1985a), and then "an indoor air quality standard for ambient tobacco smoke based on carcinogenic risk" (1985b). References to one or both of the first two papers are found within much literature on the subject of ETS that has been published since (Collishaw et al. 1984; Samet 1988; Meisner et al. 1989; Wells 1986; Sterling 1982; Wells 1989). These include some papers published as recently as 1989. In addition, the U.S. Environmental Protection Agency (USEPA 1990) currently includes references to these two papers in their Draft Guide to Workplace Smoking Policies. This document has not been formally released however, and is still in the review process.

There are no data in these papers on field measurements of ETS in office workplace environments; however, they have been referenced in many cases to argue that ETS is the major particulate component of indoor air, and hence smoking should be eliminated from the office environment. At present, research that measures components of ETS in discretionary smoking office environments has been limited—most studies contain small data sets thereby preventing precise statistical analyses. Examples of these relatively small scale ETS studies focusing on RSP where smoking was discretionary include Meisner et al. (1989), where RSP ranged up to 80 $\mu g/m^3$, with a mean of 34 $\mu g/m^3$. Also, Sterling et al. (1987) reported mean RSP levels of 37 $\mu g/m^3$ in smoking permitted areas in their Building Performance Database (BPD). Finally in this vein, Oldaker (1990) measured RSP levels in a range of offices and reported mean RSP levels of 126 $\mu g/m^3$ (mean Ultra Violet Particulate Matter [UVPM] levels of 27 $\mu g/m^3$). In any case, overall ETS levels have likely changed during the past decade due to improved ventilation rates and changing patterns of smoking in the U.S.

There is still a need for more study on all aspects of ETS in modern offices where smoking is allowed, especially in a larger variety of office environments sampled with the same methodology to highlight the influencing factors.

In an effort to provide contributory data on ETS components in office atmospheres, and to build on our understanding of which factors influence ETS levels, this study sets out to measure a series of parameters related to, or influencing, ETS in a very large sample of offices, using identical methodology in each. This provides us with up-to-date information on ETS in contrast with the data collected a decade previously.

METHODS AND MATERIALS

Obstacles which have prevented the collection of data as extensive as this before may have been: a) cost—since travel to and time in each office building constitutes a significant portion of a budget for this work; and b) access to each building. (Unless building owners or employers see some personal benefit, they are unlikely to allow their staff or tenants to be disturbed for air sampling exercises.) Each building requires individual persuasive visits allowing technicians into the building. This would normally be a prohibitive effort if the objective is to sample from hundreds of buildings.

Both cost and building access problems are eased by the nature of the indoor air diagnostic work routinely conducted by HBI. Access to many buildings is negotiated during the course of indoor air surveys allowing the ETS study to be added on to each routine indoor survey, with additional expense limited to a brief extra time period and analytical costs. In this manner, it was possible to survey several hundred buildings within practical cost constraints and without access difficulty.

During the visit to each building, the primary indoor air survey includes, as a minimum, visual inspections of the internals of each air handling system and measurements for a range of air contaminants throughout the building space. This survey is separate from the ETS study each building was subjected to, and no efforts are made in this paper to coordinate the results from the main air quality survey and the ETS studies.

The nature of this process dictates the buildings which were surveyed. Some were surveyed because of indoor air quality complaints by occupants. The majority were sampled, however, during the course of routine proactive monitoring visits to buildings perceived as generally healthy. We have no reason to suspect the buildings in this sample are not representative of office buildings throughout North America.

Unoccupied areas of buildings (e.g., areas under renovation), garages, stairwells, industrial areas, and outside terraces were avoided, although cafeterias and some areas designated as smoking lounges were included. A minimum of two ETS sample sets were taken in each building, and while it cannot be claimed that the occupants were unaware of the sampling activities, they were not informed that the sampling was related to ETS.

Data set collection procedures

A one-hour time period was allocated to each ETS sampling set. During this period, the field technician did not leave the space selected for sampling. Each sampling set consisted of the following information:

General:

- Inspector I.D.
- Client name
- Building address
- Overall building size
- Number of stories

Specific to sampling set:

- Type of business and work activity
- Location (floor/room)
- Room configuration details (partitions, supply, and return outlets)
- Room size (m^2)
- Number of people in room (average)
- Number of cigarettes smoked
- Respirable suspended particles ($\mu g/m^3$)
- Carbon dioxide ($\mu L/L$)
- Carbon monoxide ($\mu L/L$)
- Nicotine ($\mu g/m^3$)
- Temperature (°C)
- Relative humidity (%).

Smoking density was then calculated for the hour sampling period by dividing the number of cigarettes consumed in the hour by the room size, to give $cig/m^2 \cdot h$.

The methodologies used for the air sampling were as follows:

Respirable airborne-particle counts were made using a piezoelectric microbalance that measured particles in the 0.01 to 3.5 μm size range. Flow rate through the piezobalance was periodically checked at 1 L/min with a bubble flow meter, and the sensor was cleaned with alcohol swabs after every five measurements. The unit is factory-calibrated with diluted welding fumes which have shown equivalence to indoor RSPs to ±10%. The lower detection limit was set at 10 $\mu g/m^3$.

Carbon dioxide levels were measured using a nondispersive infrared absorption portable gas analyzer. Accuracy is ±2% over full scale. Periodic calibration of the instrument was with a factory-supplied span gas of 5000 μL/L CO_2. Zero was set with dry nitrogen gas and the lower detection limit was set at 50 μL/L.

Carbon monoxide concentrations were measured using a controlled potential electrolysis detector, accurate to 10% full scale. Periodic calibration of the instrument was with a factory supplied span gas of 50 μL/L carbon monoxide. The minimum detection limit was set at 1 μL/L.

Each of the above three parameters, as well as temperature and relative humidity, was measured in real-time and recorded ten times during the hour period. The real-time measurements and the average of the ten measurements were recorded in a standard field log, along with calibration data.

Airborne nicotine was measured after USEPA (1989) with a personal universal flow sampling pump drawing air through unfiltered XAD4 absorbent resin tubes. Samples were analyzed with gas chromatography. Results are expressed in total micrograms converted to $\mu g/m^3$, and the detection limit for our sampling rate of 1 L/min for a one-hour period is given as a conservative 1.6 $\mu g/m^3$ of air.

Statistical methods

General statistics. Statistical methods were used for the purposes of data description and correlation assessment between specific variables. Graphical methods were also used to evaluate relationships between specific variables.

The main goal of the statistical analysis was to evaluate differences between smoking-observed and nonsmoking-observed areas. To evaluate these potential group differences for variables such as RSP, nicotine, CO_2, and CO, t-tests were used.

Discriminant analysis. The goal of discriminant analysis (Karson 1982) was to predict group membership from several predictor variables. With these data, the discrete variable defining group membership was the type of room—either smoking-observed or nonsmoking-observed. Room type was entered into discriminant analysis with several predictor variables such as RSP and nicotine.

The discriminant analysis methodology used here is a stepwise procedure; it initially enters the most significant variable for predicting group membership, as defined by specific statistics, and proceeds to enter new variables into the model until the inclusion of additional variables does not increase prediction ability. There are other methods available that will determine the best predictor model, such as backward elimination. In many cases, however, each method will result in the same final model.

The discriminant function, on the basis of the input variables (e.g., CO_2, RSP, and nicotine levels), decides on whether a room should be classified as a smoking or a nonsmoking room (Table 3). The results of the discriminant analysis are then compared to actual room status.

Assuming that there is a significant difference between a nonsmoking and a smoking environment, then discriminant analysis should produce the following: (1) a discriminant model that is significant, and (2) a model which differentiates between smoking-observed and nonsmoking-observed rooms.

Software. A computer package by BMDP Statistical Software Inc. (#BMDP 7M) was used to generate this discriminant analysis. Standard statistical packages were used to produce the tables, graphs, and descriptive statistics.

RESULTS

Descriptive statistics

The final mix of building types surveyed is shown in Table 1. Since the establishment of designated smoking and nonsmoking areas may or may not be respected by occupants, and because even a smoking lounge may contain no smokers during our sampling period, it is not possible to classify areas as definitely smoking or nonsmoking. Instead, we can classify areas based on the smoking activity observed to be in place during the sampling period. For information, however, 20 rooms sampled were noted as designated smoking lounges. There were 254 nosmoking-observed and 331 smoking-observed data sets, giving a total of 585 data sets.

Figures 1 through 4 show frequency distributions for four parameters, divided into smoking-observed and nosmoking-observed groups. These frequency distributions illustrate the basic features of the raw data.

Table 2 displays the mean and standard deviation of, among others, the following variables: (1) RSP, (2) nicotine, (3) CO_2, (4) CO, and (5) room size. These statistics are shown for the overall data set, and are also categorized by room type (observed smoking activity), smoking or nonsmoking.

To explore in more detail the relationships between some of these factors, correlation coefficients were calculated between various parameters. Strong correlation exists between the following variables: RSP and smoking density ($r = 0.5180$, $p < 0.01$); nicotine and smoking density ($r = 0.7007$, $p < 0.01$); RSP and nicotine ($r = 0.7345$, $p < 0.01$).

Poorer correlations are calculated between the following variables: carbon monoxide and smoking density ($r = 0.1792$, $p < 0.01$); carbon dioxide and RSP ($r = 0.1763$, $p < 0.01$); carbon dioxide and nicotine ($r = 0.0841$, $p < 0.05$). It should be noted that the small p-values imply a nonzero correlation which does not mean a strong correlation. Correlations less than 0.2 should be viewed as relatively weak.

Table 1. Numbers of office types sampled.

General Commercial Office Areas	340
Banking Offices	152
Cafeterias	62
Newspaper Offices	14
Institutional (church, hospital, correctional or educational)	17
Total	585

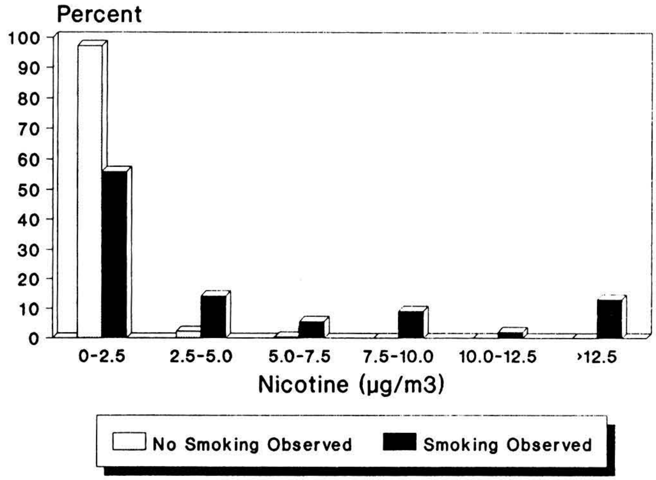


Fig. 1. Frequency distribution for nicotine measured in 585 office buildings with and without observed smoking.

Discriminant analysis

As indicated above, t-test results suggest that there is a significant difference between smoking and non-smoking rooms when considering the variables RSP ($p < 0.01$), Nicotine ($p < 0.01$), and CO ($p < 0.05$). However, there is serious overlap between the frequency distributions of smoking rooms and non-smoking rooms, particularly on the variables CO and RSP.

All factors in Table 2 were entered into the discriminant analysis (except number of cigarettes smoked). Smoker density was not entered into the

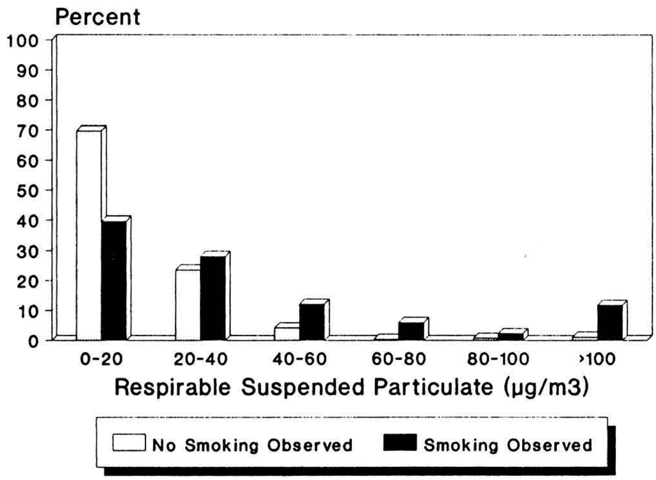


Fig. 2. Frequency distribution for respirable suspended particles measured in 585 office buildings with and without observed smoking.

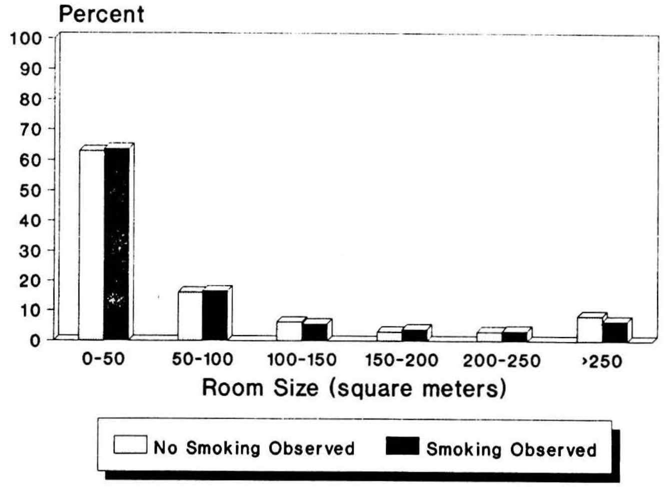


Fig. 3. Frequency distribution for room sizes of 585 office environments with and without observed smoking.

analysis since it is directly related to room type definitions— smoker density equal to zero is defined as a nonsmoking room and smoker density not equal to zero is defined as a smoking room. The discriminant analysis was significant and the variables RSP and nicotine were the only variables entered into the model. The discriminant analysis did not enter the variables CO and CO_2, nor the variables relating to room size and occupant density. All of these unentered variables do not improve the ability of the discriminant function to classify the rooms as smoking or nonsmoking.

Table 4 displays the ability of the selected model to predict room type properly. The selected model

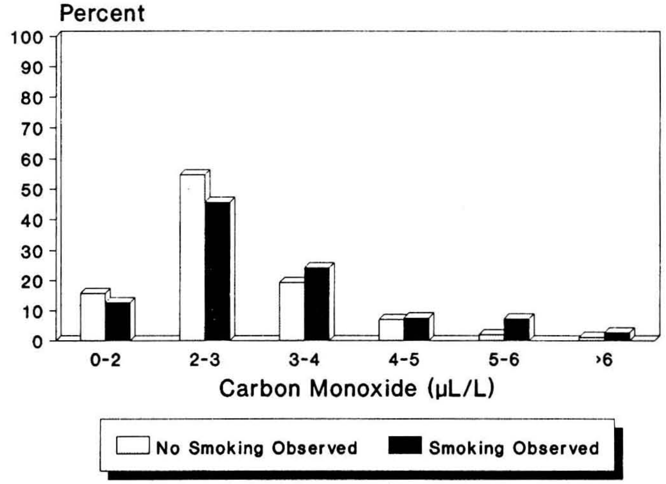


Fig. 4. Frequency distribution for carbon monoxide measured in 585 office environments with and without observed smoking.

Table 2. The mean (Standard Deviation) of variables grouped by observed smoking activity.

Observed Smoking Activity	RSP* (μg/m³)	Nicotine* (μg/m³)	CO_2** (μL/L)	CO* (μL/L)	Room Size** (m²)	# of People	# of Cigarettes Smoked
Non-Smoking	20 (17.6)	0.2 (0.8)	591 (159)	3.1 (0.90)	107 (231)	7.9 (15.7)	0.0 0.0
Smoking	46 (56.9)	6.7 (14.8)	595 (167)	3.4 (1.12)	83 (134)	7.9 (12.6)	5.9 (12.8)
Totals	35 (44.4)	3.8 (11.2)	593 (163)	3.29 (1.03)	93 (182)	7.9 (14.0)	---- ----

* Statistically significant difference between nonsmoking and smoking group.
** No statistically significant difference between nonsmoking and smoking group.

was able to classify properly 96.1% of the nonsmoking rooms as nonsmoking. However, only 41.4% of the smoking rooms were classified as smoking; 58.6% of the smoking rooms were classified as nonsmoking. Overall, 65.1 of the cases were properly classified.

Table 5 displays the mean and standard deviation of selected variables in the ETS data set. These variables are grouped according to observed status, either smoking or nonsmoking, and status provided by discriminant analysis. One possible combination, ob-

Table 3. Classification functions which determine model group membership, derived from discriminant analysis of the sample data.

Group	Constant	RSP	Nicotine
Nonsmoke	-0.8916	0.0202	-0.0557
Smoke	-1.2628	0.0284	-0.0269

Table 4. Classification of observations into smoking and nonsmoking groups by the discriminant analysis model based on sample results (the percentage of correct classifications is also shown).

Observed Status	Percent Correct	Model Status	
		Non Smoke number of sets	Smoke number of sets
Nonsmoke	96.1	244	10
Smoke	41.4	194	137
Total	65.1	438	147

Table 5. The mean (Standard Deviation) of selected variables shown for groups defined by their status as observed in the field during sampling and the discriminant analysis model based on sample results.

Observed Status	Model Status	RSP* $\mu g/m^3$	Nicotine** $\mu g/m^3$	CO_2* ($\mu L/L$)	CO* ($\mu L/L$)	Smoking Density** $cig/m^2.hr$
Nonsmoke	Nonsmoke	17.18 (9.5)	0.1 (0.6)	584 (153)	3.1 (0.8)	0.0 (0.0)
Smoke	Nonsmoke	19 (9.2)	0.9 (1.9)	566 (170)	3.3 (1.0)	0.075 (0.075)
Smoke	Smoke	85 (71.8)	14.8 (20.4)	636 (154)	3.6 (1.3)	0.30 (0.35)

*No statistically significant difference between Nonsmoke/Nonsmoke and Smoke/Nonsmoke. All other differences are statistically significant.
**Statistically significant differences between all groups.

served-status nonsmoking/model-status smoking, is not included since this combination only contains ten observations. The data show that for groups defined by observed-status nonsmoking/model-status nonsmoking and observed-status smoking/model-status nonsmoking, there is no statistically significant difference between group means for the variables CO, CO_2, and RSP. The group smoking-observed status/smoking-model status is significantly different when considering nicotine and smoker density. This difference is slight for the groups nonsmoking-observed status/nonsmoking-model status and smoking-observed status/nonsmoking-model status.

DISCUSSION

Discriminant analysis

The most significant results from the discriminant analysis are the following:

(1) RSP and nicotine contribute to the prediction of room type—smoking or nonsmoking.

(2) most (96.1%) nonsmoking rooms are classified as nonsmoking rooms, demonstrating very little evidence of ETS spillover from smoking areas, and

(3) a significant number (58.6%) of total smoking rooms are classified as nonsmoking rooms.

Table 5 suggests that smoking rooms can be separated as "light" or "heavy". The light-smoking rooms appear equivalent to nonsmoking rooms when considering, in a multivariate context, the important factors of RSP and nicotine. The heavy-smoking rooms do have elevated levels of nicotine and RSP. This indicates that there may be a rough working range of smoker density in which smoking activity does not seem to influence ETS levels significantly, as measured by RSP and nicotine.

This analysis goes part-way towards identifying what this range might be in that the mean of the light smoking range is 0.075 $cig/m^2 \cdot h$ and the median figure is 0.048 $cig/m^2 \cdot h$. There is considerable overlap, however, between the two types of smoking groups in Table 5. The median of the heavy-smoking rooms is 0.143 $cig/m^2 \cdot h$ with 20% of the heavy-smoking rooms below the median of the light-smoking rooms, and 13.4% of the light-smoking rooms above the median of the heavy-smoking rooms. This suggests that other variables which were not fully characterized in this work, such as outside air ventilation and/or air change rates, need to be considered in more detail when determining the impact of smoking in the room environment. One can see, however, that a realistic smoking density in properly ventilated rooms might be somewhere between 0.05 and 0.1 $cig/m^2 \cdot h$, or between 5 and 10 cigarettes per hour in a 100 m^2 room.

Other pertinent data

These 585 data sets reveal some other interesting information. If one examines the absolute levels of items of particular concern, such as nicotine, RSP and carbon monoxide, they show relatively conservative values. For instance, most of the RSP data in smoking-observed areas show levels well under that reported in Repace and Lowrey's early papers (1980, 1982); in general, about four times less than their mathematical model predicted for office environments of 200 $\mu g/m^3$ (Repace and Lowrey, 1987). In this model, they assumed an occupancy of 7.53 persons/100 m^2, one third of them smoking at an average rate of 2 cig/h (5.02 cig/100 $m^2 \cdot h$). In this study, in observed-smoking areas, mean RSP levels of 46.37 $\mu g/m^3$ were measured with a mean occupancy of 9.57 persons per 100 m^2, and an average observed-smoking rate of 7.14 cig/100 $m^2 \cdot h$. In fact, only eight data sets showed RSP values above this model value of 200 $\mu g/m^3$.

Our measurements of RSP and nicotine also tend to match levels reported in other recent work by Meisner et al. (1989) and Eatough et al. (1989a). Ogden et al. (1990) found ETS contributes approximately 50% to RSP which mirrors almost exactly our findings in that mean RSP levels in nosmoking-observed areas were approximately half those in smoking-observed areas.

There are statistically significant differences between smoking-observed and nonsmoking-observed areas for RSP, nicotine, and CO. While not statistically significant ($p \geq 0.10$), our data set contained smoking observed rooms with smaller sizes than nonsmoking rooms, suggesting that smokers in modern office environments may be confined to smaller rooms than nonsmokers. This possibility might justify further work, perhaps examining smokers/nonsmokers room sizes, separate from designated smoking lounges.

A clear relationship was observed between RSP and nicotine, which is not surprising in light of other studies. These studies were summarized by Eatough et al. (1989b), and show that nicotine/RSP ratios vary depending on overall ETS levels and tend towards that found in pure sidestream smoke at the highest levels of measured nicotine and RSP.

Although it is possible to identify two different groups (smoking and nonsmoking) by examining the carbon monoxide results, the distinction is not clear enough to characterize the relationship between smoking density and carbon monoxide concentrations. For instance, it was not possible to extrapolate properly the data to identify what smoking density might be associated with CO concentrations higher than the EPA ambient 24 h maximum of 9 $\mu L/L$, although it would appear to require a smoker density much greater than typical in a "discretionary smoking" office environment.

This shows that carbon monoxide is a poor indicator for ETS levels found in typical conditions. This is in contrast to Cain and Leaderer's work (1982) in experimental chambers which showed wide variations in carbon monoxide concentrations under different smoking conditions. Lower, more typical smoking rates, and larger spaces allowing for faster diffusion of CO may explain why this gas is not as good a predictor in normal offices as it is in experimental chambers.

Improved resolution for carbon monoxide (measured to +/-1 $\mu L/L$ in this study), and a lower detection limit for nicotine (set at 1.6 $\mu g/m^3$ for this study), and RSP (set at 10.0 $\mu g/m^3$) may be thought to allow for different conclusions to be drawn from the statistical analysis. However, a sensitivity analysis was performed with the discriminant analysis by setting different values for nicotine and RSP at the detection limits. For example, on a subsequent evaluation of the data with discriminant analysis, all nicotine and RSP values below the detection limit were set to zero. This produced little or no difference in the results obtained from the discriminant analysis. This strongly suggests that improved detection techniques would not change the results drawn from this study, including those conclusions concerning spillover from smoking areas.

Carbon dioxide is frequently used as an indicator of ventilation rates, and furthermore, since carbon dioxide levels are related to the number of occupants and the size of the space they occupy, these factors were also included in an attempt to establish a general ventilation status for each data set. No relationship was subsequently observed, however, between components of ETS and these factors as measured during these surveys. This does not mean that there is no relationship between total outdoor air intake for the building and overall ETS levels. But it means that local measurement of CO_2 needs to be interpreted carefully if it is to be used as an indicator of ventilation, and that it may show considerable spatial variations in a building, depending on local floor and air handling zone characteristics. This study did not examine in detail local room aspects of ventilation such as air change rates or airflow through local diffusers which may correlate much more strongly with local ETS levels. Alternatively, average levels of ETS throughout a building may also correlate with total outdoor air intake.

CONCLUSIONS

These 585 measurements of some components of ETS and other related parameters sampled during 1989 suggest overall concentrations of ETS in typical office workspaces to be considerably lower than estimated ten years previously. Some parameters, such as carbon monoxide, appear to be only weakly related to smoking activity. Discriminant analysis shows that when "blindfolded" for presence or absence of smokers, in most cases realistic smoking levels do not significantly influence the aspects of air quality that were measured, and spillover from smoking areas into nonsmoking areas appears to be minimal. This work further reinforces the position the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) has taken on ETS in office buildings in ASHRAE Standard 62-89 (1989), in that acceptable air quality can be maintained in properly ventilated offices with a moderate amount of smoking, even without smoker segregation. These data help to further define the limits of moderate smoking.

Further work to achieve this goal should address room air exchange and ventilation rates, and their relation to ETS. This might best be achieved with the use of tracer gas instrumentation. This ventilation data when combined with ETS component measurements will give us a better understanding of the relationships between smoking and ventilation in modern offices. Other influencing factors may also include furnishing types and room size, which could be studied in more detail.

Acknowledgment — Funding for this work was made available in part by the Center for Indoor Air Research, Linthicum, MD.

REFERENCES

ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers). Ventilation for acceptable indoor air quality. ASHRAE Standard 62-89, Atlanta, GA; 1989.

Cain, W.S.; Leaderer, B.P. Ventilation requirements in occupied spaces during smoking and non-smoking occupancy. Environ. Int. 8:505-514; 1982.

Collishaw, N.E.; Kirkbride, J.; Wigle, D.T. Tobacco smoke in the workplace: an occupational health hazard. Can. Med. Assoc. J. 131:1199-1204; 1984.

Eatough, D.J.; et al. The chemical composition of environmental tobacco smoke III, identification of conservative tracers of environmental tobacco smoke. Environ. Int. 15:19-28; 1989a.

Eatough, D.J.; Hansen, L.D.; Lewis, E.A. The chemical characterization of environmental tobacco smoke. In: Ecobichon, D.J.; Wu, J.M; eds. Proc. International Symposium on Environmental Tobacco Smoke. McGill University, Montreal: Toronto, Ontario: Lexington Books, D.C. Heath & Co.; 1989b:3-39.

Karson, M.J. Multivariate statistical methods. Ames, IA: Iowa State University Press; 1982.

Meisner, E.A.; et al. Particulate and nicotine sampling in public facilities and offices. J. Air Pollut. Control Assoc. 39:1577-1582; 1989.

Ogden M.W.; Maiolo, K.C.; Oldaker, G.B.; Conrad, F.W. The evaluation of methods for estimating the contribution of ETS to respirable suspended particles. In: Proc. Fifth International Conference on Indoor Air Quality and Climate, Toronto. Ottawa, Ontario: Int. Conf. Indoor Air Quality & Climate, Inc. 1990:(2)415-420.

Oldaker, G.B.; Perfetti, P.F.; Conrad, F.C.; Conner, J.M.; McBride, R.L. Results of surveys of environmental tobacco smoke in offices and restaurants. In: Kasuga, H. ed. Indoor Air Quality; International Archives of Occupational and Environmental Health Supplement. Tokyo: Springer-Verlag; 1990:99-104.

Repace, J.L.; Lowrey, A.H. Indoor air pollution, tobacco smoke, and public health. Science 208:464-472; 1980.

Repace, J.L.; Lowrey, A.H. Tobacco smoke, ventilation, and indoor air quality. ASHRAE Transactions 88 (part 1):895-914; Dallas, TX; 1982.

Repace, J.L.; Lowrey, A.H. A quantitative estimate of nonsmokers lung cancer risk from passive smoking. Environ. Int.; 11; 3-22; 1985a.

Repace, J.L.; Lowrey, A.H. An indoor air quality standard for ambient tobacco smoke based on carcinogenic risk. New York State J. Med. 85:381-383; 1985b.

Repace, J.L.; Lowrey, A.H. Environmental tobacco smoke and indoor air quality in modern office work environments. Editorial; J. Occup. Med. 29:628-629; 1987.

Samet, J.M. Involuntary exposure to tobacco smoke. Ann. Sports Med. 4:1-15; 1988.

Sterling, T.D.; Dimich, H.; Kobayashi, D. Indoor byproduct levels of tobacco smoke: a critical review of the literature. J. Air Pollut. Control Assoc. 32:250-259; 1982.

Sterling, T.D.; Collett, C.W.; Sterling E.M. Environmental tobacco smoke and indoor air quality in modern office work environments. J. Occup. Med. 29:57-62; 1987.

USEPA (United States Environmental Protection Agency). Environmental tobacco smoke: a guide to workplace smoking policies. Public Review Draft # EPA/400/6-90/004. Washington, DC: Indoor Air Div., Office of Air and Radiation; 1990.

USEPA (United States Environmental Protection Agency). Determination of nicotine in indoor air. Compendium of methods for the determination of air pollutants in indoor air; Method 1P-2A. Atmospheric Research and Exposure Assessment Laboratory, Research Triangle Park, NC; 1989.

Wells, A.J. Passive smoking mortality—a review and preliminary assessment. In: Proc. 79th Annual Meeting Air Pollution Control Association, Minneapolis, MN, June 22-27; 1986. Pittsburgh, PA: AWMA (Air & Waste Management Association); 1986.

Wells, A.J. Deadly smoke. Occup. Health Safety (September):20; 1989.

Environment International, Vol. 18, pp. 29 - 41, 1992
Printed in the U.S.A.

0160-4120/92 $5.00 +.00

THE EFFECTS OF ALTERNATIVE POLICY OPTIONS DESIGNED TO REDUCE NITROGEN FERTILIZER USE

Michael Duffy
Department of Agricultural Economics, Iowa State University, Ames, IA 50011 USA

Wen-Yuan Huang and Noel D. Uri*
Economic Research Service, U.S. Department of Agriculture, Washington, DC 20005 USA

EI 9010-200M (Received 19 October 1990; accepted 13 July 1991)

The costs associated with using different crop rotation patterns designed to reduce the use of nitrogen fertilizer under alternative agricultural policy options are measured. The policy options considered include those incorporated in the Food Security Act of 1985, a No Farm Program option, a Nitrogen Fertilizer Tax option, a Corn Sales Tax option, and a Limiting Nitrogen Fertilizer Use option. To achieve an objective of reducing the nitrogen available for potential leaching into ground water, crop rotation patterns associated with limiting nitrogen fertilizer use appears to have the lowest cost to the farmer while a corn sales tax has the highest cost. The costs are computed based on data from the Iowa State University experiment farm at Kanawha, Iowa.

INTRODUCTION

Nitrogen is an essential plant nutrient required to produce food and fiber. While the increased use of nitrogen fertilizer has contributed to increased food and fiber production in the United States in recent years, it has also been identified as a major contributor to the elevated concentration levels of nitrates in ground water in some regions of the country (Freshwater Foundation 1988; Office of Technology Assessment 1984; Nielsen and Lee 1987; USEPA 1984).

High concentration levels of nitrates in drinking water supplied from ground water have become a public concern because of their real and suspected risks to human health. The presence of nitrates in drinking water can cause potentially fatal infant methemoglobinemia (blue baby syndrome). Nitrates are also linked to nitrosamine, a potent carcinogen affecting a wide range of organs in many animal species (Cantor 1988).

Although nitrates in ground water come from various sources, the application of nitrogen fertilizer by the agricultural sector has been identified as the major contributor to the presence of nitrates in ground water in some states (Office of Technology Assessment 1984). This conclusion is supported by documented incidents of contamination by nitrogen

* The views expressed are those of the authors and do not necessarily represent the policies of the organizations with which they are affiliated.

fertilizer used by farmers in Pennsylvania, Florida, Wisconsin, California, New York, Iowa, and several other states (Nielsen and Lee 1987).

Targeting vulnerable areas to reduce nitrate leaching associated with nitrogen fertilizer use into the ground water is a plausible national environmental policy. The targeting approach recognizes the differences in the vulnerability of various types of soils to leaching and, correspondingly, prescribes different policies to minimize (or at least mitigate) nitrate leaching. Additionally, the targeting approach is an effective tool if the objective is to minimize the social cost of the program (Tietenberg 1978; Baumol and Oates 1988).

In order to reduce the use of nitrogen fertilizer on targeted cropland, a variety of methods is available. One approach is to adopt a fertilizer-reducing farming practice, such as a crop rotation in which a legume crop (e.g., soybeans) is rotated with a non-legume crop (e.g., corn). The legume crop is used to provide fixed-nitrogen as a substitute for fertilizer-nitrogen. Adoption of this sort of crop rotation can reduce the residual nitrogen in the soil through a reduction in the frequency and amount of nitrogen fertilizer applied on a field and through the more efficient use of the nitrogen fertilizer applied because of more conducive soil conditions in which to grow a crop. The benefits and costs associated with this approach are the focus of this paper.

Adopting a specific crop rotation scheme alone, however, may not reduce nitrogen fertilizer use to an optimal level. Additional controls may be needed. These include fiscal, regulatory, and liability constraints (Baumol and Oates 1988). Fiscal controls involve the imposition of an input (i.e., nitrogen fertilizer) tax, an output (e.g., corn sales) tax, the use of marketable emission (e.g., nitrate leaching) permits, or a producer subsidy to reduce nitrogen fertilizer use. The regulatory method directly limits a farmer's nitrogen fertilizer application rate in order to meet the established standard for ground water contamination. The liability approach makes a farmer responsible for any ground water contamination and thus, potentially makes a farmer reduce his or her use of nitrogen fertilizer to avoid any damage assessment.

Different policy alternatives or a combination of alternatives designed to reduce nitrate leaching into the ground water will have different adoption costs. Policy makers should at least be aware of these differentials as they strive to choose an option that reduces the nitrogen fertilizer application rate to the desired level while imposing the lowest compliance cost on a farmer.

This paper uses as the basis of its analysis the farm-level cost of adopting alternative farming practices aimed at reducing the application of nitrogen fertilizer. The analysis focuses on crop rotations for corn production because corn uses large amounts of nitrogen fertilizer and because the continuous growing of corn is a common farming practice.

In what follows, the concept of excess nitrogen will be discussed. Next, alternative policy options designed to reduce the application rate of nitrogen fertilizer which leads to the presence of excess nitrogen available for potential leaching into the ground water will be delineated and their cost to a farmer indicated. Finally, an Iowa case study will be used to estimate the relative costs to a farmer to reduce the excess nitrogen fertilizer application rate under each policy alternative.

THE DEFINITION OF EXCESS NITROGEN

To determine the amount of excess nitrogen available for potential leaching into the ground water under a farming practice (i.e., a crop rotation pattern), the nitrogen mass balance method is employed using the nitrogen cycle (Gilliam and Hoyt 1987). The amount of excess nitrogen, N_e, available for potential leaching associated with farming activities is defined as the difference between the amount of nitrogen applied from all sources on one hectare of cropland and the amount of nitrogen present in both plants and crops harvested and removed, N_{plt}, at the end of the growing season. The amount of nitrogen applied includes that from nitrogen fertilizer, N_f, nitrogen credited from previous legume crops, N_{leg}, and nitrogen from manure application, N_{man}. (Note that if no animal manure is applied on the field, the term N_{man} is set equal to zero.) The excess nitrogen available for potential leaching is thus computed as

$$N_e = N_f + N_{leg} + N_{man} - N_{plt} \quad (1)$$

Note that this definition is concerned with the excess nitrogen caused only by human farming activities since an accurate estimate of the excess nitrogen available for leaching from all sources is virtually impossible to obtain. The problem is associated with the difficulties in distinguishing between leaching and denitrification and with delineating between nitrogen losses and changes in the organic nitrogen level in the soil (Blackmer 1987). Equation (1) assumes that, for a given hectare, the amount of nitrogen available for plant uptake from atmospheric nitrogen absorbed by the soil and nitrogen from the organic matter in the soil are negligible after subtracting nitrogen losses attributable to other factors. These other factors include nitrogen losses due to denitrification, volatilization, water run-off, and soil erosion. It also assumes that the excess nitrogen leaves the field at the end of each growing season. Finally, it assumes a long-run steady-state of nitrogen residue level in the soil. Any of the assumptions above can be removed and a different estimate of the excess nitrogen can be calculated. For instance, for a particular cropland site encountering significant soil erosion, the nitrogen loss due to soil erosion can be estimated and subtracted from the right-hand-side of Equation (1). Thus, the results are conditional upon the assumptions made and they will obviously vary based on how the issues of denitrification, volitization, and so forth are incorporated into the analysis. For this reason, the notion of a global optimal level of nitrogen fertilizer use is elusive. Consequently, a local optimum (i.e., an optimum based on the set of explicit assumptions that are made) will be computed.

Figure 1 illustrates the estimation of the excess nitrogen available for potential leaching. The yield function in the figure describes corn yield as a function of the amount of nitrogen fertilizer applied under the continuous planting of corn (i.e., planting corn year after year on the same field). (Note that this yield function is based on field experiment data. These data are discussed below.) The intercept of the function reflects the inherent productivity of the soil. The per hectare amount of the excess nitrogen is the amount of nitrogen applied in excess of N_z where N_z is the application rate of nitrogen fertilizer that will minimize the presence of excess nitrogen in the soil. For example, if a farmer applies the amount N_o of nitrogen fertilizer per hectare to maximize his or her net farm income (an economic optimum), the excess nitrogen, N_e, will be a function of the difference between N_o and N_z. (Note that the economically optimal nitrogen fertilizer application rate is determined

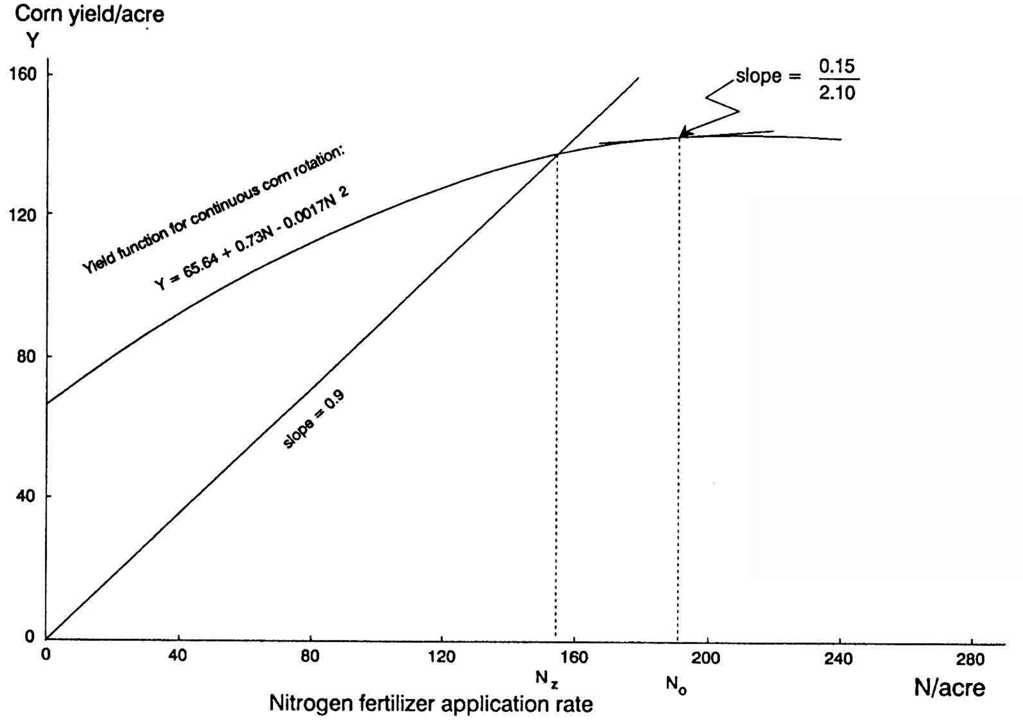


Fig. 1.Optimal fertilizer application rate for maximizing net farm income, N_o, and the optimal fertilizer application rate for minimizing excessive nitrogen, N_z.

by solving the relationship that equates the change in the yield resulting from one additional kilogram of nitrogen fertilizer to the ratio of the nitrogen fertilizer price and the corn price.) The amount of nitrogen removed is a product of the internal nitrogen required by the crop being grown and the per hectare quantity of the crop produced. For the present study, it is assumed that the internal nitrogen requirement is 0.01 kg of nitrogen per liter of corn harvested (Fertilizer Institute 1976). This number obviously is an approximation and it may vary with the planting season, the soil type, and the soil fertility. Note that there is considerable controversy associated with the magnitude of the internal nitrogen requirement for corn. The interested reader is referred to the Conservation Foundation (1987), the Fertilizer Institute (1976), the Office of Technology Assessment (1984), and White (1989) for a discussion of the relevant issues.

Next, because the corn yield response to nitrogen fertilizer is a function of many factors including soil type, soil fertility, temperature and precipitation, responses under actual farming conditions are likely to be different than those indicated here. Therefore, in determining the excess nitrogen available for potential leaching for a particular parcel of cropland, it would be necessary to estimate the response based on site-specific historical information.

As defined, the concept of excess nitrogen has considerable practical appeal. Using the indicated definition, a farmer is able to estimate the amount of nitrogen added and the amount of nitrogen removed from a field to calculate the nitrogen residual in the soil. A farmer using this relationship can apply the optimal amount of nitrogen fertilizer to minimize the excess application of nitrogen. A farmer can also use it to approximate the amount of nitrogen available for potential leaching in areas where soil conditions favor water infiltration. In these areas, reducing the excess nitrogen that is available for potential leaching is tantamount to reducing excess nitrogen leaching into the ground water.

POLICY OPTIONS TO REDUCE NITROGEN FERTILIZER USE

As noted above, rotating crops is one way a farmer can reduce his or her application of nitrogen fertilizer. Various crop rotations will be evaluated to provide information on the relative cost of adopting alternative farming practices designed to reduce the nitrogen fertilizer application rate. The cost to a farmer of the rotations considered will vary from one farm policy alternative to another. The farm-level performance of various crop rotations under five different farm policy alternatives is considered. The alternatives are enumerated below.

Food Security Act of 1985 Program

Under this program, cropland which employs a crop rotation pattern to reduce the nitrogen fertilizer application rate is currently (or is eligible to be) in the existing farm program (as detailed in Glaser 1986). This option is used as the basis for comparison of the different crop rotation patterns and policy options considered.

As a caveat, the most current manifestation of the farm program is contained in the Food, Agriculture, Conservation and Trade Act of 1990. The aspects of the farm program applicable to crop rotation and, hence, nitrogen fertilizer use considerations remain little changed from the 1985 legislation. The main difference pertains to crop base acreage which is now divided into three categories (instead of the two found in the Food Security Act of 1985). The categories include the cropland included in the Acreage Reduction Program, the permitted acreage on which program crops are planted and deficiency payments may be paid, and flexible acreage. (The first two categories are contained in the Food Security Act of 1985.) Producers can plant up to 25% of crop base acreage to any commodity, except fruits and vegetables on the flexible acreage component. If an alternative crop is planted on this acreage, it will be eligible for nonrecourse loans and marketing loans but not deficiency payments. Given this latter condition, it is not yet clear whether farmers will take advantage of the flexible acreage provision.

No Farm Program option

The cropland which needs to use a crop rotation pattern to reduce the nitrogen fertilizer application rate is not (or cannot be) in the Food Security Act of 1985 Program when this option is in effect. This alternative is also applied to situations in which a farmer does not (or is not eligible to) participate in the Food Security Act of 1985 Program. The purpose in considering this option is to investigate the nitrogen application rate and cost to a farmer of foregoing government program benefits if he or she chooses not to participate in the Food Security Act of 1985 Program.

Fertilizer Tax option

The objective of this alternative is to use a tax on nitrogen fertilizer to reduce the nitrogen fertilizer application rate so that zero excess nitrogen is available for potential leaching into the ground water. That is, the objective is to force N_e to equal zero.

With this alternative, the cropland on which different crop rotations are practiced is allowed to be in the Food Security Act of 1985 Program. A fertilizer tax, however, is imposed to discourage a farmer from generating excess nitrogen for potential leaching into the ground water. A nitrogen fertilizer tax that achieves a zero level excess nitrogen available for potential leaching is determined (see below) and imposed for each crop rotation.

Corn Sales Tax option

The objective of this policy alternative is to employ a corn sales tax to reduce the nitrogen fertilizer application rate to minimize excess nitrogen available for potential leaching. For this alternative, the cropland on which alternative rotations are used is allowed to be in the Food Security Act of 1985 Program. An ad valorem (per liter sales) tax is imposed on the corn produced. An optimal corn sales tax is determined (see below) and imposed for each crop rotation.

Limiting Nitrogen Fertilizer Use option

This alternative endeavors to control the nitrogen fertilizer application rate to minimize excess nitrogen. In doing so, the cropland on which a crop rotation is used is allowed to be in the Food Security Act of 1985 program. The amount of nitrogen applied to that cropland, however, cannot exceed the amount of nitrogen in the corn harvested and the stalks removed from the field (if the farmer elects to do this).

DETERMINATION OF NITROGEN FERTILIZER APPLICATION RATES

Different policy options can have different impacts on a farmer's decision with regard to the application rate of nitrogen fertilizer. If it is assumed that a farmer growing corn endeavors to maximize revenue over the cost of production, then he or she will increase the amount of nitrogen applied up to the point where the additional revenue generated due to the additional crop yield just equals the added cost of the nitrogen fertilizer. These values for a farmer operating the various policy alternatives are given in Table 1. What one garners from this table is that any tax or restriction on nitrogen fertilizer use will directly affect the rate at which nitrogen fertilizer is applied. For example, under the Food Security Act of 1985 Program, a farmer would apply fertilizer up to the point where the increase in revenue due to a higher yield associated with the application of nitrogen fertilizer equals the nitrogen fertilizer price. Additionally, the absence of any farm program variables such as the target price, the program yield, and/or the

Table 1. Optimal application rate of nitrogen fertilizer.

Policy Option		Value of the Marginal Product of Nitrogen Fertilizer	Marginal Cost of Nitrogen Fertilizer
(a)	Farm Program	$P\ (\partial Y/\partial N)$	r
(b)	No Farm Program	$P\ (\partial Y/\partial N)$	r
(c)	Nitrogen Fertilizer Tax	$P\ (\partial Y/\partial N)$	$r + t$
(d)	Corn Sales Tax	$(P - s)\ (\partial Y/\partial N)$	r
(e)	Limiting Fertilizer Use	$(P - (k(h)))\ (\partial Y/\partial N)$	$r + h$

$Y(N)$ is the corn field function whereby yield is a function of the nitrogen fertilizer application rate;
P is the market price of corn;
$\delta Y/\delta N$ is the marginal product of corn with respect to nitrogen fertilizer price;
t is the ad valorem nitrogen fertilizer tax;
s is the ad valorem corn sales tax;
k is the amount of nitrogen in corn grains;
h is the shadow price associated with the constraint requiring that the amount of nitrogen fertilizer applied must be exactly equal to the amount of nitrogen removed from the field.

percentage of base acreage set-aside from the expressions indicates that these factors will not affect a farmer's decision with regard to the rate at which to apply nitrogen fertilizer. Participation in the Food Security Act of 1985 Program involves a lump-sum payment to a farmer participating in the program regardless of his or her nitrogen fertilizer application rate. If a farmer anticipating that the future program yield will be based on his or her historical yield, however, a higher target price for corn may encourage him or her to increase the fertilizer application rate in order to increase the program yield which would, in turn, lead to an increase in future payments.

Since it is assumed that there is no change in either the agricultural commodity market prices or the nitrogen fertilizer price under both the Food Security Act of 1985 Program and the No Farm Program option, the nitrogen fertilizer application rate under the No Farm Program option will be the same as under the Food Security Act of 1985 Program. It is assumed that only a relatively few number of hectares will be included in any crop rotation program. Consequently, any resulting change in corn production (either an increase or a decrease output) would have minimal, if any, effect on either corn and nitrogen fertilizer prices. Under the No Farm Program option, an increase in the amount of nitrogen applied would be expected if a farmer plants more hectares since he or she is not subject to the acreage reduction requirement existing under the Food Security Act of 1985 Program.

For the Nitrogen Fertilizer Tax option, an ad valorem tax is added to the nitrogen fertilizer price. The de facto result is an increase in the fertilizer cost which will lead to a reduction in the nitrogen fertilizer application rate if the quantity of fertilizer applied in response to a change in the price of fertilizer is different than zero. This appears to be the case. Uri and Konyar (1990) explore this issue in greater detail. A farmer would reduce the application rate to the level, N^*, where the added revenue due to an increase in the use of nitrogen fertilizer, P (,Y/,N), equals the cost of fertilizer plus the tax, r + t. A tax rate that achieves zero excess nitrogen available for potential leaching, as defined above, can be found by varying the tax rate.

For the Corn Sales Tax option, imposing a tax on output should result in a reduction in the nitrogen fertilizer application rate. A farmer would reduce his or her application rate to the point where the value of the added revenue due to an increase in the use of nitrogen fertilizer ((P-s) (,Y/,N)), which is now adjusted for the ad valorem sales tax, equals the cost of the fertilizer, r. The optimal tax rate, the one that reduces the excess nitrogen available for potential leaching into the ground water to zero, can be found by varying the tax rate.

In order to determine the optimal nitrogen fertilizer application rate under the Limiting Nitrogen Fertilizer Use option, it is necessary to know the amount of nitrogen in corn grains and plants and to determine the shadow price associated with the constraint requiring that the amount of nitrogen fertilizer applied be exactly equal to the amount of nitrogen removed from the field. A mathematical programming model (see below) can be used to determine this latter value. For this, the optimal nitrogen fertilizer application rate is determined based on equating an adjusted value of the marginal product to the cost of nitrogen fertilizer plus the shadow price associated with the nitrogen fertilizer application rate constraint.

A COMPARISON OF COMPLIANCE COSTS

A farmer participating in the deficiency payments program might incur a reduction in net farm income if he or she must reduce the fertilizer application rate in order to reduce excess nitrogen. The magnitude of the loss in net farm income is referred to as the compliance cost. A farmer has an incentive to comply and stay in the Food Security Act of 1985 Program if the benefits of participating in the farm program (in the form of deficiency payments) exceed the cost of reducing excess nitrogen. In this section, the relative costs of the various policy options are indicated. Corn production for the continuous planting of corn is used for the illustration. The conclusions, however, can be extended to various crop rotations.

The per hectare net farm income under the Food Security Act of 1985 Program can be expressed as

$$NI_p = P\ (Y(N)) + DP - r\ N - C \qquad (2)$$

where Y/N is the corn yield function, N is the per hectare nitrogen fertilizer application rate, P is the market price of corn, DP is the deficiency payment, r is the per unit cost of nitrogen fertilizer, and C denotes the fixed costs excluding the nitrogen fertilizer cost.

The difference in net farm income between the limiting nitrogen fertilizer use and fertilizer tax, ND_{lf}, is

$$ND_{lf} = t\ N^* \qquad (3)$$

where N^* is the optimal nitrogen fertilizer application rate and t is the ad valorem nitrogen fertilizer tax. The value of ND_{if} is positive. That is, under the Fertilizer Tax option, a farmer would incur a larger reduction in net farm income than under the Limiting Nitrogen Fertilizer Use option. A farmer operating under the Fertilizer Tax option not only suffers a loss from a reduction in output (since yield will be less because less nitrogen fertilizer is applied) but also from the increased cost of nitrogen fertilizer while under the Limiting Nitrogen Fertilizer Use option, a farmer would realize a net farm income loss only from the output decline.

Next, a farmer would incur a larger compliance cost to reduce excess nitrogen under the Corn Sales Tax option than under the Fertilizer Tax option. Using the Equation (2), the difference in the net farm income between the fertilizer tax and the corn sales tax is

$$ND_{fs} = s\,(Y(N^*)) - t\,N^* \tag{4}$$

where s is the ad valorem corn sales tax.

Since optimal nitrogen fertilizer application rates, N^*, are the same for both alternatives, the following relationship exists:

$$(r + t)/P = r/(P - s) \tag{5}$$

Solving for t in Equation (5), recalling that N^* equals $k(Y(N^*))$ where k is the amount (in kilograms of active ingredient) of nitrogen contained in one liter of corn grains (Fig. 1), and making the appropriate substitutions into Equation (4), ND_{fs} can be expressed as

$$ND_{fs} = s\,(Y(N^*)\,(1 - k\,((r/(P - s)))). \tag{6}$$

The term $(r/(P - s))$ in Equation (6) is the slope of yield function evaluated at N^*. Since the expression $(k\,((r/(P - s)))$ is less than 1, ND_{fs} is positive. This means that a farmer would have a larger net farm income (thus, a lower compliance cost) under the Fertilizer Tax option than under the Corn Sales Tax option.

Given these foregoing considerations, is the difference in the compliance cost quantitatively significant among various policy options? Does the compliance cost associated with participating in the farm program exceed the benefits? These questions are empirical in nature and, thus, have to be answered by empirical analyses. To do so, an Iowa case study will be used to compare the compliance cost and the program benefits of various policy alternatives. It is assumed that a farmer will be in compliance if the farm program benefits under a specific option exceed the compliance cost. Because experimental data are used, however, any conclusions must be tempered by the realization that the results might not be applicable for all regions under different crop rotation schemes.

AN IOWA CASE STUDY

A farm-level crop rotation evaluation model is used to estimate the farm-level cost of departing from a continuous planting of corn associated with alternative programs to reduce nitrate leaching into the ground water. The model is discussed in Huang and Lantin (1990). In the model, it is assumed that a farmer is a profit-maximizer and that he or she has full knowledge of the fertilizer-yield relationships associated with various crop rotation patterns. The continuous planting of corn is the focus of attention because it is a common farming practice accounting for about 26% of the number of corn hectares planted (Daberkow and Gill 1989). The continuous planting of corn uses nitrogen fertilizer relatively inefficiently and could result in a large amount of excess nitrogen available for potential leaching into the ground water. This conclusion is tentative. The linkage is not yet firmly established.

The farm-level cost to be estimated and used in the analysis is defined as the loss in net farm income associated with adopting an alternative crop rotation instead of continuously planting corn. Thus, the cost of switching from the continuous planting of corn, j1, to an alternate rotation, j2, under a specific policy option, $ND_{j1,j2}$, is defined as

$$ND_{j1,j2} = NI_{j1} - NI_{j2} \tag{7}$$

where NI_{ji} denotes the net farm income associated with cropping pattern ji.

The cost effectiveness of adopting an different crop rotation pattern is the farm-level cost to reduce one unit of excess nitrogen available for potential leaching into the ground water.

The reduction in excess nitrogen by adopting rotation j2 over the continuous planting of corn (i.e., j1), $NR_{j1,j2}$, is

$$NR_{j1,j2} = N_{ej1} - N_{ej2} \tag{8}$$

where N_e is defined previously.

The adoption cost to a farmer to switch to rotation j2 from j1, $NL_{j1,j2}$, is the ratio of the reduction in net farm income and the reduction in the excess nitrogen available for potential leaching. That is,

$$NL_{j1,j2} = ND_{j1,j2} / NR_{j1,j2}. \quad (9)$$

The adoption cost will be used to evaluate the cost-effectiveness of adopting an alternative crop rotation to reduce excess nitrogen available for potential leaching. A crop rotation is considered to be efficient in reducing the excess nitrogen available for potential leaching if the associated value of NL is small relative to the value of NL for all of the rotations considered. A policy of promoting an efficient rotation in order to minimize the excess nitrogen available for potential leaching into the ground water can potentially lead to the least cost to the society of all alternatives available (Baumol and Oates (1988)).

DATA

Various data sources are used to facilitate the analysis. Cost of production and average yield data are from Duffy and Chase (1988). The cost data represent average production costs for farms in Iowa (Iowa State University 1989). The commodity price and the target price data are from the Economic Research Service (1990). The December 1989 nitrogen fertilizer price ($0.07/kg) is assumed to prevail. The yield data (relating yield and nitrogen fertilizer use) are obtained derived from the Iowa State University research farm study at Kanawha, Iowa (Iowa State Experiment Station 1989). These data are used to estimate the yield functions for the specific crop rotations used in the analysis. A complete listing of the estimates is available from the authors upon request. The alternative crop rotations considered are three-year rotations of corn and legumes. The reason for selecting as the basis of analysis rotations of less than 4 years is because the marginal gain of nitrogen fixed by a legume crop declines drastically as longer rotations are used (Huang and Lantin 1990). The crop rotations considered are soybeans-corn-corn (BCC), meadow-corn-corn (MCC), corn-soybeans-corn (CBC), soybeans-soybeans-corn (BBC), meadow-meadow-corn (MMC), and soybeans-corn-soybeans (BCB). These rotations are common in the Corn Belt region of the United States (Daberkow and Gill (1989)). The nitrogen application rate for corn production varies considerably from one rotation to the next. Net farm income under these different rotations also varies significantly. In each rotation, only corn production receives nitrogen fertilizer.

ANALYZING THE POLICY OPTIONS

The excess nitrogen fertilizer application rate and the adoption cost of each crop rotation under the five policy alternatives discussed previously are computed. Note that under the No Farm Program option, the assumptions concerning the target prices and acreage set-aside (under the Acreage Reduction Program (ARP)) are eliminated as is the fixed program yield. Under the Fertilizer Tax option, the tax has been determined to be about $0.17/kg above the nitrogen fertilizer price for corn rotations with soybeans while the tax is about $0.32/kg for the continuous planting of corn. As indicated previously, the tax is determined by increasing the tax rate to the level at which the excess nitrogen available for potential leaching into the ground water in each rotation approaches zero. Due to the way the tax is computed, if the policy option is adopted on a broad scale for different regions of the country, it should theoretically vary by site as well as by rotation since the corn yield functions vary. This might not be politically viable in which case representative (average) yield functions would have to be estimated and used in setting the tax rate. The tax is added to the fertilizer price in solving the model. Under the Corn Sales Tax option, a sales tax of $0.047/L for corn compared with a market price of $0.060/L is estimated for the continuous planting of corn, and a tax of $0.035/L is calculated for the corn-after-soybeans rotation. As in the case of the Fertilizer Tax option, the tax would vary by location and crop rotation if the Corn Sales Tax policy alternative were adopted. The tax is subtracted from the corn market price for each rotation. Since no excess nitrogen is observed for the MMC rotation under the Food Security Act of 1985 Program, there is no need to impose either a fertilizer or a corn sales tax for this particular rotation. Under the Limiting Nitrogen Fertilizer Use option, a constraint which imposes zero excess nitrogen available for potential leaching is added to the model. The constraint ensures that the amount of nitrogen applied for the production of corn is less than or equal to the nitrogen contained in the grain harvested and plants removed from the field.

Excess nitrogen application rates

Based on the yield functions estimated from field experiment data, it appears that the excess nitrogen fertilizer application rate—and coincidentally, the excess nitrogen available for potential leaching—will vary among crop rotations under the different policy options. The results in Table 2 show that under both the Food Security Act of 1985 Program and the

Table 2. Excessive nitrogen fertilizer application rate under alternative policy options.

Crop Rotation	Farm Program	No Farm Program	Nitrogen Fertilizer Tax	Corn Sales Tax	Limiting Fertilizer Use
	-- Pounds per Acre over Three Years --				
CCC	194	195	0	0	0
BCC	105	105	0	0	0
MCC	65	65	-30	-30	-30
CBC	82	82	0	0	0
BBC	41	41	0	0	0
MMC	-30	-30	-30	-30	-30
BCB	41	41	0	0	0

No Farm Program option, the CCC rotation has a relatively large excess nitrogen fertilizer application rate while the crop rotations in which corn is rotated with soybeans or meadow demonstrate a significant reduction in the excess nitrogen fertilizer application rate. (Meadow is an alfalfa hay crop. It is assumed to make no contribution to net farm income.)

Under the Fertilizer Tax option, the Corn Sales Tax option, and the Limiting Nitrogen Fertilizer Use option, the excess nitrogen fertilizer application rate is approximately equal to and, for two rotations is less than, zero. Note that a negative excess nitrogen fertilizer application rate implies that part of the nitrogen in the harvested grain is that fixed by meadow (alfalfa).

Table 3. Cost to a farmer to switch from continuously growing corn to a nitrogen-reducing rotation.

Crop Rotation	Farm Program	No Farm Program	Nitrogen Fertilizer Tax	Corn Sales Tax	Limiting Fertilizer Use
	-- Dollars per Acre over Three-Years --				
CCC	0	259	228	601	59
BCC	-11	158	95	353	12
MCC	39	208	112	232	58
CBC	-11	162	100	362	14
BBC	26	109	58	191	31
MMC	92	175	92	92	92
BCB	23	109	56	194	28

Adoption costs

The estimated adoption costs of the various rotations under the alternative policy options are shown in Table 3. A farmer's adoption cost is the difference in net farm income received from a CCC rotation under the Food Security Act of 1985 Program and an alternative rotation under either the Food Security Act of 1985 Program or the one of the alternative policy options. The information in the table indicates that a farmer in the Food Security Act of 1985 Program could improve his or her net farm income by adopting either the BCC or the CBC rotation. These rotations are the major farming practices in the Corn Belt (Daberkow and Gill 1989). A farmer opting for the No Farm Program alternative would realize a lower net farm income. The reduction could be as high as \$640/ha (under the CCC practice) and as low as \$269/ha (under the BBC or BCB rotations). The difference is attributable to the farmer not receiving deficiency payments and losing base acreage (which is based on a five year average) under the BBC and BCB rotations.

If reducing excess nitrogen available for potential leaching into the ground water is the policy objective, the Limiting Nitrogen Fertilizer Use option has the lowest cost to a farmer while the Corn Sales Tax option shows the largest net farm income loss to a farmer. For instance, if a farmer must limit fertilizer use, he or she could have an income loss of \$146/ha (for the CCC pattern) while a farmer could have an income loss of \$1484/ha if a corn sales tax is imposed. The loss due to the corn sales tax is far greater than the government program benefits under the Food Security Act of 1985 Program (\$640/ha). The farmer would be better off by not participating in the Food Security Act of 1985 Program or by switching to an alternative rotation. The net farm income loss under the input (fertilizer) tax option also is substantially larger than under the Limiting Nitrogen Fertilizer Use option. This is because a farmer under the Fertilizer Tax option would suffer a net farm income loss not only from a reduction in production but also from an increase in the cost of fertilizer while a farmer under the Limiting Nitrogen Fertilizer Use option would suffer an income loss only from the production reduction. Thus, the compliance cost is less under the Limiting Nitrogen Fertilizer Use option than under the other options analyzed. Additionally, a farmer would more likely be in compliance under the Limiting Nitrogen Fertilizer Use option because the compliance cost is less than the benefits foregone from the farm program.

Efficient policy options

A farmer seeking to maximize profit is expected to be concerned with the cost of adopting an alternative crop rotation scheme under the alternative policy options. He or she would, given a choice of alternative rotations under a specific policy designed to reduce the excess nitrogen available for potential leaching, be expected to select the one with the lowest adoption cost.

The farm-level cost associated with reducing by one kilogram the excess nitrogen fertilizer application rates under various policy options are found in Table 4. The negative costs in the table for specific rotations indicate that a farmer should gain by switching to those rotations. A farmer also could gain by switching to one of the rotations with a compliance cost less than the nitrogen fertilizer price. One such rotation is the BCB rotation under both the Food Security Act of 1985 Program and the Limiting Nitrogen Fertilizer Use option.

The results shown in Table 4 indicate that the Food Security Act of 1985 Program and the Limiting Nitrogen Fertilizer Use option have the lowest costs for reducing the excess nitrogen fertilizer application rate. These two options constitute the least-cost policy alternatives from which it is possible to identify an efficient policy. These are discussed below.

Efficient Policy #1 — Compliance under the Food Security Act of 1985 Program. This option is selected because it is relatively efficient in reducing the excess nitrogen fertilizer application rate (and hence the excess nitrogen available for potential leaching into the ground water) and can be verified on the field (that is, enforcement is relatively straightforward). The efficient rotations are BCC, CBC, BCB, and BBC. The negative cost for the BCC and CBC rotations indicate that a farmer would realize a gain in net farm income by switching to one of these rotations. A farmer also would reduce fertilizer expense by switching to the BCB rotation because the cost of reducing by one kilogram the excess application rate of nitrogen fertilizer (\$0.06/kg) is less than the cost of applying one additional kilogram of nitrogen fertilizer (\$0.07/kg). Furthermore, a farmer would have an economic incentive to remain in the Food Security Act of 1985 Program if the program benefits of a rotation exceed the compliance cost. For example, a farmer would have a compliance cost of \$227/ha for switching to the MCC rotation. This is less than the program benefits of \$640 for continuing the CCC practice. Since the compliance cost is less than the program benefits, the farmer should comply and stay in the Food Security Act of 1985 Program.

Table 4. Reduction in net farm income associated with reducing the excessive nitrogen fertilizer application rate.

Crop Rotation	Farm Program	No Farm Program	Nitrogen Fertilizer Tax	Corn Sales Tax	Limiting Fertilizer Use
		-- U.S. Dollars per Pound --			
CCC	--	--	1.18	3.05	0.30
BCC	-0.12	1.77	0.49	1.82	0.06
MCC	0.30	1.60	0.63	1.19	0.29
CBC	-0.12	1.82	0.52	1.86	0.07
BBC	0.17	0.71	0.30	0.98	0.16
MMC	0.47	0.47	0.47	0.47	0.47
BCB	0.14	0.71	0.29	1.00	0.14

Efficient Policy #2 — Compliance by Limiting Nitrogen Fertilizer Use. This option is selected because it has the lowest cost to a farmer where the objective is to minimize the excess nitrogen fertilizer application rate. This option requires a farmer to limit his or her nitrogen fertilizer application rate for each crop rotation while giving the farmer flexibility in selecting the crop rotation. Under this policy, a farmer would be expected to gain by switching to the BCC, CBC, or BCB rotation because the compliance cost for these rotations is computed to be less than the fertilizer price. Furthermore, since the compliance cost of each rotation is less than the program benefits, it appears to be advantageous for a farmer to stay in the farm program and comply with the limitation on nitrogen fertilizer use.

IMPLICATIONS OF ADOPTING AN EFFICIENT POLICY

Sensitivity of the price impacts

If all the farmers currently using the CCC rotation in the United States switch to an alternative rotation, based on the foregoing analysis a reduction in corn production and an increase in the production of other crops might be expected. Such changes may, however, cause fluctuations in the market price of corn and other crops. A decline in the soybeans price or an increase in the corn price will lead to a higher compliance cost for a corn-soybeans rotation. The magnitude of the increase differs among the policy alternatives which may affect the relative order of efficiency. For this reason, a sensitivity analysis was conducted to investigate whether the change in the price of soybeans relative to corn affects the cost effectiveness of the various rotations under the Food Security Act of 1985 Program, the Fertilizer Tax option, and the Limiting Nitrogen Fertilizer Use option. In the analysis, the soybeans/corn price ratio is allowed to range from a high of 2.76 under the low corn price ($0.060/L) to a low of 1.93 under a high corn price ($0.085/L). (The price of soybeans is assumed to remain at $0.165/L.) To compute the price ratio for the low soybeans price, demand elasticity estimates of -0.32 for corn and -0.60 for soybeans are used (Green and Price 1986). Also, it is assumed that the estimated 26% of national corn acreage currently under the continuous planting of corn is converted to a corn-soybean-corn rotation and that the 1987 national average yields will be realized. The compliance cost for four rotations considered (BCC, CBC, BBC, and BCB) is relatively smaller under the Limiting Nitrogen Fertilizer Use option over the range of price ratios investigated. For the low price ratio, a farmer should gain the most by adopting the BBC or the BCB rotation.

Sensitivity of reducing the target price

The level of the corn target price can also affect the efficiency of a policy. The compliance cost is expected to decline as the target price is reduced. The efficiency gap, the difference in compliance costs between limiting nitrogen fertilizer use and maintaining the current level of fertilizer use, should be slightly less as the target price is reduced. Regardless of the level of the target price, limiting nitrogen fertilizer use appears to be more efficient than imposing a nitrogen fertilizer tax. The efficiency gap between limiting nitrogen fertilizer use and maintaining the Food Security Act of 1985 Program is reduced and reversed as the target price is reduced.

Consideration of nitrogen fixed by soybeans

Corn grown after soybeans will use the nitrogen fixed by the soybeans plants. The fixed nitrogen in the form of nitrate, if not used, could also leach into the ground water. To minimize the excess nitrogen available for potential leaching under the various policy alternatives considered, it is necessary for the nitrogen fixed and left by the soybeans plants and nitrogen from fertilizer sources to equal the amount of nitrogen in the corn grain and plants removed from the field. Based on the model developed and the assumptions previously delineated, it was found that a tax on nitrogen fertilizer of $0.28/kg would be needed to ensure that the fixed nitrogen plus fertilizer nitrogen are removed from the field. The tax is about one and one-half times the tax needed to insure that the amount of fertilizer nitrogen applied approximates the amount of nitrogen removed. Also, it was determined that a corn sales tax of $0.045/L would be required to achieve zero excess nitrogen available for potential leaching when fixed nitrogen (from growing soybeans) is present as compared with a tax of $0.035 required to remove only the fertilizer nitrogen applied. Thus, based on the analytical model developed, to reduce the potential for nitrate leaching from both soybean-fixed nitrogen and fertilizer nitrogen, an increase in the cost of compliance is recommended.

POTENTIAL PROBLEMS IN POLICY IMPLEMENTATION

Implementing an efficient policy to minimize the excess nitrogen available for potential leaching into the ground water will most likely require the use of both targeting and compliance. First, cropland to be targeted for the use of alternative nitrogen reducing rotations needs to be identified according to vulnerability to ground water contamination. Second, rotations to be used under alternative policy options should be identified according to adoption cost as well as some selected efficiency criteria. In this study, the compliance cost for reducing excess nitrogen available for potential leaching into the ground water has been used. Third, a farmer would have to use a specific rotation(s) and/or limit his or her nitrogen fertilizer use on targeted cropland in order to place the cropland vulnerable to nitrate leaching in the farm program.

A number of implementation problems can be expected. For example, a farmer may challenge the method of classifying vulnerable cropland and the legality of discriminating against cropland on the basis of its degree of vulnerability. Fortunately, the concept of targeting vulnerable cropland is not new to farmers. Farmers are familiar with policies of this nature because they are incorporated in the Conservation Reserve Program and the Conservation Compliance Provisions of the Food Security Act of 1985 (Glaser 1986). Next, the lack of a consistent national method of identifying vulnerable cropland is a potential problem. The DRASTIC criterion (Allen et al. 1987; Huang and Mizer 1987) has been suggested. However, its accuracy has yet to be validated by field tests.

Use of compliance as a policy tool will require that a farmer adopt pre-approved rotations for vulnerable cropland in order to be placed in the farm program and to limit nitrogen fertilizer application rates. Rotation compliance will likely cause few implementation problems because it can be verified on the field. Limiting nitrogen fertilizer use, on the other hand, can pose a verification problem. First, the optimal nitrogen fertilizer application rate must be determined and second, there must be a monitoring of nitrogen fertilizer use to ensure that the optimal rate is not exceeded. To determine the optimal fertilizer application rate, an inexpensive and accurate soil test is needed. Fortunately, such a test has been developed by Blackmer (Iowa State University 1990). Also needed, however, is a low cost method to monitor fertilizer application rates. Such a method has yet to be found.

CONCLUSIONS

The costs associated with using different crop rotation patterns designed to reduce the use of nitrogen fertilizer under alternative agricultural policy options have been measured in the foregoing analysis. The policy options considered have included the Food Security Act of 1985 Program, a No Farm Program option, a Nitrogen Fertilizer Tax option, a Corn Sales Tax option, and a Limiting Nitrogen Fertilizer Use option. Based on the notion that the amount of excess nitrogen available for potential leaching should be minimized, the analysis suggests that crop rotation patterns associated with limiting nitrogen fertilizer use will have the lowest cost to the farmer while a corn sales tax would have the highest cost.

REFERENCES

Allen, L.; Bennett, T.; Lehr, G.H.; Petty, R.J.; Hackett, G. DRASTIC: A standardized system for evaluating groundwater pollution potential using hydrogeological settings. EPA/600/2-87/035, 1987. Available from: U.S. Environmental Protection Agency, Robert S. Kerr Environmental Research Laboratory, Ada, OK.

Baumol, W.; Oates, W. The theory of environmental policy; 2nd Edition. Cambridge: Cambridge University Press; 1988.

Blackmer, A.M. Losses and transport of nitrogen from soil. In: D'Itri, F.M.; Wolfson, L.G., eds. Rural groundwater contamination; Chapter 5. Chelsea, MI: Lewis Publishers Inc.; 1987.

Cantor, P. Health effects of agrichemicals in groundwater: What do we know? Agricultural Chemicals and Groundwater Protection: Emerging management and policy. In: Proc. conference St. Paul, MN, October 22-23, 1988. Available from: Society of Agricultural Engineers, Chicago, IL.

Conservation Foundation. Groundwater Protection. Washington, DC: The Conservation Foundation; 1987.

Daberkow, S.; Gill, M. Common crop rotations among major field crops. In: Agricultural resources: Inputs situation and outlook report, AR-15; August 1989. Available from: Economic Research Service, U.S. Department of Agriculture, Washington, DC.

Duffy, M.; Chase; C. Impacts of the 1985 Food Security Act on crop rotations and fertilizer use; 1988. Department of Agricultural Economics, Iowa State University, Ames, IA.

Economic Research Service. Agric. Outlook, AO-165 (September):52-53; 1991. U.S. Department of Agriculture, Washington, DC.

Freshwater Foundation. Nitrates and Groundwater: A Public Health Concern; 1988. The Freshwater Foundation's Health and Environment Network, Navarre, MN.

Fertilizer Institute. The Fertilizer Handbook; 2nd Edition. Washington, DC: The Fertilizer Institute; 1976.

Gilliam, J.W.; Hoyt, G.D. Effect of conservation tillage on the fate and transport of nitrogen. In: Logan C., ed. Effects of conservation tillage on groundwater quality: nitrates and pesticides. Chelsea, MI: Lewis Publishers; 1987.

Glaser, L. Provisions of the Food Security Act of 1985. AIB No. 498; 1986. Economic Research Service, U.S. Department of Agriculture, Washington, DC.

Green, R.; Price, M. Short run price elasticities obtained from FAPSIM - 1986 base year. Working Paper; 1986. Economic Research Service, U.S. Department of Agriculture, Washington DC.

Huang, W.; Lantin, R. An analysis of policy options for adopting alternative farming practices to reduce nitrate leaching. Draft Report, March 1990. Economic Research Service, U.S. Department of Agriculture, Washington, DC.

Huang, W.; Mizer, K. Using a soil data base system for soil and resource conservation policy analysis. In: Proc. National Symposium on Conservation Systems; Optimum erosion control at least cost; December 1987. Available from: American Society of Agricultural Engineers, Chicago, IL.

Iowa State Experiment Station at Kanawha. Experiment Station Report ORC87-14,22; 1986. Iowa State University, Ames, IA

Iowa State University. Estimated costs of crop Production - 1989. Extension Publication, FM-1712, December 1989. Iowa State University, Ames, IA.

Iowa State University. Extension News; I-TTL-T2-T3-U2, February 1990; Iowa State University, Ames, IA.

Nielsen, E.; Lee, L. The magnitude and costs of groundwater contamination from agricultural chemicals: A national perspective. AER-576; October 1987. Economic Research Service, U.S. Department of Agriculture, Washington, D.C.

Office of Technology Assessment. Protecting the Nation's groundwater from contamination. Washington, DC: U.S. Government Printing Office; 1984.

Tietenberg T. Spatially differentiated air pollutant emission charges: An economic and legal analysis. Land Econ. 54:265-277; 1978.

USEPA (U.S. Environmental Protection Agency). National statistical assessment of rural water conditions; 1984. U.S. Environmental Protection Agency, Washington, DC.

Uri, N.D.; Konyar, K. The substitution of energy for other inputs in the production of corn in the United States. Appl. Energy 37:85-98; 1990.

White, W. Sources of nitrogen and phosphorus. Washington, DC: Resource Washington, Inc.; 1989.

Environment International, Vol. 18, pp. 43 - 54, 1992
Printed in the U.S.A.

0160-4120/92 $5.00 +.00

ADAPTATION TO INDOOR AIR POLLUTION

Lars Gunnarsen
Danish Building Research Institute, Hørsholm, Denmark

P. Ole Fanger
Laboratory of Heating and Air Conditioning, Technical University of Denmark, Lyngby, Denmark

EI 8909-236M (Received 15 June 1989; accepted 29 June 1991)

The change in the perception of polluted air was studied during the first 15 min of exposure in climate chambers. Subjects, 16 female and 16 male, ages 18-30 y, served as air quality judges during 42 exposures. They were exposed to different concentrations of human bioeffluents (500-4000 µL/L CO_2), tobacco smoke (0.25-2.5 µL/L CO), and emissions from building materials (-). The subjects voted every 2 min on scales for odor intensity and acceptability of the air quality, while they were exposed to constant levels of the air pollution. Perception of bioeffluents reached a low level independent of concentration after a few minutes. Adaptation to tobacco smoke caused acceptability to increase, but votes still depended on concentration. Ventilation for comfort may be reduced considerably if a few minutes of discomfort are acceptable or if the occupants are exposed to a gradually increased pollution level during the first 10 min or more of their stay in a space.

INTRODUCTION

Ever since the classical experiments of Yaglou (1936), standards for ventilation have primarily been based on people's perception of the air quality. Comfort criteria have often proved to be the most restrictive for indoor air quality.

Ventilation requirements have been set up based on the first impression of the air quality although adaptation often modifies the perception considerably. It was felt to be unrealistic to tell people to disregard their first negative impression and wait a few minutes until they had adapted to the pollution. Furthermore, the available data quantifying the effect of adaptation were limited.

In polluted spaces, where people often walk in and out, the initial impression is of major concern. In other spaces which are occupied by the same persons for several hours, the impression after the initial adaptation becomes more important. It may be possible to adapt people at a high comfort level gradually by slowly increasing the level of pollution. This applies in particular to spaces where people enter simultaneously, and where they are the main polluters. Spaces like theaters, classrooms, and meeting rooms are typical examples. In other cases, it may be possible to adapt people gradually before they enter a given room by proper control of the air quality in entry halls and corridors.

Earlier investigations of phenomena involving adaptation have concentrated on specific single-component odorants and irritants (Cain 1985; Engen 1987; Ekman et al. 1967; Berglund 1978; Stone 1972). Cain (1985) presented a model for the time course of olfactory adaptation to single components. He found that perceived intensity reaches a stable level of approximately 40% of the initial magnitude after 3 min of adaptation.

Pollution indoors is usually more complex comprising a large number of single pollutants. A person may experience changes in both the concentration and composition of indoor pollution.

Perception of air pollution may depend on several adaptational phenomena. For some pollutants, the time effects may cause fewer dissatisfied persons after a short exposure, while dissatisfaction may grow after a longer period (one hour or more). In the present study, only the first 15 min of exposure were studied.

Transients in air quality are experienced not only when air quality in a room is changing but also when persons walk from one room to another. Often transients are both qualitative and quantitative. This makes the real life situation complex. It is our aim to establish a model for the perception of air quality during transients.

The purpose of the present investigation is to study discomfort caused by typical indoor pollution before, during, and after a transient period of adaptation. When entering a room, the air may seem unacceptable, but during an adaptational period, the sensation of odor may decrease while the irritation may increase or remain constant (Engen 1986). The combined effect of these two sensory processes will be quantified.

METHOD

In this study, human bioeffluents, tobacco smoke, and emissions from building materials were studied. Perception of pollution from one source, as well as perception of pollutants after previous exposure to other pollutants were studied, with subjects in different adaptational states.

Facilities

The experiments took place in the climate chambers of the Laboratory of Heating and Air Conditioning. Two of the chambers were similar in shape and equipment (Albrechtsen 1988). Stainless steel was used for all lining and ductwork. Each chamber had a total volume including recirculation ducts of 28.5 m^3. Air entered the chambers via a plenum through a perforated floor and left via ducts in the ceiling. The air was well mixed by a recirculation rate as high as 50 h^{-1}. Outdoor air was supplied through a series of filters including activated carbon. The supply of outdoor air was controlled by individually calibrated arrangements of orifice plates. During all experiments, curtains were hung in the chambers dividing them into a section for judges and a section invisible to judges where pollution sources could be placed. The third chamber, designed for thermal environmental studies, was used as a reference (Kjerulf-Jensen 1975). Air enters and leaves the chamber in the same way as in the twin chambers. Traditional materials are used in ductwork and the chamber is plastic-lined. The supply of outdoor air was 1000 L/s, or 30 L/s per person when 32 persons occupied the chamber.

Temperatures in all chambers were kept constant at 22 °C (±0.3 °C). The humidity was in the range of 3-7 g/kg (20-40 %RH), and no attempt was made to control it.

Bioeffluents were produced by the subjects. They polluted and rated the air quality at the same time. Carbon dioxide was used as an indicator for this pollution (8,9). It was monitored by an infrared CO_2 analyzer, Uras 7N from Hartmann & Braun.

Tobacco smoke was produced by filter cigarettes with a content in the smoke per cigarette of:

18 mg	tar	(main stream);
1.5 mg	nicotine	(main stream);
21 mg	CO	(main stream); and
44.4 μm^3	CO	(during experiments).

The main stream values are the manufacturer's official ratings according to ISO and CORESTE standards. The CO emission during experiments was established by Cain (1983) with similar cigarettes and test conditions. They were lit by persons behind the curtains at a predetermined rate. After lighting, the cigarettes were placed in an ashtray to produce only sidestream smoke. Carbon monoxide was used as the indicator of tobacco smoke (Cain 1983). Monitoring was done by a Gas Filter Correlation CO analyzer, model 48, from the Thermo Electron Corporation.

Building materials were selected from commonly used materials. Two equal sets were used. They comprised: wooden chipboard, nylon carpet with a latex backing, gypsum plates coated with water-based acrylic paint, and stainless steel plates with acrylic-based sealant and iso-cyanate lacquer. There is no known chemical or physical indicator for human perception of pollution from these materials. No monitoring was done during experiments. Pollution levels were calculated as a constant (=64) divided by the steady state outdoor air supply rate measured in L/s.

Subjects

Thirty-two persons served as judges (and as pollution sources during experiments with bioeffluents). They were students or white collar workers aged 18 to 30 years. They were as a group consistent with the standard person introduced by Fanger (1988). Their hygienic standard corresponded to 0.7 bath/day and changing underwear every day.

During previous experiments with similar subjects at the same level of activity by Rasmussen et al. (1985), the CO_2 emission per person was found to be 4.69 mL/s. During the experiments they were divided into four groups, each group comprising four women and four men, five of them smokers and three nonsmokers. They were not allowed to smoke in the chambers.

Scales

The subjects voted on odor intensity on a modified Yaglou (1936) scale; acceptability was voted on a new scale. Scales and corresponding questions are shown in Fig. 1.

Experimental procedure

Experiments each lasting 4 h were performed on four different days with the following program:

Day 1:	adaptation to bioeffluents;
Day 2:	adaptation to pollutants from building materials;
Day 3:	cross adaptation between the pollutants; and
Day 4:	adaptation to tobacco smoke.

During experiments on days 1, 2, and 4, the concentration of pollution in the twin chambers was increased stepwise. Every 15 min, a group of subjects entered a chamber and was seated for 15 min. They voted on air quality just after entering and every 2 min during the stay.

During the experiment involving cross adaptation, the judges were first exposed to one pollution type for 15 min and then exposed to a second type of pollution. For each type of pollution, the subjects were exposed to the highest concentration applied in the previous experiments with single pollution sources. The shifting between chambers and the pollution build-up was directed so that each pollution type was judged when the subjects were in the following four adaptational states:

1 - refreshed;
2 - adapted to bioeffluents;
3 - adapted to tobacco smoke; and
4 - adapted to pollution from building materials.

RESULTS

Scale comparison

Figure 2 shows the relation between votes for intensity and acceptability and between percentage of dissatisfied persons and votes for acceptability. The dissatisfied votes are defined as all votes below 0 on the acceptability scale. For both, the intensity/acceptability and the dissatisfied/acceptability relationships, it is remarkable that there was no significant difference between bioeffluents, tobacco smoke, building materials, and adaptational status. The change in votes due to adaptation was 95% and took place within the first 6 min of exposure. The initial non-adapted votes were given just after entering the chambers, and the adapted votes were given from 8 to 14 min after entering the chambers. The remaining votes representing the transient period were not analyzed.

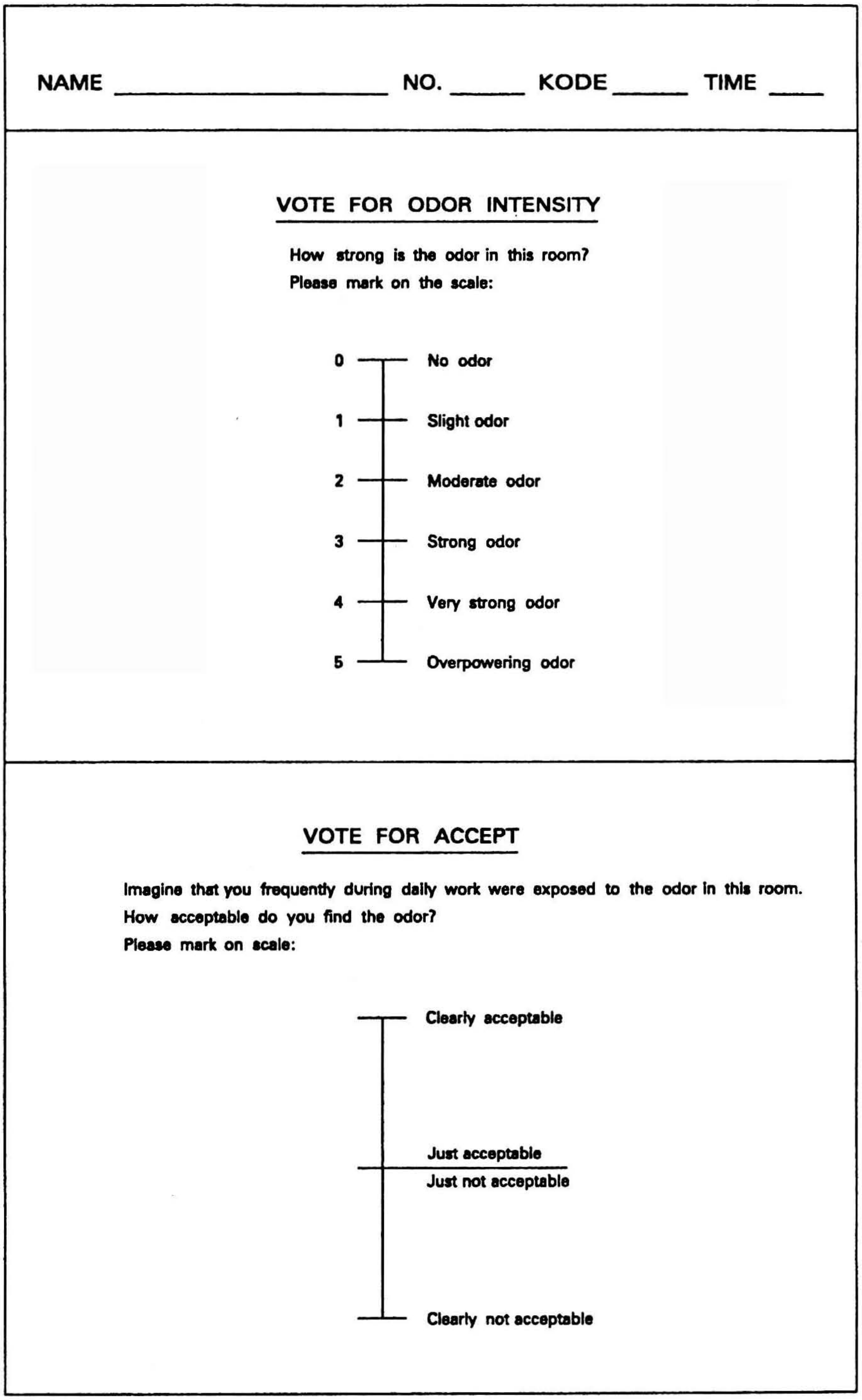
Bioeffluents

Votes for intensity and acceptability versus CO_2 concentration obtained during experiments with bioeffluents are shown in Fig. 3 for adapted and non-adapted persons.

The adapted subjects voted low intensity and high acceptability rather independent of pollution level. The non-adapted subjects felt the odor to be more intensive and less acceptable at an increasing air pollution level. This is in good agreement with previous studies (Fanger 1988; Rasmussen et al. 1985; Berg-Munch et al. 1985). Based on the CO_2 emission rate per person of 4.69 mL/s, the corresponding steady-state ventilation rates were calculated. Converting acceptability votes to a percentage of dissatisfied at the same time gives Fig. 4. Fanger's (1988) definition curve of one olf (= one standard person) is shown for comparison. Apparently, adapted persons do not distinguish between low and high levels of bioeffluents. Generally, when adapted, the subjects perceive the investigated range of concentrations to be acceptable.

Tobacco smoke

Votes for intensity and acceptability versus CO concentration obtained during experiments with tobacco



NAME ______________________ NO. ______ KODE ______ TIME ____

VOTE FOR ODOR INTENSITY

How strong is the odor in this room?
Please mark on the scale:

0 — No odor
1 — Slight odor
2 — Moderate odor
3 — Strong odor
4 — Very strong odor
5 — Overpowering odor

VOTE FOR ACCEPT

Imagine that you frequently during daily work were exposed to the odor in this room.
How acceptable do you find the odor?
Please mark on scale:

Clearly acceptable

Just acceptable
Just not acceptable

Clearly not acceptable

Fig. 1. Scales and corresponding questions used in the experiments. For data analysis the intensity scale ranges from 0 to 5 and the acceptability scale from -1 to +1, where 0 indicates the shift from acceptable to not acceptable.

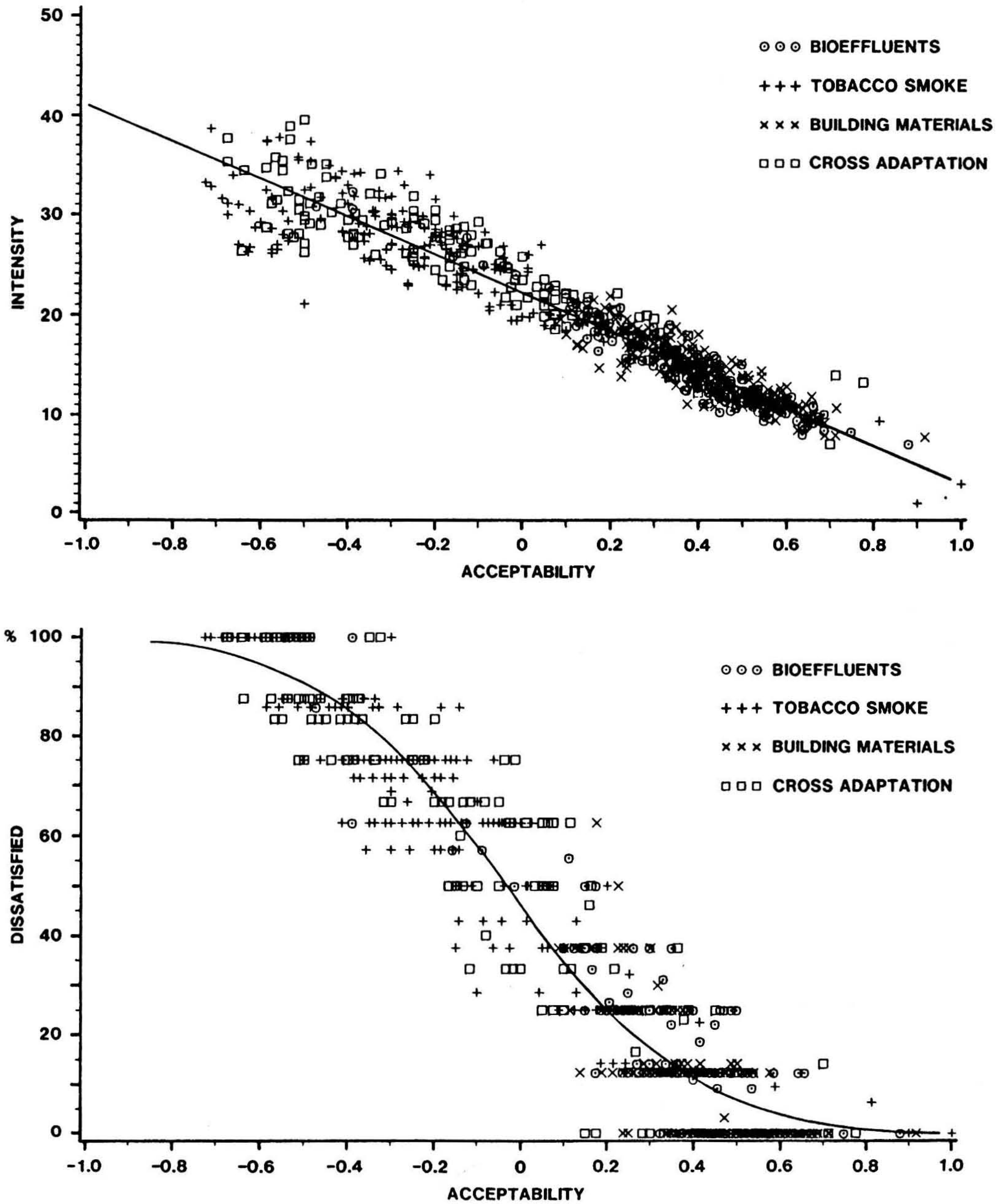


Fig. 2. Simultaneous votes for intensity and acceptability and relation between percentage of dissatisfied persons and votes for acceptability. Each point on the figure represents the mean of eight votes.

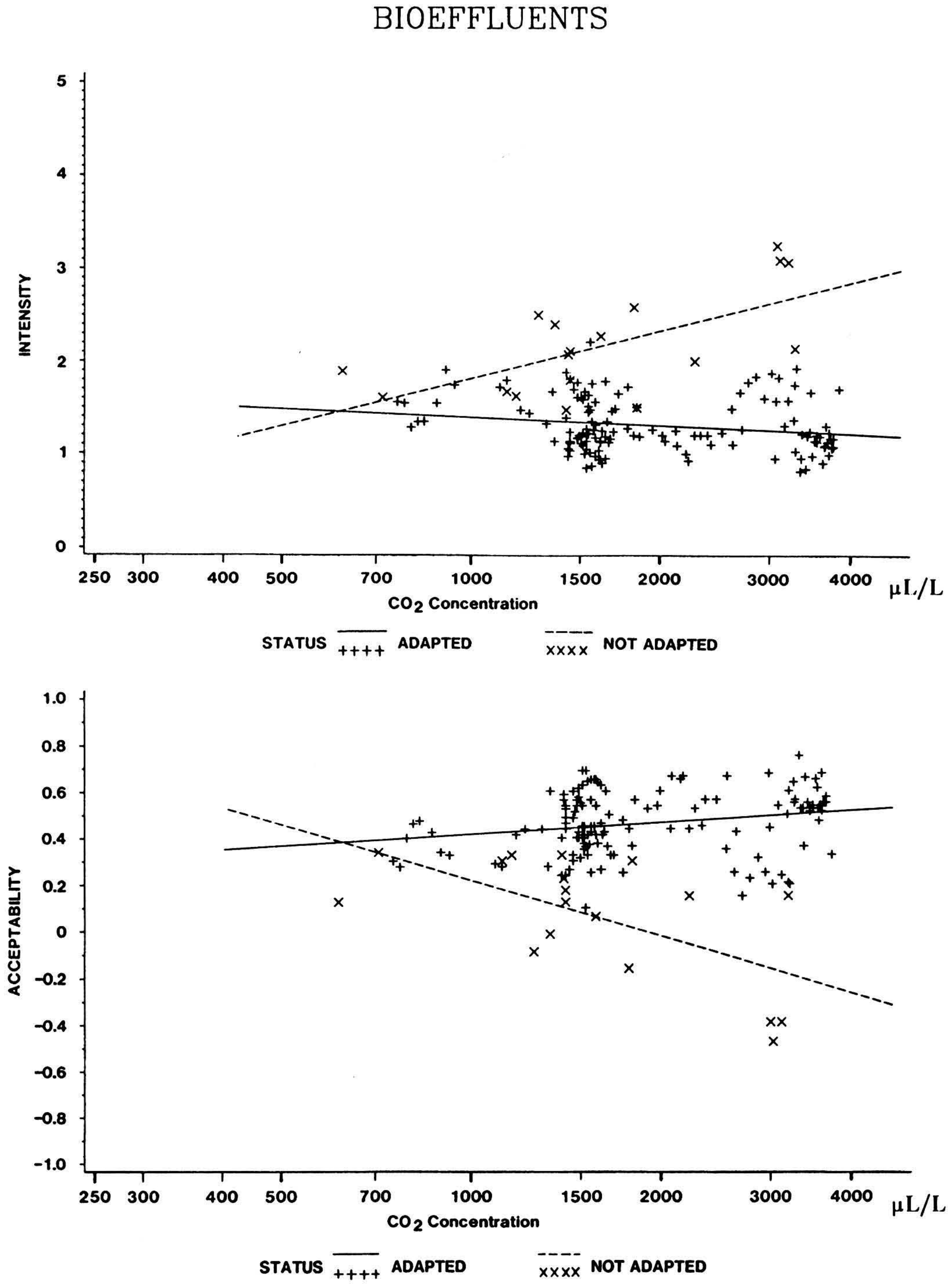


Fig. 3. Votes for intensity and acceptability versus CO_2 concentration for exposure to bioeffluents. Each point in the figure represents the mean of eight votes. The CO_2 concentration is the level above outdoors.

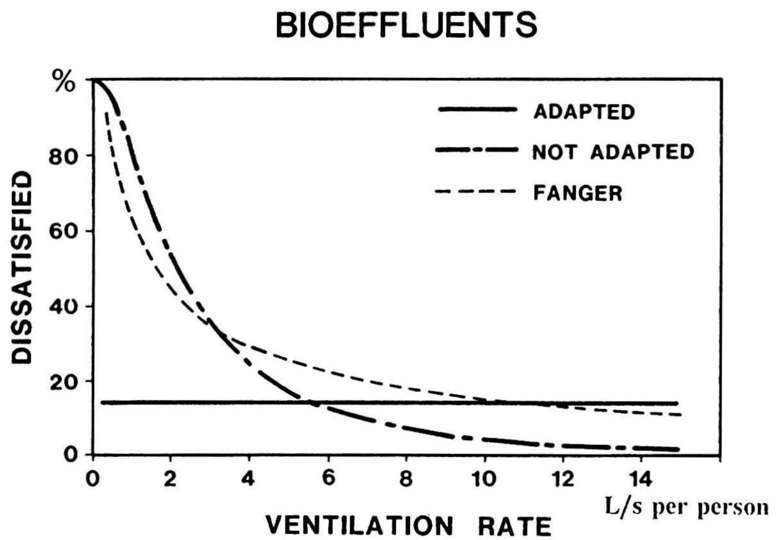


Fig. 4. Relation between steady-state ventilation rates and dissatisfied persons shown for adapted and non-adapted persons exposed to bioeffluents. Fangers (1988) definition curve for one olf equal to one standard person is shown for comparison.

smoke are shown in Fig. 5. Intensity increased and acceptability decreased with increasing concentration both for non-adapted and for adapted subjects. But the adapted felt the intensity slightly less intensive and more acceptable than the non-adapted subjects.

Figure 6 illustrates the dissatisfied subjects as a function of the ventilation per cigarette based on the CO emission. The current results show a higher dissatisfaction than that established by Cain et al. (1983). For moderate tobacco smoking in the range of 30-50%, the adaptation of the initially dissatisfied subjects reduces the required ventilation at a given level of dissatisfaction to approximately 50% of the requirements based on initial perception.

Pollution from building materials

The votes for intensity and acceptability are shown in Fig. 7. Apparently, the materials polluted the incoming air only slightly. Votes are close to the votes for background at all pollution levels. This makes interpretation of results difficult.

Cross adaptation

Votes for intensity and acceptability are shown in Fig. 8. Adaptational status is seen to influence the perception of the different types of pollution. Not only adaptation to actual pollution or self-adaptation is important, but adaptation to one type of pollution seems to have a notable effect on the immediate perception of other pollutants.

Adaptation to bioeffluents makes perception of environmental tobacco smoke and building material pollutants more acceptable and less intense than after previous exposure to fresh air. In this case, adaptation to one type of pollution produces cross adaptation to other pollutants. However, previous exposure to tobacco smoke seems to have a different effect on the immediate perception of other pollutants. Bioeffluents and building material pollutants feel worse than after exposure to fresh air. This is like a negative adaptation. Adaptation to emissions from building materials has an effect similar to adaptation to bioeffluents on perception of the other types of pollution. But still the level of pollution from building materials was low and the results less significant.

Each value in the figure is the mean of 16 votes. The standard deviation on these values was approximately 0.2 for acceptability and 0.4 for intensity. Only the modifying effect of previous exposure to bioeffluents on perception of tobacco smoke is statistically significant for both acceptability and intensity.

DISCUSSION

Adaptation may be a reason for not experiencing more complaints in bad indoor climate. Adaptation is

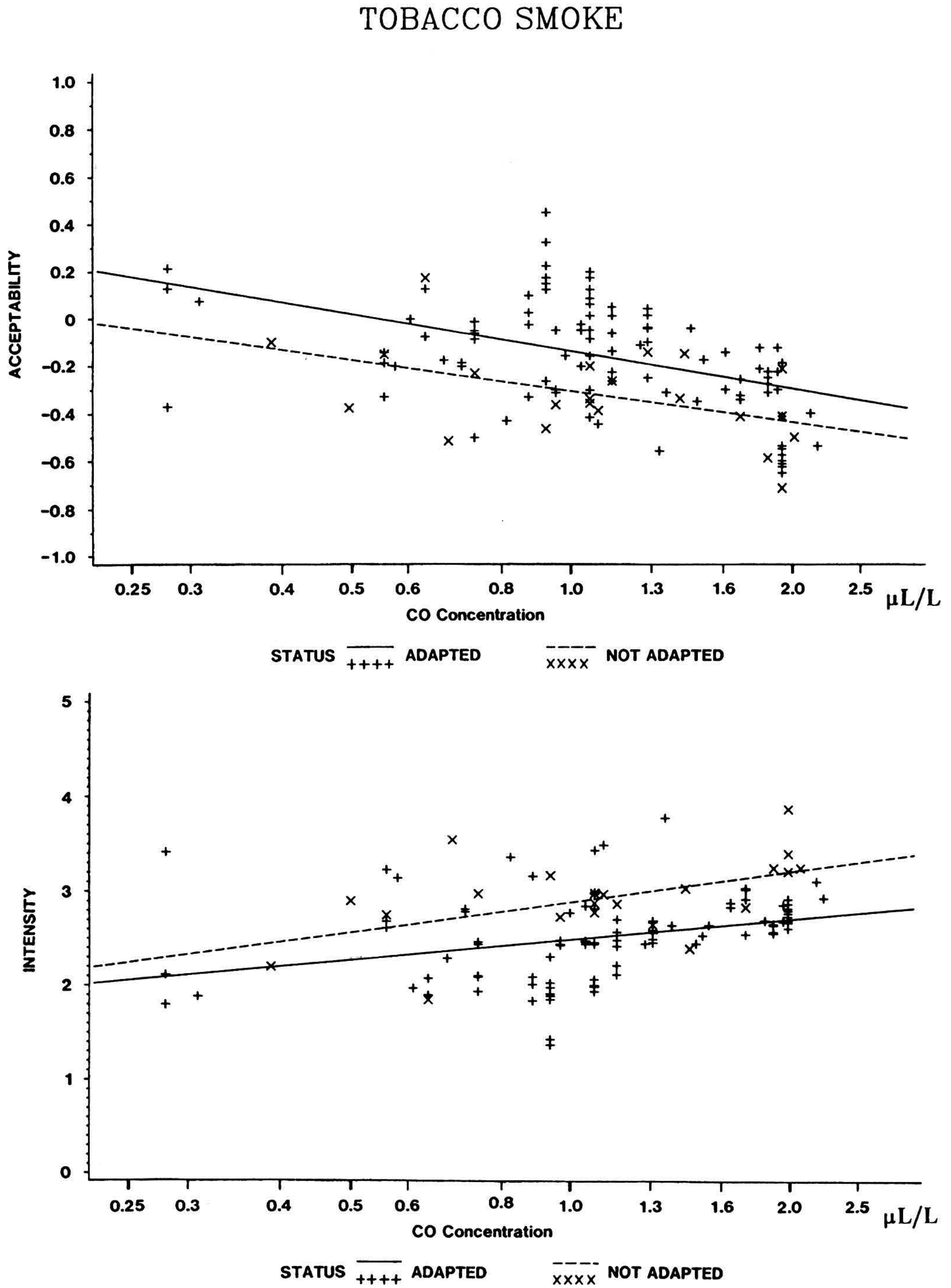


Fig. 5. Votes for intensity and acceptability versus CO concentration above outdoors for exposure to environmental tobacco smoke. Each point in the figure represents the mean of eight votes.

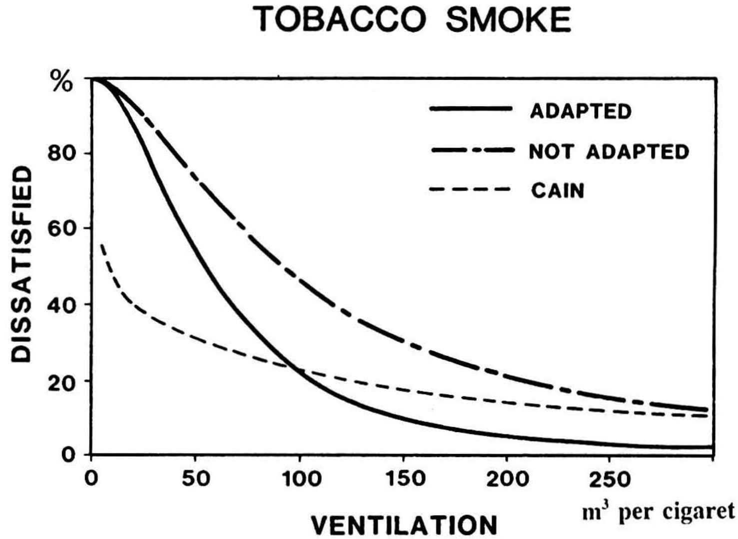


Fig. 6. Relation between steady state ventilation and percentage of dissatisfied persons shown for adapted and non-adapted persons exposed to environmental tobacco smoke. Results of Cain et al. (1983) are shown for comparison.

seen to have a modifying effect on perception of common indoor air pollution. Supply of outdoor air may be reduced whenever a few minutes of discomfort during adaptation is acceptable. Auditoriums, theaters, and big offices are some of the places where it should be considered to take advantage of adaptation.

The investigated lower levels of human bioeffluents represent concentrations often found in indoor air. Bioeffluents exceeding 2 mL/L CO_2 are unusual. The full adaptation to levels as high as 4 mL/L is an impressive validation of the effect of adaptation. The investigated levels of environmental tobacco smoke may all be found indoor. The level of pollution from building materials during the experiments are probably rather low.

The new continuous scale for acceptability is seen to be a promising candidate for future studies on air quality. It provides information not only on whether each subject finds the air quality acceptable or not, but also on how far he or she is from switching to the alternative vote. The clearly indicated switching point between acceptable and not acceptable makes interpretation possible without introducing a possible bias due to an arbitrary limit value. The scale may be used for the quantification of many other sensory stimulations including pain, noise, and illumination.

The fact that the sense of smell is likely to adapt while the general chemical sense is not (Engen 1986) indicates that during an adaptational period, intensity of odor weakens and irritation persists or may even grow. The nearly constant relation between acceptability, percentage of dissatisfied persons, and odor intensity, independent of the type of pollution and whether the subjects were adapted or not, is an important result. Apparently, humans do not distinguish between stimulation of the general chemical sense and odorous stimulation when voting on the scales presented in this study.

A possible explanation of the difference in adaptation for the three types of pollution is that human bioeffluents stimulate mainly the olfactory sense, while tobacco smoke and building material pollution comprise many irritants.

The subjects voted background pollution in the empty chambers and in the reference chamber to be in the range of 1.2 - 1.9 for intensity and 0.2 - 0.6 for acceptability. This indicates that the outdoor air was slightly polluted before it entered the chambers. The relatively short time period studied may be a limitation to the general use of the results.

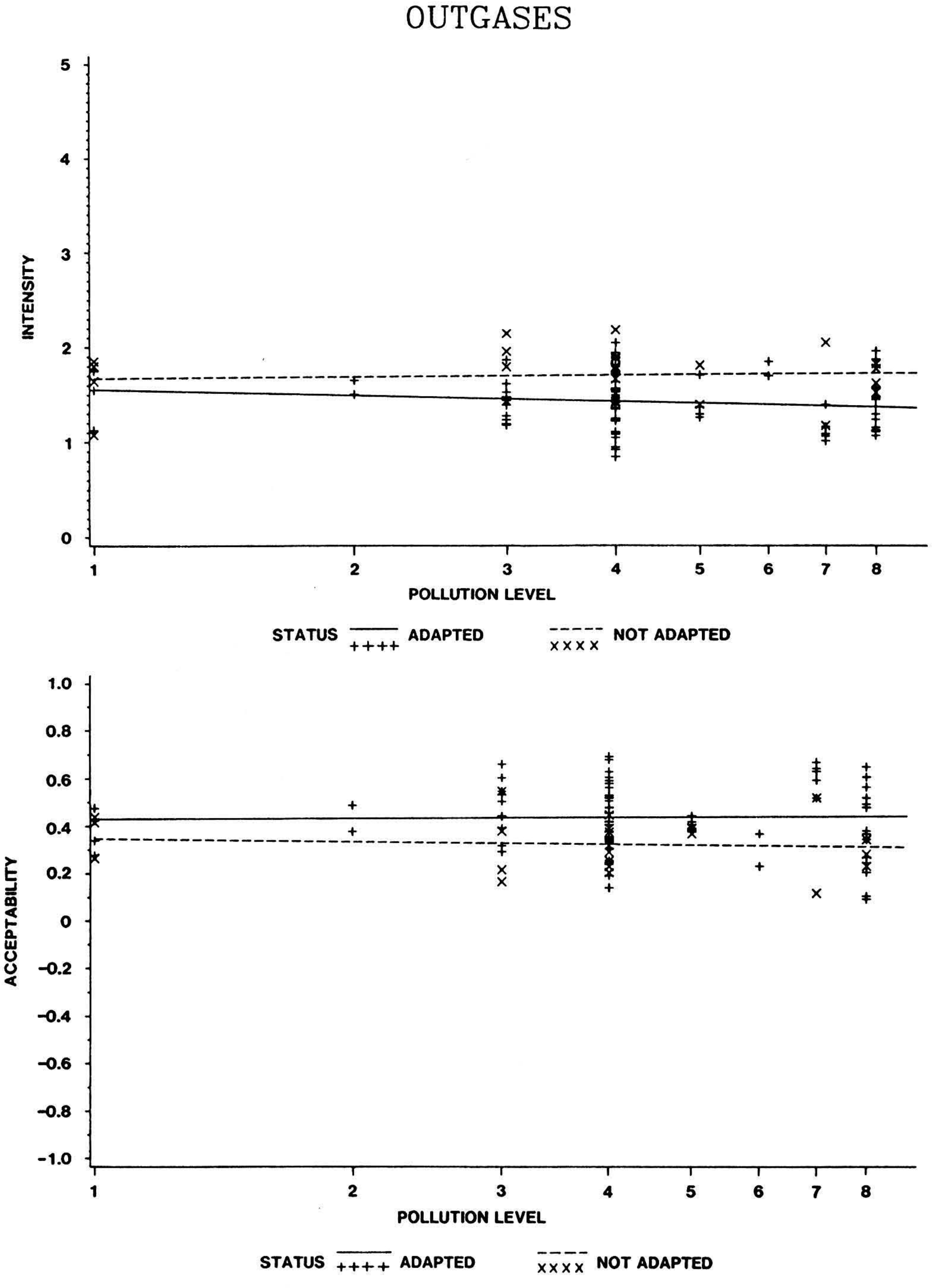


Fig. 7. Votes for intensity and acceptability versus a calculated level for exposure to building material pollution. Each point in the figure represents the mean of eight votes.

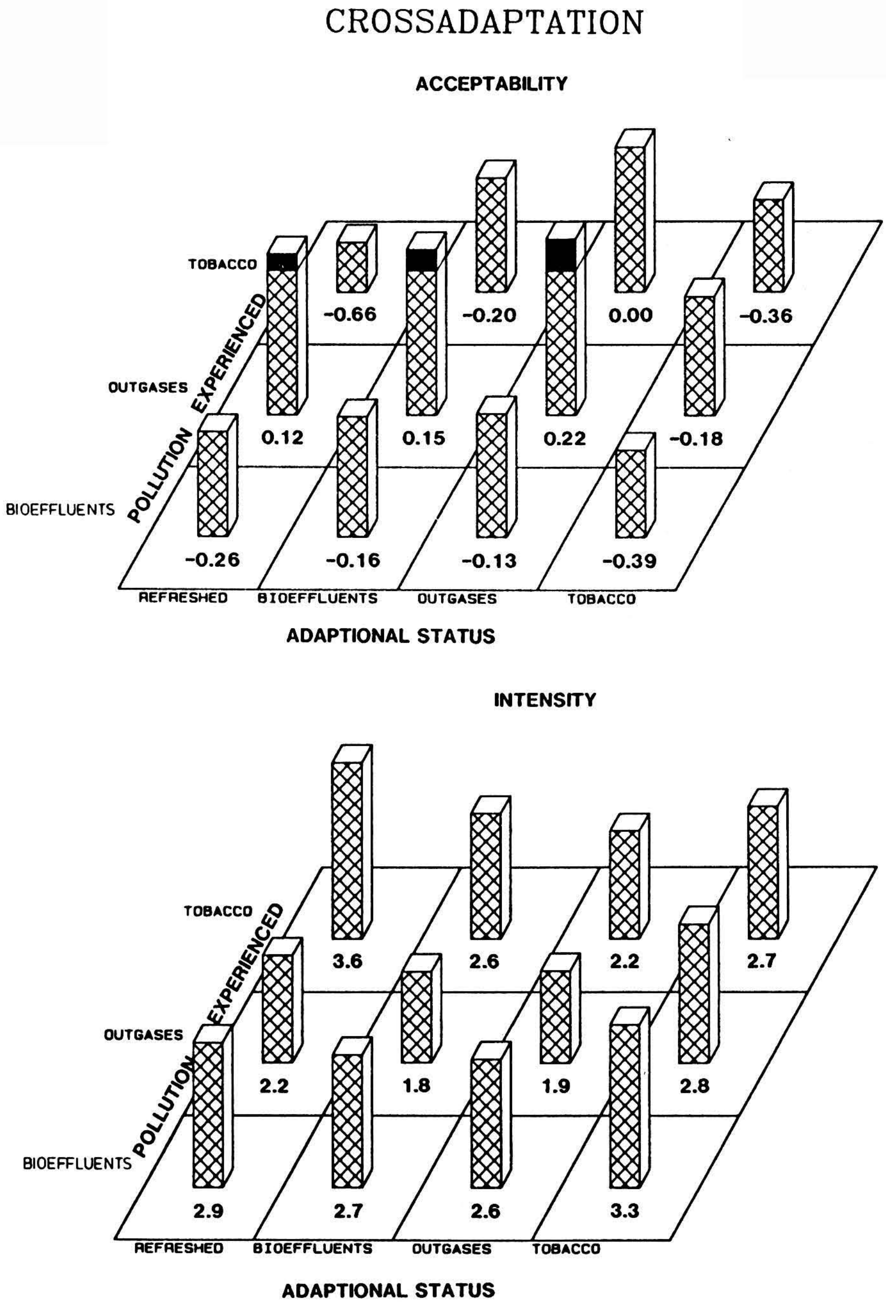


Fig. 8. Initial votes for intensity and acceptability when the subjects were exposed to one pollutant after previous exposure to another pollutant. Pollution levels equivalent to: Bioeffluents: 3500 μL/L CO_2; tobacco smoke: 2,2 μL/L CO; pollutants from building materials: Level 8 from previous experiments.

CONCLUSIONS

The air is perceived least acceptable immediately after people enter a space with air pollution. After some minutes, people may adapt and the air is felt more acceptable. Adaptation improves acceptability of air quality considerably when humans pollute the air; some improvement occurs when moderate tobacco smoking is the source, while only a small improvement is observed when building materials are the main source of pollution. When designing ventilation for adapted people, human bioeffluents may be neglected if a minimum ventilation rate per person of 1-2 L/s is assured, and the ventilation requirements based on moderate tobacco smoking may be reduced to 50%. The ventilation for the control of building-material pollution may probably only be reduced slightly.

Both positive and negative effects of cross adaptation were seen. Previous adaptation to bioeffluents may cause fewer people to be dissatisfied when exposed to environmental tobacco smoke or pollutants from building materials. On the contrary, previous adaptation to environmental tobacco smoke may cause more people to be dissatisfied when suddenly exposed to other types of pollution.

Further research is recommended studying the acceptability of pollutants as a function of time over several hours. The new continuous acceptability scale is recommended for future studies of indoor climate.

REFERENCES

Albrechtsen, O. Twin climatic chambers to study sick and healthy buildings. In: Berglund, B.; Lindvall, T., eds. Proc. of CIB conference Healthy Buildings '88. Vol. 3:25-30; Stockholm: Swedish Council for Building Research; 1988.

Berglund, B.; Berglund, U; Lindvall, T. Olfactory Self and Cross Adaptation: Effects of time of adaptation on perceived odor intensity. Sens. Processes 2:191-197; 1978.

Berg-Munch, B.; Clausen, G.; Fanger, P. O. Ventilation requirements for the control of body odor in spaces occupied by women. Environ. Int. 12:195-199; 1985.

Cain, W. S. et al. Ventilation requirements in buildings 1. Control of occupancy odor and tobacco smoke odor. Atmos. Environ. 17:1183-1197; 1983.

Cain, W. S. Perception of odor intensity and the time course of olfactory adaptation. ASHRAE Trans. 80:53-75; 1985.

Ekman, G.; Berglund, B.; Lindvall, T. Perceived intensity of odor as a function of time of adaptation. Scand. J. Psychol. 8:177-186; 1967.

Engen, T. Perception of odor and irritation. Environ. Int. 12:177-187; 1986.

Engen, T. Adaptation to odors. In: Seifert, B.; Esdorn, H.; Fischer, M.; Rüden, H.; Wegner, J., eds. Proc. 4th international conference on indoor air quality and climate, Indoor Air '87. Berlin: Institute for Water, Soil and Air Hygiene; Vol 2:671-675; 1987.

Fanger, P. O. Introduction of the olf and the decipol units to quantify air pollution sources perceived by humans indoors and outdoors. Energy Build. 12:1-6; 1988.

Kjerulf-Jensen, P.; Nishi, Y.; Sraichen, H.; Rascati, R. A test chamber design for investigating man's thermal comfort and physiological response. ASHRAE Trans. 81:73-82; 1975.

Rasmussen, C.; Clausen, G. H.; Berg-Munch, B.; Fanger, P. O. The influence of human activity on ventilation requirements for the control of body odor. Fanger, P. O., ed. In: Proc. Clima 2000 World congress on heating, ventilating and air-conditioning '85. ASHRAE; CIB; IIR. Vol. 4:357-362; 1985. Available from: REHVA, Copenhagen.

Stone, H.; Pryor, G. T.; Steinmetz, G. A comparison of olfactory adaptation among seven odorants and their relationship with several physicochemical properties. Percept. Psychophys. 12:501-504; 1972.

Yaglou, C.P.; Riley, E. C.; Coggins, D. I. Ventilation Requirements. ASHVE Trans. 42:133-162; 1936.

Environment International, Vol. 18, pp. 55 - 61, 1992
Printed in the U.S.A.

0160-4120/92 $5.00 +.00

LIFE CYCLE ANALYSIS AND ECOLOGICAL BALANCE: METHODICAL APPROACHES TO ASSESSMENT OF ENVIRONMENTAL ASPECTS OF PRODUCTS

Walter Klöpffer and Gerd Rippen
Battelle Europe, Battelle Institute e.V., Frankfurt am Main, Germany

EI 9101-103M (Received 22 January 1991; accepted 19 July 1991)

Life Cycle Analysis (LCA) is a method which allows the development of objective criteria and procedures for the assessment of the environmental impacts of products, based on the total life cycle of the product (from cradle to grave). Packaging materials are taken as an example in order to demonstrate the principle of "eco-balancing" or comparing different products which fulfil the same function. This comparative assessment is the real strength of LCA. The criteria to be used are described and a general way of performing an LCA is presented. As an example, different packaging used for milk is analysed by means of LCA and eco-balancing.

INTRODUCTION

Numerous products of everyday life have become the subject of public criticism because of their actual or assumed environmentally hazardous effects. Manufacturers, government agencies, and environmentally-minded consumers, therefore, have a legitimate interest in having the environmental impacts of products assessed as objectively as possible. This aspect is so much more important as substitute products and methods which replace the criticized products may possibly lead to the same or even higher environmental impacts. Therefore, it is necessary to consider carefully in each individual case which product (of the same technical suitability) is more environmentally compatible.The process of this consideration consists of two phases:

(1) Scientific and technical investigations to determine the feasibility, usability, and environmental impact of different alternatives (including an estimation of the consequences of non-production of a product).

(2) Political decisions based on the results of Phase 1 and on additional aspects which are beyond the techno-scientific domain (Hartkopf and Bohne 1983).

In this context, only the environmental aspects will be discussed, exemplified by packaging materials. Packaging materials, especially if made of plastics, have been subject to particularly strong criticism for about 20 years. Therefore, attempts were being made at a very early stage to develop objective assessment criteria and methods (Oberbacher et al. 1974; Hunt et al. 1974) which cover the entire life of the package including its disposal. This systems-analytical approach, which has recently become known as product life cycle assessment or analysis (LCA), (Fava et al. 1991), "Produktlinienanalyse" (Projektgruppe ökologische Wirtschaft 1987; Schmincke and Rubik 1988) or "Oekobilanz" (ecological balance) (Bundesamt für Umweltschutz 1984), is suited in principle for investigating all the products that consist of a manageable number of components. As most of the analyses that have been reported so far in publications are limited to packaging, the present paper also uses these as examples. The environmental problems we are facing in the packaging sector can be roughly divided into two categories:

(1) psychological (emotional) problems of acceptance or objection; and

(2) technical problems with respect to environmental compatibility of the products (Bojkow 1989).

The feeling that the package is superfluous results in it being discussed unobjectively. However, this is a real problem with respect to waste disposal. According to the figures given in Table 1 (Franke 1984), the share of packages in the weight and the volume of domestic waste (including other types of residential refuse, which at present account for 30 Tg/a, are 30 to 35% and about 50%, respectively. In the USA, the annual mass of domestic waste is as high as 140 Tg/a), and the per capita generation of domestic waste of 700 kg/a is more than twice as high as that in Western Europe (OECD 1985). These facts, in combination with the shortage of dumping space and the emission problems of incineration (shifting the waste problem into the atmosphere), lead to political measures to reduce the waste amounts.

CRITERIA FOR OBJECTIVE COMPARISON OF PACKAGING SYSTEMS

To compare and assess different packaging materials or systems objectively, one has to indicate the criteria on which the comparison or assessment is to be based. From the point of view of environmental impact, the following criteria can be used:

(1) energy consumption;

(2) emission of pollutants; and

(3) type and amount of waste.

Energy consumption is in the center of most of the global and of many of the regional environmental problems, such as the greenhouse effect, forest dieback, and exhaustion of natural resources. Energy consumption is easy to compare quantitatively for different packaging materials and methods. It is important to note that the inherent energy content of the packaging material (Kindler and Nikles 1979; 1980) should be included in the balance.

Emissions can be assessed in principle according to the same criteria as chemicals (Frische et al. 1982): persistence/accumulation (Klöpffer 1989), ecotoxicity (Rudolph and Boje 1987), mobility and (human) toxicity (Greim 1989). A quantification beyond the emitted substance amounts, however, is difficult; the use of limit values has been tried for scoring the environmental hazard (Bundesamt für Umweltschutz 1984).

Waste production is the main argument against unlimited use of packages and the cause for governmental measures. The problems in transportation are due to the large volume; in incineration to hazardous gases (Greim 1989); and in dumping to the

Table 1. Share of packages in domestic waste of the FRG (Franke 1984).

	Mass [Tg/a]	Volume [10^6 m^3/a]
Domestic waste	20	60
Packages	≈ 8	≈ 30
Beverage packages	≈ 2	≈ 7-8

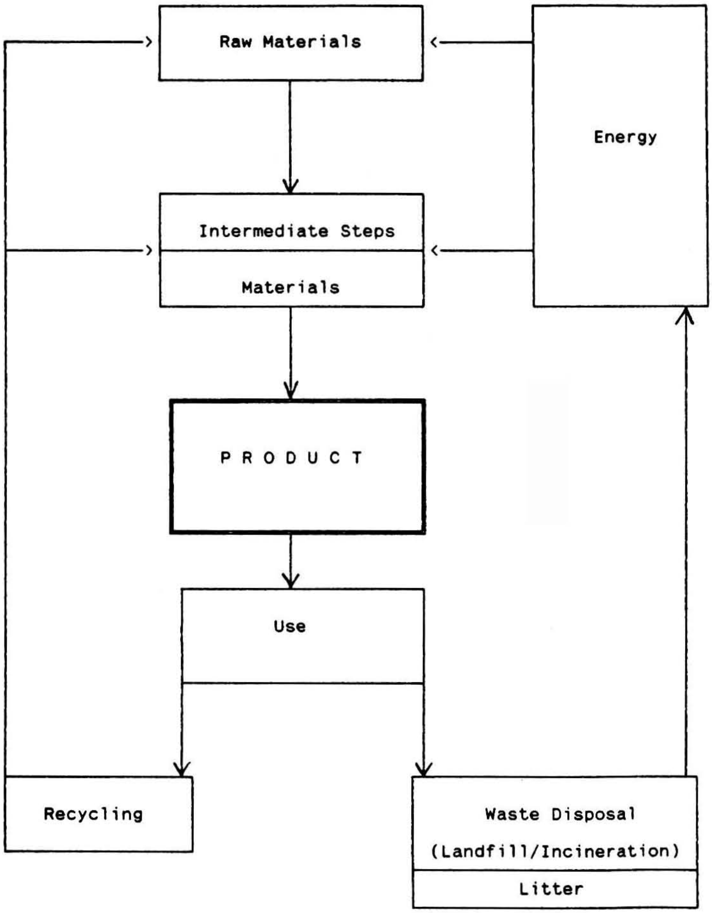


Figure 1. Basic principles of a product life cycle analysis.

space required. An advantage is that most of the packages are compacted at the waste dump to a smaller volume than they had during transportation.

THE METHOD OF PRODUCT LIFE CYCLE ANALYSIS

For some time now, it was generally accepted that only a complete analysis of the entire life cycle of a product, in this case a package, can yield a reasonable measure of environmental impact (Oberbacher et al. 1974; Franke 1984; Lundholm and Sundström 1985, 1986; Schmincke and Rubik 1988). Figure 1 shows the basic principles of a product life cycle analysis. The vertical arrangement corresponds to the process chain analysis which is usual in technology for determining the process energy, but is not sufficient for environmental assessment.

Product life cycle analysis starts from the raw materials and analyzes all the steps in the manufacture of the finished product, in its use, and in its disposal (recycling and waste disposal) or non-disposal (litter). Energy supply for production and partial recovery of energy in waste incineration play an important part. The use of packages normally is environmentally neutral, unlike other products of everyday life, such as automobiles.

In the case of complex products, this analysis may be intricate, because each part has to be traced back to the raw materials. It is therefore best to use the methods of system analysis for breakdown and organization (Franke 1984).

Raw materials in a narrow sense are the inorganic and organic raw materials such as minerals, coal, petroleum, wood, etc. In a broader sense, relatively simple materials and intermediate products such as metals, plastics, glass, paper, or cardboard may be designated as raw materials. Product life cycle analysis requires that the analysis be carried out down to the minerals, because the very first stages may involve environmentally hazardous processes, emissions, waste generation, and high energy consumption.

Typical examples of intermediate steps in the production of packages are melting and extrusion, sheet metal production, production of films and laminated films, and the production and cleaning of bottles, cans, bags, boxes, and other containers. Energy consumption, emissions, and waste situation must be quantified for these steps. Further steps are filling, production of packages and containers, and actual use.

Controlled disposal of waste in industrial countries is largely done by dumping and incineration. The ratio of dumping to incineration differs greatly in the individual countries; in the Federal Republic of Germany, for example, the major proportion of domestic waste and industrial refuse similar to domestic waste is disposed of by dumping (Umweltbundesamt 1989a), while the proportion of waste which is incinerated is about 30% (Reimann 1989). In Switzerland (Bundesamt für Umweltschutz 1984) and in Sweden, domestic waste is predominantly incinerated (about 70 to 80%). Problems in the disposal of packages by transportation and dumping mainly result from the space required.

Waste incineration, which leads to reduced volume, is the subject of discussion about hazardous emissions. These discussions mainly relate to the formation of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/PCDF) from chlorinated precursor substances during and after the incineration process (Der Rat von Sachverständigen für Umweltfragen 1987; Verein Deutscher Ingenieure 1987). Incineration permits part of the inherent energy content to be recovered by utilization of heat; in product life cycle analysis, this is accounted as a bonus.

Recycling means to return materials into the production process; however, the use of such recovered raw materials need not necessarily result in manufacture of the same product. Reuse of beverage packages in the form of returnable bottles poses special problems in product life cycle analysis. In this case, the trip number (TN) of the bottles has to be taken into account. According to calculations made by the Umweltbundesamt in Berlin, the trip number of returnable bottles averages about 40, and under favorable conditions it may be even higher (German Federal Environmental Agency 1989b). Favorable conditions for the system of returnable packages exist in cases of a well-established deposit and returning system; sturdy and standardized bottles; distribution mainly in crates; and short deliveries (decentralized distribution).

In the Federal Republic of Germany, these conditions exist in particular for the 0.5 L beer bottle and for the 0.7 L mineral water bottle. If these favorable conditions do not exist, the trip numbers are assumed to be much smaller (Franke 1984; Lundholm and Sundström 1985; Umweltbundesamt 1989b; Königs 1989; Lemke and Possmann 1989; Oberbacher 1975). The total range of trip numbers reported is approximately $TN \leq 10$ and 60.

For returnable glass packages, the ecological loads due to bottle cleaning and transportation have to be taken into account. For non-returnable glass bottles, a well-established recycling system exists in many countries which does not cover the often necessary outer package (usually made of cardboard). The recycling system reduces, but does not solve the problem of disposal of large amounts of waste glass.

ECOLOGICAL BALANCES

This method of product life cycle analysis establishes quantitative and qualitative data on the environmental impact of a packaging system while optionally also considering the goods inside the package (Fig. 1). The results apply to a specific country or to a homogeneous economic territory. They have to be revised as soon as decisive changes occur in the production, distribution, or waste disposal methods.

It has been emphasized (Bundesamt für Umweltschutz 1984; Dräger 1989) that the special advantage of product life cycle analysis consists in comparing different systems for the same goods. The comparison of the advantages and disadvantages of different packages (or different products or systems) from the point of view of environmental impacts may be called ecological balance. However, the term ecological balance is often used as a synonym of product life cycle analysis.

The input data and other qualitative data required for ecological balance originate from the product life cycle analyses of the products to be compared. However, they must be appropriately standardized for comparison. A reasonable reference quantity (functional unit) for beverages is the filling volume. The data are normally related to 1000 L (1 m^3) of liquid (Oberbacher et al. 1974; Franke 1984; Bundesamt für Umweltschutz 1984; Lundholm and Sundström 1985). A similar functional unit for other products has to be defined in each individual case. The ecological balance is exemplified here by the problem of milk packaging, which has been discussed by numerous authors (Oberbacher et al. 1974; Franke 1984; Bundesamt für Umweltschutz 1984; Lundholm and Sundström 1985). It is not intended to give a final judgement here, but to present the principle of ecological balance and to show the weak points which still exist. The older publications dealing with work performed in the early 1970s (Oberbacher et al. 1974; Oberbacher 1975) report that under the boundary conditions existing at that time, the non-returnable package for milk was the only non-returnable package which was favorable in comparison with the returnable glass package. In all other systems examined at that time, the returnable glass package was more favorable. A particularly favorable result was obtained for the tubular polyethylene package for milk, which has an extremely low weight of 7 - 7.5 g/L (Oberbacher 1975; Bundesamt für Umweltschutz 1984), but unfortunately has not yet found the deserved acceptance by the consumers.

Of the common milk packages, the leading paper and plastic composite (PPC) may be compared with the returnable glass package in the following. The data originate from three detailed studies:

(1) Bundesamt für Umweltschutz 1984, on the basis of a study by EMPA in St. Gallen;

(2) System Analytical Study by Franke in Berlin 1984; and

(3) Tetra Brik Umweltprofil in Malmö 1986 (Lundholm and Sundström 1986).

For the returnable glass package, a mean trip number of 20 to 25 is assumed. The bottle weight used for the estimates in the above studies varies between 370 g (Franke 1984) and 480 g (Lundholm and Sundström 1986). The mean weight of a one-liter glass bottle used in the Swiss study is 400 g. The bottle closure consists of 1.3 g. aluminum (Bundesamt für Umweltschutz 1984) or of 0.27 g aluminum (thin foil) for the wide-neck bottle (Franke 1984).

The 1 L PPC package is assumed to have a weight between 25 g (Bundesamt für Umweltschutz 1984; Lundholm and Sundström 1986) and 27 g (Oberbacher et al. 1974; Oberbacher 1975), of which 4.5 - 5 g (17 - 20%) is the polyethylene portion.

The calculated energy values are compiled in Table 2. In order to improve the comparability, the electric energy was uniformly increased by a factor of 3 (Bundesamt für Umweltschutz 1984; Lundholm

Table 2. Energy balance of milk packaging systems (MJ/1000L).

Source	Paper/Polyethylene (PPC)	Returnable glass system (Trip Number)	
BUS/EMPA (1984)	1770	726	(20)
Franke (1984)	970*	400*	(25)
Lundholm (1986)	2060**	1930	(20)
Klöpffer (1989)	1860	860	(20)

* Original data changed: electric energy x 3.03; inherent energy content of the packaging material added in case of PPC.

** 50 % incineration

Table 3. Waste volume (L/1000 L milk).

	Paper/polyethylene	Returnable glass system (trip number = 20)
Refuse collection	500	≤ 55
Dumping	22	≤ 8

and Sundström 1986) to account for the losses in (thermal) electricity generation. The high values for the glass bottle used by Lundholm and Sundström (1986) probably result from data of an obsolete glass factory. On the whole, the returnable glass bottle is more favorable with respect to energy consumption. The lower values reported by Franke (1984) have to be examined.

In Table 3, waste volumes are considered as they are related to the disposal of the empty packages (excluding the wastes generated in the production of raw materials). The volume of non-returnable packages during garbage collection is much higher (Oberbacher 1975; Bundesamt für Umweltschutz 1984; Franke 1984), whereas the space required for dumping is not necessarily higher because of compression. The paper/PE package is superior in incineration, where useful heat can be gained. In adddition, the CO_2 production (greenhouse effect) may be considered natural in this case, as the material originates essentially from regenerative raw materials (4/5 cardboard from wood).

The emissions of the two systems, which are disregarded in this context, are more difficult to compare. This parameter can be included in the ecological balance only if the measured data are listed and compared in detail, but this would go beyond the scope of the present paper. Another problem arises from the combination of the various parameters in one quantitative overall assessment. One such possibility is to determine the costs (Oberbacher et al. 1974; Oberbacher 1975) which are incurred for the disposal of the pollutants (e.g., biological oxygen demand in sewage treatment plants; waste by dumping and by incineration). Unfortunately, this does not permit the environmental impact to be properly assessed, because it cannot be quantified on a financial basis. Furthermore, the scoring method or determination of a coefficient (Oels 1988; Bundesamt für Umweltschutz 1984), which is applied in similar cases, is not free from non-scientific considerations. These include political values used in the rating of the scores, which are beyond the objectivity of science (Hartkopf and Bohne 1983).

LITTER

The litter problem is often treated emotionally; as early as 1930, Freud stated: "We are annoyed and call it 'barbarian', which is the opposite of cultured, if we find the paths of the Wienerwald littered with carelessly dropped papers" (Das Unbehagen in der Kultur 1930). Litter does not enhance roadsides, public parks, forests, etc. Its conspicuousness in the eyes of the public makes litter one of the main environmental problems. However, there are significantly larger environmental problems (Deutscher Bundestag 1988). The conspicuousness of litter permits and facilitates its collection. Litter is primarily a problem of organization and education and only secondarily a serious environmental problem.

REFERENCES

Bojkow, E. Getränkeverpackung und Umwelt—Auswirkungen der Verpackung von Getränken und flüssigen Molkereiprodukten auf die Umwelt—Daten und Fakten zur Verpackungsdiskussion. Wien: Springer Verlag; 1989.

Bundesamt für Umweltschutz, ed. Oekobilanzen von Packstoffen. Schriftenreihe Umweltschutz Nr. 24; Bern: 1984

Der Rat von Sachverständigen für Umweltfragen: Umweltgutachten 1987. Stuttgart: Kohlhammer Verlag; 1987.

Deutscher Bundestag. Schutz der Erdatmosphäre. Zwischenbericht der Enquête-Kommission "Vorsorge zum Schutz der Erdatmosphäre"; Bonn 1988.

Dräger, K. Vergleich der ökologischen Relevanz verschiedener Packmitteloptionen am Beispiel flüssiger Haushaltsprodukte. Seifen-Öle-Fette-Wachse 115:249-252; 1989.

Fava, J.A.; et al., eds. SETAC Workshop Report: A technical framework for life cycle assessments. August 18-23, Smugglers Notch, VT. Society of Environmental Toxicology and Chemistry, Washington, D.C.; 1991.

Franke, M. Umweltauswirkungen durch Getränkeverpackungen. Systematik zur Ermittlung der Umweltauswirkungen von komplexen Prozessen am Beispiel von Einweg- und Mehrweg-Getränkebehaltern. Berlin: E.F.-Verlag für Energie- und Umwelttechnik GmbH; 1984.

Freud, S. Abriss der Psychoanalyse / Das Unbehagen in der Kultur. 1st edition of 2nd work 1930. Frankfurt am Main: Fischer Verlag; 1970:379-408.

Frische, R.; Esser, G.; Schönborn, W.; Klöpffer, W. Criteria for assessing the environmental behavior of chemicals: Selection and preliminary quantification. Ecotox. Environ. Safety 6:283-293; 1982.

Greim, H. Rauchgasemissionen aus Müllverbrennungsanlagen—Toxikologische Bewertung. UWSF—Z. Umweltchem. Ökotox. 1(3):17-19; 1989.

Hartkopf, G; Bohne, E. Umweltpolitik—Grundlagen, Analysen und Perspektiven. Vol. 1. Opladen, Germany: Westdeutscher Verlag; 1983.

Hunt, R.G.; Franklin, W.E.; Welch, R.0.; Cross, J.A.; Woodal, A.E. Resource and environmental profile analysis of nine beverage container alternatives. Report of Midwest Res. Inst. to U.S. Environmental Protection Agency, Washington, D.C.; 1974.

Kindler, H.; Nikles, A. Energiebedarf bei der Herstellung und Verarbeitung von Kunststoffen. Chem.-Ing.-Tech. 51:13; 1979.

Kindler, H.; Nikles, A. Energieaufwand zur Herstellung von Werkstoffen—Berechnungsgrundsätze und Energieäquivalenzwerte von Kunststoffen. Kunststoffe 70:802-807; 1980.

Klöpffer, W. Persistenz und Abbaubarkeit in der Beurteilung des Umweltverhaltens anthropogener Chemikalien. UWSF — Z. Umweltchem. Ökotox. 1(2):43-51; 1989.

Königs, P. Vereinfachte Umlaufzahlenermittlung—ein weiterer Schritt zu den Fakten. Confructa Studien 33(I/II):6-12; 1989.

Lemke, T.; Possmann, P. Ermittlung von Umlaufzahlen für 1-Liter-Gebinde in ausgewählten Betrieben der Fruchtsaftbranche. Confructa Studien 33(I/II):14-27; 1989.

Lundholm, M.P.; Sundström, G. Resourcen- und Umweltbeeinflussung durch zwei Verpackungssysteme für Milch, Tetra Brik und Pfandflasche. Tetra Brik, Malmö, Sweden; 1986.

Lundholm, M.P.; Sundström, G. Resourcen und Umweltbeeinflussung—Tetrabrik aseptic Kartonpackungen sowie Pfandflaschen und Einwegflaschen aus Glas. Tetra Brik, Malmö, Sweden; 1985.

Oberbacher, B. Ökologischer Nutzwert der Einwegflasche—ein systemanalytischer Ansatz. Müll Abfall 8:234-238; 1975.

Oberbacher, B.; et al. Abbaubare Kunststoffe und Müllprobleme. Beitrage zur Umweltgestaltung. Heft A 23. Berlin: E. Schmidt Verlag; 1974.

OECD. OECD environmental data—Données OCDE sur l'environnement Compendium 1985. Paris: OECD; 1985.

Oels, H.-J. Umweltauswirkungen verschiedener Verpackungsformen und Lösungsmöglichkeiten der daraus resultierenden Probleme. Paper presented at "Verpackungstechnik' 88", Dortmund, FRG, December 13-14, 1988. Available from: Umweltbundesamt, Berlin.

Projektgruppe ökologische Wirtschaft. Produktlinienanalyse: Bedürfnisse, Produkte und ihre Folgen. Köln, Germany: Kölner Volksblattverlag; 1987.

Reimann, D.0. Müllverbrennungsschlacke—Inhaltsstoffe, Menge und Verwertbarkeit. UWSF—Z. Umweltchem. Ökotox. 1(2):18-25; 1989.

Rudolph, P.; Boje, R. Ökotoxikologie nach dem Chemikaliengesetz—Grundlagen für die ökotoxikologische Bewertung von Umweltchemikalien. In: Rippen, G. Handbuch der Umweltchemikalien. 2nd edition, Vol. 1. Landsberg, Germany: ecomed; 1987:5-105.

Schmincke, E.; Rubik, F. Produktlinienanalyse und Bewertung von Kunststoffen. Informationsdienst Chemie & Umwelt (Freiburg) 9:8-11; 1988.

Umweltbundesamt. Daten zur Umwelt 1988/89; 3rd edition. Berlin: E. Schmidt Verlag; 1989a.

Umweltbundesamt. Verpackungen für Getränke ; 5. Fortschreibung 1970-1986 (Kurzfassung). Texte 3/89. Berlin: E. Schmidt Verlag; 1989b.

Verein Deutscher Ingenieure. Dioxin—eine technische, analytische, ökologische und toxikologische Herausforderung. Kolloquium Mannheim, May 5-7, 1987. VDI Berichte 634. Düsseldorf, Germany: VDI Verlag; 1987.

Environment International, Vol. 18, pp. 63 - 72, 1992
Printed in the U.S.A.

0160-4120/92 $5.00 +.00

SUBJECTIVE AND OBJECTIVE EVALUATION OF AN OFFICE ENVIRONMENT

I. Eide and E. Brandsdal
Statoil, Health Department, Stavanger, Norway

B. Malvik
SINTEF, Trondheim, Norway

EI 9103-115M (Received 11 March 1991; accepted 24 August 1991)

An office environment has been evaluated objectively by means of measurements of air quality and climate and subjectively by means of self-administered questionnaires. The main problem reported by the employees was dry air. However, relative air humidity was mainly in the range of 36-39% due to humidification. Air quality with respect to measured dusts and vapours was good and the mean temperature in the office areas was 22.8 °C. The sensation of dry air and the occurrence of work-related symptoms were significantly influenced by sex and position level. When adjusted for these background factors there was a statistically significant relation between the sensation of high temperature and the sensation of dryness. The implications of the findings are discussed.

INTRODUCTION

Irritation of skin, eyes and upper airways, headache, and fatigue are symptoms that often have been associated with enclosed and air-conditioned buildings (Burge et al. 1987; Finnegan et al. 1984; Hedge et al. 1989; Mølhave 1985; Robertson et al. 1985; WHO 1984). Symptoms of this kind were the background for the present investigation of air quality and climate in an office building. In particular, there had been complaints about dry air, although the ventilation system was equipped with a central humidification unit intended to prevent relative humidities below 35%.

Traditional occupational hygiene surveys often fail to explain the reason for the complaints and symptoms. For example, contaminants may be present in low concentrations and there may be complex interactions between different factors, e.g., between electrostatic forces and dust which has been suggested to cause skin rashes (Nilsen 1982; Wedberg 1987). Furthermore, sex and psychosocial factors may influence the prevalence of building sickness (Burge et al. 1987; Hedge et al. 1989; Jaakkola et al. 1987; Skov et al. 1987; Skov et al. 1989) and high temperatures, vapours, and dusts have an impact on man's perception of air humidity and mucous membrane symptoms (Andersson et al. 1975; Jaakkola et al. 1987; Jaakkola et al. 1989; Mølhave and Bach 1985; Mølhave et al. 1986; Valbjørn and Kousgård 1987).

Present address for correspondence: Ingvar Eide, Statoil, Research Centre, Postuttak, N-7004 Trondheim, Norway.

The purpose of the present investigation was to evaluate air quality and climate in an office building by means of objective measurements, and to assess the prevalence of complaints and subjective symptoms by means of self-administered questionnaires. Due to the complaints about dry air, it was emphasized on those factors known to affect the perception of air humidity and the occurrence of mucous membrane symptoms. Both physical, chemical, and psychosocial factors were considered as these may interplay in a complex way. The questionnaire study was carried out anonymously as desired by the employees, implying that objective measurements could not be correlated with the subjective evaluations on an individual level.

METHODS

The office building was approximately five years old at the time of the survey, mechanically ventilated, and equipped with a central humidification unit (steam) which was activated at relative humidities below 35%. The air change rate was 4/h. The air outlets were located in the ceilings and the air was supplied at a temperature of 12-13 °C. Air was not recirculated. Sampling and measurements were carried out in the different areas of the office building during three consecutive days in December 1986. All measurements were done in a height of approximately 1.2 m (breathing zone). Temperature and humidity were also measured one year earlier in a pilot study, and registered continuously electronically. At the time of the present survey, 1278 persons were employed in the building.

The measurements

For a gravimetric determination of airborne aerosols, a portable piezobalance, TSI Model 5500 with a cut size of 3.5 µm, was used. For a numerical determination, an Aerosol Particle Counter Model 225/519 from Royco Instruments was used. The particles were separated into the ranges 0.3-3.0 and 3.0-12.0 µm. Concentrations of aerosols were determined as mean values during 1-2 min. Each day, 40-50 readings were recorded.

In order to identify mineral fibres, air was sampled through Nuclepore polycarbonate filters with 0.4 µm pore size. The size of each sample was approximately 500 L of air, collected over periods of 4 h. The filters were analysed using scanning electron microscopy (SEM) with an x-ray microanalyzer.

Volatile organic compounds in the air were enriched on activated charcoal tubes (SKC lot. 120). The sampling rates were from 450-550 mL min^{-1} and sampling volumes ranged from 600 - 800 L. The charcoal tubes were desorbed with carbon disulfide (Merck Uvasol Spectroscopic grade). The samples were analysed on a Hewlett-Packard 5890 gas chromatograph equipped with a flame ionization detector (FID) and a Supelco SBP 1 column (60 m × 0.75 mm i.d.).

Formaldehyde was adsorbed on N-benzylethanolamine-coated sorbent tubes (Orbo-22 from Supelco). Also direct-reading indicator tubes were used (Dräger tube formaldehyde 0.2/a). Dräger tubes were also used for the determination of ozone in rooms with copy machines (Dräger tube ozone 0.05/a). Formaldehyde was desorbed from the sorbent tubes with iso-octane (Merck Uvasol spectroscopic grade) in an ultrasonic bath. The analyses were carried out on a Hewlett-Packard 5890 gas chromatograph equipped with a flame ionization detector and a Supelco fused silica Carbowax 20 M column (30 m × 0.25 mm i.d.).

Samples of organic vapours and formaldehyde on sorbent tubes were taken in duplicate on each location. Each sample was collected over a period of 24 h.

Electrostatic charge on visual display units, as well as on the operators, were measured with an Electrostatic Locator (ACL International, Model 300).

Spores of bacteria and fungi were collected on selective growth medium in Petri dishes which were placed in the air outlets of the ventilation system.

A psychrometer (Assman) was used for the determination of air temperatures (dry bulb) and relative humidities. In addition to the measurements carried out during the three days survey, temperature and humidity were also determined in a pilot study one year earlier and on several other occasions using the psychrometer. In addition, there was a continuous electronic registration of temperature and humidity (Tour-Anderson, DEGL D-60-20 and DEGHRL D-60-45, respectively). The electronic registration of relative humidity was used to start the humidification unit, implying that relative humidities below 35% should occur only intermittently.

The questionnaire survey

Self-administered questionnaires with pre-coded response categories were distributed among the entire workforce of 1278 employees in the office building in December 1986, simultaneously with the physical survey. The questionnaires were in Norwegian and were designed in cooperation with representatives of the employees according to principles described by Reeves and Harper (1981). The questionnaire covered the subjective perception of temperature, humidity and draught, the prevalence of work-related symptoms, work with visual display units, smoking habits, background factors like sex, age, position level (job category), and psychosocial factors like job satisfaction. The terms used to classify the perception of temperature, humidity and draught, position level, and job satisfaction are given in Table 3 to 5. The work-related symptoms were classified in terms familiar to the employees; these terms are given in Table 6 and Fig. 2. The questionnaires were completed anonymously by 936 of the employees, implying a response rate of 73%. The respondents were representative with respect to background factors like sex, position level, and age.

For statistical treatment of the data, multivariate analysis by means of crosstabulations was used (Hellevik 1984). The method overcomes measurement problems in regression analysis which requires data with a normal distribution at a high level of measurement. In the present survey, most variables are on an ordinal scale. Furthermore, the different sizes of subgroups are compensated for by the use of size-weighted differences in proportions. The coefficients obtained are measures of the influence of each variable adjusted for the other independent variables in the model.

RESULTS

The measurements

The results from the gravimetrical and the numerical determination of the aerosols are given in Table 1. The results obtained during the first and second day of the survey were in accordance with results obtained in the pilot study one year earlier. An increase in the aerosol concentration was observed the third day of the survey, probably due to stormy weather generating aerosols of sodium chloride from the sea. Sampling of aerosols was not carried out when tobacco smoking was observed. The aerosol concentrations in Table 1 therefore represent the background level. In the presence of environmental tobacco smoke, the concentrations increased 10 to 100 times.

Table 1. Concentration of airborne dust.

Day	Number m^{-3} 0.3-3.0μm	Number m^{-3} 3.0-12μm	$\mu g\ m^{-3}$ <3.5μm
1	$1.0\times10^7-2.8\times10^7$	$1.8\times10^4-1.3\times10^5$	20-30
2	$6.0\times10^6-2.0\times10^7$	$1.8\times10^4-1.3\times10^5$	20-30
3	$2.0\times10^7-2.2\times10^8$	$8.0\times10^3-9.6\times10^5$	30-50

Table 2. Temperature and humidity.

	Temperature ± SD °C	Humidity ± SD %
1985 pilot	22.6 ± 0.6	36.3 ± 5.8
1986 manual	22.8 ± 1.0	36.6 ± 3.6
1986 electronic	22.7 ± 0.8	38.8 ± 3.1

Mineral fibres in the air were not identified in any of the filter samples; nor were growth of bacteria or fungi from the ventilation system detected on the selective growth medium.

The concentration of organic vapours was lower than 0.5 mg m^{-3}. The most abundant compounds were toluene and xylenes. Concentrations of formaldehyde and ozone were below the detection limits (60 and 35 µg m^{-3}, respectively).

During the three days survey, the mean relative humidity measured with the psychrometer was 36.6% (Table 2). This is in accordance with the measurements one year earlier and with the electronical readings and confirms that due to the humidification unit, the relative humidity will only occasionally be lower than 35%.

The mean temperature was 22.8 °C (Table 2). Also, the temperature registrations were in accordance with the measurements one year earlier and with the electronic registrations.

Personal electrostatic charge was not found, probably due to the antistatic properties of the carpets and a satisfactorily high air humidity. Approximately one third of the visual display units had

Table 3. The subjective perception of air humidity (% of respondents).

	Dry	Satisfactory	Humid	N=100%
Sex:				
Female	58	40	2	297
Male	27	72	1	614
Total:	37	62	1	911
Position level:				
Section head, manager	18	80	2	170
Supervisor	35	64	1	127
Engineer, consultant	34	65	1	397
Operator, skilled worker	64	37	0	52
Secretary	57	41	2	156
Job satisfaction:				
Very satisfactory	27	73	0	275
Satisfactory	39	60	1	477
Unsatisfactory	49	47	4	125
Very unsatisfactory	60	40	0	20

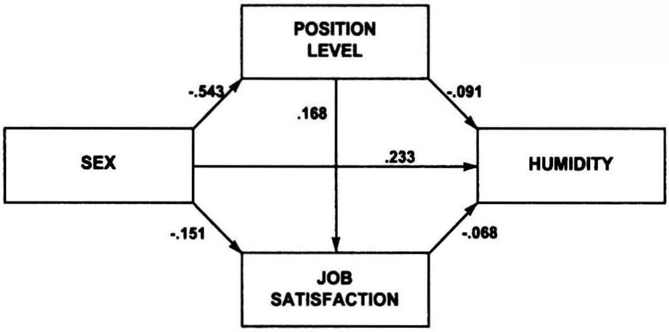


Fig. 1. Interrelations between background factors and the subjective perception of air humidity.

Table 4. The subjective perception of temperature (% of respondents).

	Warm	Satisfactory	Cold	N=100%
Sex:				
Female	19	63	18	294
Male	16	77	7	612
Total	17	73	10	906
Position level:				
Section head, manager	11	83	7	169
Supervisor	21	70	9	127
Engineer, consultant	17	73	10	396
Operator, skilled worker	20	68	12	50
Secretary	20	65	15	155
Job satisfaction:				
Very satisfactory	15	75	9	273
Satisfactory	16	73	11	474
Unsatisfactory	21	66	13	126
Very unsatisfactory	30	55	15	20

Table 5. The subjective sensation of draught (% of respondents).

	Never	Occasionally	Often	N=100%
Sex:				
Female	55	39	6	293
Male	69	28	3	611
Total	65	31	4	904
Position level:				
Section head, manager	70	26	4	171
Supervisor	67	32	2	127
Engineer, consultant	67	30	3	389
Operator, skilled worker	57	37	6	49
Secretary	55	38	7	159
Job satisfaction:				
Very satisfactory	72	26	2	274
Satisfactory	64	32	4	474
Unsatisfactory	55	41	4	120
Very unsatisfactory	48	33	19	21

an electrostatic charge of 3000-7000 Volts. Many of these units were, however, equipped with antistatic screens that removed the charge.

The questionnaire survey

As many as 37% of the respondents felt that the air was dry. According to Table 3, the sensation of dry air varies with position level, sex, and job satisfaction. Figure 1 visualizes the interrelations between these three parameters and the statistically significant influence of sex and position level on the subjective perception of air humidity. The relation between job satisfaction and the sensation of dry air is, however, not statistically significant when adjusted for sex and position level (Table 6).

The positive relation between sex and the subjective perception of air humidity means that women, to a greater extent than men, perceive the air as dry. The negative relation between position level and the perception of air humidity means that persons at higher position levels perceive the air as dry to a lesser degree than persons at lower position levels.

Table 6. Influence of different factors on the subjective evaluation of indoor climate and the occurrence of subjective symptoms. The coefficients are measures of the influence of each independent variable adjusted for the two others in the model.

Influence on	Influence of		
	Sex	Pos.lev.	Job.satisf.
Humidity	0.233***	-0.091**	-0.068
Temp.	-0.007	-0.023	-0.014
Draught	0.105*	-0.039*	-0.068
			Dry air
Headache	0.103***	-0.083***	0.069*
Irr.eye	0.086**	-0.092***	0.028
Irr.nose	0.073***	0.077***	0.132***
Irr./dry skin	0.181***	-0.037***	0.153***
Skin rash	0.101**	0.014**	0.064*
			VDU
Humidity	0.250***	-0.075***	0.011
Headache	0.103***	-0.105***	0.033
Irr.eye	0.079**	-0.076***	0.096**
Irr./dry skin	0.205***	-0.059***	0.045
Skin rash	0.124***	0.011***	-0.009
			ETS
Humidity	0.239***	-0.094***	0.075
			Temp.
Humidity	0.244***	-0.092***	0.195**
			Draught
Temp.(low)	0.115***	0.038***	0.117***

***P<0.001; **P<0.01; *P<0.05

The subjective evaluation of the temperature conditions demonstrates that, especially among women, there are approximately equally as many who feel the air is warm than cold (Table 4). Altogether, 73% are satisfied with the indoor air temperature.

Only 4% responded that they "often" are bothered by draught, while 31% are bothered by draught "occasionally" (Table 5). The subjective sensation of draught is dependent on sex and position level (Table 6).

Figure 2 shows the prevalence of work-related symptoms occurring "often" and "occasionally" among the employees. The occurrence of work-related symptoms is dependent on sex and position level (Table 6). Skin problems and irritation of upper airways occur more often among those who perceive dry air (Table 6).

There is a relation between the occurrence of eye irritation and work with visual display units. However, there is no apparent influence of work with visual display units on the occurrence of other work-related symptoms or the sensation of dry air. Furthermore, there is no statistically significant relation between the sensation of dry air and the subjective

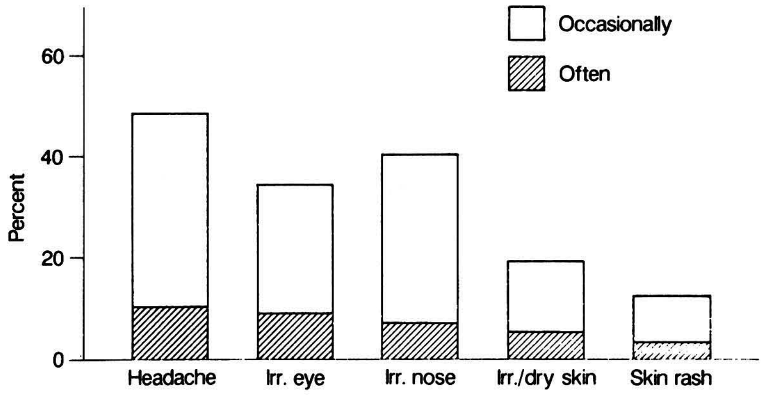


Fig. 2. Work related symptoms occurring often and occasionally (% of respondents).

feeling of exposure to environmental tobacco smoke (Table 6).

A most striking finding is the very strong relation between the sensation of high temperature and the sensation of dry air when adjusted for the most important background factors, sex and position level (Table 6). There is also an independent and statistically significant relation between the experience of draught and the sensation of low temperature (Table 6).

DISCUSSION

The main problem as experienced by the employees is dry air; a percentage of 37% dissatisfied employees is higher than criteria values of 20 and 10% given by ASHRAE (1989) and Scanvac (1991), respectively. Furthermore, there is a statistically significant relation between the perception of dry air and the prevalence of work-related symptoms. It is known that the prevalence of sick building symptoms, including the sensation of dry air, is higher among women than among men (Burge et al. 1987; Hedge et al. 1989; Jaakkola et al. 1987; Skov et al. 1987; Skov et al. 1989). Furthermore, it has been demonstrated that the prevalence of these symptoms relates to the position level and, usually, there is a relation between sex and position level in most companies (Burge et al. 1987; Skov et al. 1987; Skov et al. 1989). The present work confirms all these findings and demonstrates that both sex and position level each independently influence the perception of air humidity and the prevalence of work related symptoms (Table 6).

Due to the central humidification unit in the ventilation system, the air humidity will only occasionally be lower than 35% which is confirmed by the measurements. Usually, 30% is considered sufficient. Even 20% may be sufficient if the temperature is below 20-22 °C (Andersson et al. 1975; Wyon 1987). In fact, it has been demonstrated that man is almost incapable of judging air humidity in the range of 20-70% in clean air (Andersen et al. 1973; Göthe et al. 1987).

Therefore, the sensation of dry air in the present survey may be related to some factor other than air humidity. In the absence of tobacco smoking, the concentrations of dust and vapour are at lower levels than reported in other non-residential buildings (Hansen et al. 1987; Valbjørn and Skov 1987; Turk et al. 1987) and within acceptable limits (Scanvac 1991). The concentrations of organic vapours are below those levels that have been reported to give mucus membrane symptoms (Mølhave and Bach 1985; Mølhave et al. 1986). There are no indications that those who complain about dry air are those who are bothered by environmental tobacco smoke (Table 6). The multivariate analyses of the data from the questionnaire survey demonstrate a significant relation between the subjective sensation of high temperature and dry air. According to the measurements, the mean air temperature is 22.8 °C with a standard deviation of 1.0 °C. The recommended level is 20-22 °C (Andersson et al. 1975; Göthe et al. 1987; Seppänen 1987). It has been demonstrated that sick building symptoms including the sensation of dryness, may disappear by lowering the air temperature to the recommended level (Jaakkola et al. 1987; Jaakkola et al. 1989).

Based on all the factors discussed above (the measurements, data from current literature and the correlation between the subjective evaluation of temperature and humidity), it is suggested that in the present survey high temperature is a contributing factor to the sensation of dryness. It is emphasized that this suggestion can only be proved by a follow-up study. In our office building, the temperature was lowered after the present survey had been carried out. However, as the complaining seemed to cease, it was decided by the management and representatives of the employees that priority should not be given to another investigation.

Another possible reason for the sensation of dryness that cannot be ruled out is environmental tobacco smoke (ETS), although there is no correlation between the subjective evaluation of humidity and the subjective feeling of being exposed to ETS. The reported concentrations of airborne dust were low. The measurements were, however, carried out when tobacco smoking was not observed, and the data represent background values. Tobacco smoking was permitted in the building and, when it occurred, the concentrations of airborne dust increased 10 to 100 times in the vicinity of the source.

A percentage of 27% of the respondents was dissatisfied with the temperature conditions; this percentage being relatively evenly distributed among those who felt the air as cold and those who felt the air as warm. Experiments in climate chambers have demonstrated that, as a theoretical minimum, there will be 5% of the employees dissatisfied (Fanger 1972). Possible reasons for the present finding are variations in temperature (as demonstrated by the relatively large standard deviations), differences in clothing, and in physical activity among the employees.

The present approach comprising both an objective and a subjective evaluation of the indoor environment has been useful, although the design does not permit any causal relationship between the subjective and the objective evaluations to be drawn. In some instances, the measurements confirm the subjective evaluation made by the employees. In other instances, there are discrepancies between the two kinds of evaluations. By comparing them it is, however, possible to obtain indications of what the problems are and which factors should be studied closer. Although the reasons for the sick building symptoms may be physical or chemical, the occurrence of them are influenced by several other factors.

Acknowledgment — The filters were analysed by B. K. Johnsen and W. Eduard at the National Institute of Occupational Health, Oslo, Norway. The identification of microorganisms were carried out by S. Gravesen at the Allergologic Laboratory, Copenhagen, Denmark. The authors also wish to thank K. Bøe and A. Skogland, Statoil, Stavanger, Norway for valuable support and encouraging discussions.

REFERENCES

ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.). Ventilation for acceptable indoor air quality. Standard 62-1989. ASHRAE, Atlanta, GA.

Andersen, I.; Lundquist, G.R.; Proctor, D.F. Human perception of humidity under four controlled conditions. Arch. Environ. Health. 26: 22-27; 1973.

Andersson, L.O.; Frisk, P.; Löfstedt, B.; Wyon, D.P. Human response to dry, humidified and intermittently humidified air. Swedish Building Research, Document D11; 1975. ISBN 91-540-2510-9. Swedish Building Research, Stockholm.

Burge, S.; Hedge, A.; Wilson, S.; Bass, J.H.; Robertson, A. Sick building syndrome: A study of 4373 office workers. Ann. occup. Hyg. 31: 493-504; 1987.

Fanger, P.O. Thermal comfort. New York, NY: McGraw-Hill Book Company; 1972.

Finnegan, M.J.; Pickering, C.A.C.; Burge, P.S. Sick building syndrome: prevalence studies. Br. Med. J. 289: 1573-1575; 1984.

Göthe, C.-J.; Ancker, K.; Bjurström, R. Relative humidity, temperature and subjective perception of "dry air". In: Seifert, B.; Esdorn, H.; Fischer, M.; Ruden, H.; Wegner, J., eds. Proc. 4th international conference on indoor air quality and climate. Vol. 3. Berlin: Institute for Water, Soil and Air Hygiene; 1987: 443-447.

Hansen, S.O. Klyve, L.B.; Malvik, B.; Mathiesen, H.M. Indoor climate and health problems. Report STF15 A87017; ISBN 82-595-4529-2; 1987. SINTEF, Trondheim.

Hedge, A.; Burge, P.S.; Robertson, A.S.; Wilson, S.; Harris-Bass, J. Work-related illness in offices: a proposed model of the "sick building syndrome". Environ. Int. 15:143-158; 1989.

Hellevik, O. Introduction to causal analysis. London: Allan and Unwin; 1984.

Jaakkola, J.J.K.; Heinonen, O.P.; Seppänen, O. (1987) Mechanical ventilation in an office building and sick building syndrome. A short-term trial. In: Seifert, B.; Esdorn, H.; Fischer, M.; Ruden, H.; Wegner, J., eds. Proc. 4th international conference on indoor air quality and climate. Vol. 2. Berlin: Institute for Water, Soil and Air Hygiene; 1987:454-458.

Jaakkola, J.J.K.; Heinonen, O.P.; Seppänen, O. Sick building syndrome, sensation of dryness and thermal comfort in relation to room temperature in an office building: need for individual control of temperature. Environ. Int. 15:163-168; 1989.

Mølhave, L. Volatile organic compounds as indoor air pollutants. In: Gamage, R.B.; Kaye, S.V.; Jacobs, V.A., eds. Indoor air and human health. Chelsea, Mich.: Lewis Publishers Inc.; 1985: 403.

Mølhave, L.; Bach, B. Indoor climatic complaints and atmospheric pollution with volatile organic compounds. Ugeskr. Læger 147:4032-4036; 1985.

Mølhave, L.; Bach, B.; Pedersen, O.F. Human reactions to low concentrations of volatile organic compounds. Environ. Int. 12:167-175; 1986.

Nilsen, A. Facial rash in visual display unit operators. Contact Dermatitis. 8:25-28; 1982.

Reeves, T. K.; Harper, D. Surveys at work. A practitioner's guide. Maidenhead, Berkshire: McGraw-Hill Book Company (UK) Limited; 1981.

Robertson, A.S.; et al. Comparison of health problems related to work and environmental measurements in two office buildings with different ventilation systems. Br. Med. J. 291:373-376; 1985.

Scanvac (Federation of the Scandinavian HVAC Organisations). Classified indoor climate systems. Guidelines and specifications. Swedish Indoor Climate Institute, Stockholm; 1991.

Seppänen, O.A. Ventilation and indoor air quality. In: Seifert, B.; Esdorn, H.; Fischer, M.; Ruden, H.; Wegner, J., eds. Proc. 4th international conference on indoor air quality and climate. Vol. 3. Berlin: Institute for Water, Soil and Air Hygiene; 1987:152-156.

Skov, P.; Valbjørn, O.; DISG. The "sick" building syndrome in the office environment: The Danish town hall study. Environ. Int. 13:339-349; 1987.

Skov, P.; Valbjørn, O.; Pedersen, B. V.; DISG. Influence of personal characteristics, job-related factors and psychosocial factors on the sick building syndrome. Scand. J. Work Environ. Health. 15:286-295; 1989.

Turk, B.H.; Grimsrud, D.T.; Brown, J.T.; Geisling-Sobotka, K.L.; Harrison, J.; Prill, R.J. Commercial building ventilation rates and particle concentrations. In: Seifert, B.; Esdorn, H.; Fischer, M.; Ruden, H.; Wegner, J., eds. Proc. 4th international conference on indoor air quality and climate. Vol. 1. Berlin: Institute for Water, Soil and Air Hygiene; 1987:610-614.

Valbjørn, O.; Kousgård, N. Headache and mucus membrane irritation. An epidemiological study. In: Seifert, B.; Esdorn, H.; Fischer, M.; Ruden, H.; Wegner, J., eds. Proc. 4th international conference on indoor air quality and climate. Vol. 2. Berlin: Institute for Water, Soil and Air Hygiene; 1987:249-254.

Valbjørn, O.; Skov, P. Influence of indoor climate on the sick building syndrome prevalence. In: Seifert, B.; Esdorn, H.; Fischer, M.; Ruden, H.; Wegner, J., eds. Proc. 4th international conference on indoor air quality and climate. Vol. 2. Berlin: Institute for Water, Soil and Air Hygiene; 1987:593-597.

Wedberg, W.C. Facial particle exposure in the VDU environment: the role of static electricity. In: Knave, B.; Widebäck, P.-G., eds. Work with display units. North-Holland: Elsevier Science Publishers B.V.; 1987: 151.

WHO (World Health Organization). Indoor air quality research. EURO reports and studies 103; 1984. WHO, Vienna.

Wyon, D.P. Buildings fit for people to live and work in. Swedish Building Research, Document G20:195-202; 1987. Swedish Building Research, Stockholm.

Environment International, Vol. 18, pp. 73 - 86, 1992
Printed in the U.S.A.

0160-4120/92 $5.00 +.00

A MODEL FOR THE CRITICAL HOURLY CONCENTRATION, RECEPTOR DISTANCE, AND METEOROLOGICAL CONDITIONS FOR POINT SOURCES WITH MOMENTUM-DOMINATED PLUME RISE

Alexander P. Economopoulos
Environmental Technology Section, Institute of Nuclear Technology and Radiation Protection, National Centre for Scientific Research, DEMOKRITOS, Aghia Paraskevi, Athens 153 10, Greece

EI 9008-185M (Received 24 September 1990; accepted 27 July 1991)

A point source pollutant dispersion model is developed, allowing fast evaluation of the maximum one-hour-average ground concentrations, along with the corresponding critical receptor distance and meteorological conditions (wind speed and stability class) for urban and rural areas, with or without plume spread during plume rise. Site-specific meteorological data are not required, as the computed concentrations are maximized against all valid combinations of wind speed, stability class, and mixing heights. The model combines, under a constrained numerical extremization algorithm, the minimum mixing height model of Benkley and Schulman as adapted for urban areas by Economopoulos, with the dispersion relations of Briggs and Pasquill-Gifford for urban or rural settings respectively, the plume spread during plume rise correlation of Pasquill, and the momentum plume rise relations of Briggs. The model is particularly suited for air pollution management studies, as it allows fast screening of selected point sources in study areas and evaluation of the ways to have their impact reduced. Also, for regulatory purposes, as it allows accurate setting of minimum stack height requirements as a function of the exit gas volume and velocity, the pollutant emission rates, and their hourly concentration standards.

INTRODUCTION

Dispersion models constitute a prominent element in environmental management studies, since they link emission rates and emission reduction alternatives to air pollution levels, providing thus the basis for the formulation of rational pollution control strategies (Economopoulos and De Koning 1989). Simplicity, however, both in terms of model use and data requirements, is an important element for their widespread use.

Naturally, the formulation of simple models has been pursued over many years. Recent developments in this area include a seasonal or annual dispersion model for traffic and space heating emissions in urban settings (Economopoulos in press, a) which combines ease of use with reasonable accuracy, as well as a short term model for critical impact analysis of point sources under thermal plume rise conditions (Economopoulos in press, b).

In the present paper, a short-term dispersion model is developed allowing fast critical impact analysis of emissions from point sources under momentum plume rise conditions. The computed maximum hourly concentrations provide a useful yardstick for the purpose of identifying point sources, from which the impact may not be acceptable. For, if some air quality standards are to be violated, those violated first and foremost are normally the short-term ones.

The momentum plume rise becomes dominant when the temperature of the exhaust gas is not much higher than that of the ambient air. In practice, this situation is commonly encountered with exhaust gases from fugitive sources and processes, with ventilation gas from storage and transportation systems (e.g., in fertilizer, textile filament, metallurgical, or nonmetallic minerals processing industries), or with scrubber tail gases. For such cases, use of the present model allows fast estimation of the maximum ground concentration, as well as the critical distance and meteorological conditions (wind speed and stability class) leading into it. Relatively unstable pollutants can be dealt with, but flat terrain topography remains a requirement, as in most Gaussian dispersion models. As site-specific meteorological data are not used, the model inputs are restricted to the physical dimensions of the stack, the volume of the released gas, and the pollutant emission rates. The model is thus suitable for the fast screening of selected point sources within a study area, for the purpose of assessing whether their ground impact is likely to violate acceptable short-term air quality standards, as well as for exploring mitigation options. The model is also suitable for regulatory purposes, as it makes possible to set minimum stack height requirements as function of the exit gas volume and velocity, the pollutant emission rates, and their hourly concentration standards.

NOTATION

ACMS	= Stack gas volume, Actual m^3/s
C_j	= One-hour average normalized ground-level concentration of pollutant j equal to ψ_j/Q_j, $\mu g/m^3/Mg/h$
C_{cr}	= Critical one-hour average normalized ground-level pollutant concentration, úg/m^3/Mg/h
D	= Internal stack diameter at gas exit level, m
F_m	= Momentum plume rise parameter defined by Equation (12), Actual m^3/s
F_t	= Thermal plume rise parameter defined by Equation (9), Actual m^2/s
H	= Physical stack height, m
H_{eff}	= Effective plume height at the receptor, m
H_f	= Effective final plume height, m
K	= Pasquill stability class, 1 to 6, or A to F
K_{cr}	= Critical Pasquill stability class corresponding to C_{cr}, 1 to 6, or A to F
L	= Depth of mixing layer, m
L_m	= Depth of mixing layer due to mechanical turbulence, m
Q_j	= Rate of emission of pollutant j from all identical neighbouring stacks, Mg/h
t	= Time required for a released pollutant to reach the receptor, s
$t_{1/2}$	= Half-life of a reactive pollutant, s
T_a	= Ambient air temperature, °K
T_s	= Stack gas exit temperature, °K
U	= Wind speed at anemometer height (10m), m/s
U_{cr}	= Critical wind speed at anemometer height (10m) corresponding to C_{cr}, m/s
U_s	= Wind speed at the physical stack height level, m/s
V_s	= Exit gas velocity, m/s
x	= Distance of a receptor from stack, m
x_{cr}	= Critical receptor distance corresponding to C_{cr}, m
x_f	= Distance to final plume rise, m
z	= Height of a receptor, m
ΔH_d	= Stack downwash, m
ΔH_r	= Momentum plume rise, m
σ_y	= Standard deviation of concentration distribution in the horizontal plane, adjusted, if required, for buoyancy-induced dispersion, Equation (3), m
σ_y'	= Standard deviation of plume concentration distribution in the horizontal plane, m
σ_z	= Standard deviation of the concentration distribution in the vertical plane, adjusted, if required,for buoyancy-induced dispersion, Equation (4), m
σ_z'	= Standard deviation of plume concentration distribution in the vertical plane, m
ψ_j	= One-hour average concentration of pollutant j, $\mu g/m^3$
$(\psi_{std})_j$	= Maximum allowed one-hour concentration of pollutant j, $\mu g/m^3$

In situations where violation of the air quality standards is anticipated, more detailed follow-up dispersion estimates using computer models with site-specific meteorological data are advisable. One can investigate, for example, the impact on specific receptors, compute the frequency of exceeding certain concentration levels, or assess the overall impact from multiple sources.

DIFFUSION OF GASEOUS OR AEROSOL POLLUTANTS

A fundamental assumption in most air pollution models is that of the Gaussian distribution of plume spread, in both the horizontal and vertical planes. Additional assumptions, commonly made to simplify the diffusion equations, postulate steady-state conditions, constant eddy diffusivities, complete reflection at the ground and at the mixing layer top under unstable or neutral conditions, and stable pollutants, which follow the turbulent motion of the atmosphere. As the objective of this study is to assess the maximum emission impact from a given stack, we are primarily interested in computing the ground concentrations (z = 0) below the plume centreline (y = 0). Under such conditions the well-known Gausssian diffusion equations become:

For unlimited mixing or for stable meteorological conditions,

$$C = \frac{1}{\pi \sigma_y \sigma_z U_s} \exp\left[-\frac{1}{2}\left[\frac{H_{eff}}{\sigma_z}\right]^2\right] \tag{1}$$

and for limited mixing under unstable or neutral conditions,

$$C = \frac{1}{\pi \sigma_y \sigma_z U_s} \sum_{n=-\infty}^{n=\infty} \exp\left[-\frac{1}{2}\left[\frac{H_{eff}+2nL}{\sigma_z}\right]^2\right] \tag{2}$$

DISPERSION COEFFICIENTS

The standard deviation coefficients of the plume concentration, σ_y' and $\sigma_z'$are computed from the relations of Briggs for urban areas, as reported by Gifford (1976) and derived from the tracer experiments of McElroy and Pooler (1968), or from the relation of Pasquill (1961, 1974) and Gifford (1961) for rural areas. The standard deviation coefficients used in our model, σ_y and σ_z, are adjusted when the buoyancy induced dispersion assumption is made, so as to include the additional spread that takes place during the plume rise (Pasquill 1976). Thus:

$$\sigma_y = \begin{cases} \sigma_y' & \text{with no-buoyancy-induced dispersion,} \\ (\sigma_y'^2 + \sigma_b^2)^{0.5} & \text{with buoyancy-induced dispersion} \end{cases} \tag{3}$$

$$\sigma_z = \begin{cases} \sigma_z' & \text{with no-buoyancy-induced dispersion,} \\ (\sigma_z'^2 + \sigma_b^2)^{0.5} & \text{with buoyancy-induced dispersion} \end{cases} \tag{4}$$

where,

$$\sigma_b = \frac{\Delta H_r}{3.5} \tag{5}$$

WIND SPEED PROFILE

The wind speed at the stack height, U_s, which is used in the diffusion equation to account for the initial dilution of the emitted pollutants and to represent the conditions throughout the vertical dispersion field, is computed as a function of the measured wind speed at the anemometer height (10 m above the ground), U, from the following power-law equation:

$$U_s = U\,(H/10)^p \tag{6}$$

The exponent p values used here are the same as in USEPA regulatory models such as RAM (Catalano et al. 1987). These, for urban areas and for stabilities A to F, are 0.15, 0.15, 0.20, 0.25, 0.30, and 0.30, respectively; for rural areas and stabilities A to F, they are 0.07, 0.07, 0.10, 0.15, 0.35, and 0.55, respectively.

EFFECTIVE PLUME HEIGHT

The effective plume height, H_{eff}, as given in Equation (7) below, is a function of the stack downwash, ΔH_d, and the momentum rise, ΔH_r:

$$H_{eff} = H - \Delta H_d + \Delta H_r \tag{7}$$

Stack downwash occurs, according to Briggs (1969), in situations where $V_s < 1.5U_s$ reducing the effective stack height by $2D(1.5-V_s/U_s)$ m. In momentum-dominated plume rise situations, which are of interest in this study, stack downwash can be ignored since V_s is normally high. This is the only simplifying assumption introduced in our model over those used in most Gaussian dispersion computer models.

Plume rise takes place due to momentum or buoyant forces stemming from the high velocity or the elevated temperature, respectively, of the exhaust gas. This momentum or thermal plume rise is an important parameter in dispersion calculations, as it affects significantly the computed level of ground pollutant concentrations.

In order to calculate the effective plume height, we must first determine whether a plume rise is momentum- or buoyancy-dominated. Briggs suggested that the plume rise is momentum-dominated when the ΔH_r due to momentum exceeds that due to buoyancy. Based on this and on Briggs plume rise correlations, it is possible to compute a cross-over temperature difference ΔT_{cr}. If it is exceeded by the difference in the temperatures of the exhaust gas and the ambient air, the plume rise is buoyancy-dominated, otherwise momentum-dominated.

Under stability classes A to D, the cross-over temperature difference is found by setting Equation (5.2) of Briggs (1969) equal to the combination of Equations (6) and (7) of Briggs (1971) and solving for ΔT_{cr}:

$$\Delta T_{cr} = \begin{cases} 0.02970 \dfrac{T_s\, V_s^{0.3333}}{D^{0.6667}} & \text{for } F_t < 17.61 \\ 0.00575 \dfrac{T_s\, V_s^{0.6667}}{D^{0.3333}} & \text{for } F_t = 17.61 \text{ or } > 17.61 \end{cases} \tag{8}$$

where

$$F_t = ACMS \, \frac{T_s - T_a}{T_s} \tag{9}$$

Under stability classes E and F, the cross-over temperature difference is found by setting Equation (59) of Briggs (1975) equal to Equation (4.28) of Briggs (1969) and solving for ΔT_{cr}. Assuming further that $\theta T_a/\theta z = 2$ °C/100m for stability E and that $\theta T_a/\theta z = 3.5$ °C/100m for stability F, one gets:

For stability class E,

$$\Delta T_{cr} = 0.00867\; T_a^{0.5}\; V_s \tag{10}$$

for stability class F,

$$\Delta T_{cr} = 0.01147\; T_a^{0.5}\; V_s \tag{11}$$

As the critical impact from any stack, under both buoyant or momentum plume rise conditions, occurs always under unstable meteorological conditions (see below and Economopoulos in press, b), only Equations (8) and (9) above are relevant to our analysis.

For the remainder of this paper, the underline assumption is that the plume rise is momentum-dominated, otherwise another model (Economopoulos in press, b) should to be used.

For the following analysis, the momentum plume rise parameter, F_m, is introduced, which will control fully, not only the momentum rise of the plume, but also, along with the stack height H, the critical impact from any particular stack. This parameter is defined by Equation (12) below:

$$F_m = D\; V_s \tag{12}$$

Momentum rise occurs close to the point of release under any stability class condition. Thus, the distance to final rise can be assumed to be zero,

$$x_f = 0 \tag{13}$$

and thus, the effective plume height, H_{eff}, above any receptor is always equal to the final plume height, H_f.

Introducing the momentum plume rise parameter F_m from Equation (12) into Briggs' (1969, 1971, 1972, 1973) plume rise correlations, one obtains the following equations for the effective plume height for the various stability classes:

Under stability classes A to D,

$$H_{eff} = H + 3\, \frac{F_m}{U_s} \tag{14}$$

under stability class E,

$$H_{eff} = \text{smaller of} \begin{cases} H + 3 \dfrac{F_m}{U_s} \\ H + 1.24 \dfrac{F_m^{0.6667} \, Ta^{0.5}}{(T_s \, U_s)^{0.3333}} \end{cases} \quad (15)$$

and under stability class F,

$$H_{eff} = \text{smaller of} \begin{cases} H + 3 \dfrac{F_m}{U_s} \\ H + 1.129 \dfrac{F_m^{0.6667} \, Ta^{0.5}}{(Ts \, Us)^{0.3333}} \end{cases} \quad (16)$$

CREDIBLE, MOST ADVERSE MIXING HEIGHTS

From Equation (2), it would appear that under limited-mixing conditions, the concentration C at any particular receptor increases as the mixing height L decreases. The theoretical maximum value is attained when L becomes equal to the effective plume height at the receptor, H_{eff}, as any further decrease in the mixing height yields zero concentration at the receptor. The latter stems from the assumption, commonly made in dispersion models, that the impact from any point source at a receptor ceases to exist when the plume centreline above that receptor crosses the inversion layer, as it is commonly assumed that vertical diffusion is very slow above the inversion capping a mixing layer.

The occurrence of mixing heights, as low as the effective plume height, under the critical wind speed and stability class conditions, is not always probable, nor even always possible. Indeed, in the case of very short stacks, the occurrence of very low mixing heights (as low as 10 m) is unrealistic under unstable conditions, especially in urban areas. Similar is the case for medium height stacks with high F_m values, where high critical wind speeds under unstable conditions are computed and where their simultaneous occurrence with relatively low mixing heights is also unrealistic.

Based on the above, indiscriminate use of the correlation $L = H_{eff}$ for the purpose of maximizing the ground impact from Equation (2), leads often into over-estimates. Thus, a minimum credible mixing height has to be introduced into our model, if the computed critical concentrations are to be realistic for all stack heights and F_m values. The mixing height correlation due to mechanical turbulence proposed by Benkley and Schulman (1979) appears most suitable for this purpose. On the basis of this model and its calibration over flat rural areas, the following relations were derived (Economopoulos in press, b), for the credible, most adverse mixing heights, to be used along with Equation (2) above:

For urban settings,

$$L = \text{larger of} \begin{cases} 207 \, U \\ H_{eff} \text{ from Equations (14) to (16) above.} \end{cases} \quad (17)$$

For rural settings,

$$L = \text{larger of} \begin{cases} 90 \, U \\ H_{eff} \text{ from Equations (14) to (16) above.} \end{cases} \quad (18)$$

Equations (17) and (18) above allow maximization of the computed ground impact from a point source using, whenever possible, the mathematically most adverse mixing height H_{eff}. However, depending on the wind speed and the type of study area, a minimum level is superimposed transforming the values of L, and the computed maximum values of C from Equation (2), from the mathematical, most adverse into the credible, most adverse ones.

ANALYSIS OF FUNCTIONAL DEPENDENCIES AND CRITICAL CONDITIONS

For a given stack, stability class, and wind speed, one can use Equation (12) to calculate the momentum plume rise parameter, F_m, Equation (6) to compute the wind speed at the physical stack height, U_s, Equations (14) to (16) to estimate the effective plume height, H_{eff}, and Equations (17) or (18) to calculate the credible, most adverse mixing height, L. Finally, for a given receptor distance x, the value of the dispersion parameters σ_y' and σ_z' can be computed for urban or rural settings from Briggs' equations as reported by Gifford (1976) and derived from the tracer experiments of McElroy and Pooler (1968), or from Pasquill (1961, 1974) and Gifford (1961) correlations, respectively. The results can be introduced in Equations (3), (4), and (5) to compute σ_y and σ_z, which are adjusted to include the buoyancy-induced dispersion if required, and into Equations (1) or (2) to compute the ground concentration below the plume centerline under stable and unstable conditions, respectively. If one is to estimate the critical ground concentration from that stack, the above procedure has to be repeated for various combinations of stability class, wind speed, and receptor distances, until the overall maximum concentration is obtained.

To simplify the above procedure, Equations (14) to (16) can be introduced into (17) and (18), as well as, along with Briggs or Pasquill-Gifford dispersion correlations, into (3) to (5); and the resulting correlations, along with Equation (6), can be introduced into (1) or (2) (depending on the value of K), to eliminate U_s, H_{eff}, L, σ_y and σ_z. The resulting correlations are fairly complex and vary depending on the assumptions made (urban or rural area, buoyancy or no-buoyancy induced dispersion). For the discussion to follow, however, we are more interested on the functional dependence of C on the other system variables, rather than on the analytical form of the derived correlation. This dependence can be expressed through the following simple correlations:

For stability classes A to D,

$$C = f\,(H, F_m, K, x, U, \text{urban/rural area type, buoyancy-/no-buoyancy-induced dispersion assumption}) \quad (19)$$

and for stability classes E and F,

$$C = f\,(H, F_m, T_s, T_a, K, x, U, \text{urban/rural area type, buoyancy-/no-buoyancy-induced dispersion assumption}). \quad (20)$$

In deriving Equations (19) and (20) above, the observation was made that the wind speed at the stack height, U_s, is a function of U, the stability class K, and the type of area under consideration (urban or rural) as evidenced by Equation (6) and the selection of values for the parameter p. Similarly, the effective plume height, H_{eff}, given from Equations (14) to (16) above, depends on H, F_m, T_s, T_a, U, K, and the type of area under consideration (urban or rural). The dispersion parameters σ_y and σ_z, given by Equations (3) to (5), depend on the receptor distance x, the stability class K, and the type of area under consideration (urban or rural), used to define σ_y'and σ_z', as well as on H_{eff} and on the buoyancy or no-buoyancy induced dispersion assumption. Finally, the credible, most adverse mixing height L, given by Equations (17) and (18), is a function of U, H_{eff}, and the type of area under consideration (urban or rural).

For any given stack and emission conditions, there is a unique combination of receptor distance, surface wind speed, and stability class, which yields the critical ground concentration. Thus, the maximality condition for ground concentration leads into a unique determination of the variables K, x and U. Equations (19) and (20) can thus be written in the form:

For stability classes A to D,

$$C_{cr} = f\,(H, F_m, \text{urban/rural area type, buoyancy-/no-buoyancy-induced dispersion assumption}) \quad (21)$$

and for stability classes E and F,

$$C_{cr} = f\,(H, F_m, T_s, T_a, \text{urban/rural area type, buoyancy-/no-buoyancy-induced dispersion assumption}). \quad (22)$$

Critical ground concentrations from stack emissions are always encountered under unstable conditions and thus, Equation (22) above is of no end-use. Equation (21) shows that for any given combination of area type (urban or rural) and dispersion assumptions (buoyancy- or no-buoyancy-induced dispersion), C_{cr} can be plotted against the physical stack height, H, as function of the parameter F_m. This makes it possible to present in a simple graphical form the results of a constrained numerical extremization algorithm, which solves Equations (2) to (6) and (12) to (18) to compute C as function K, U, and x, and seeks to maximize C yielding C_{cr}, U_{cr}, x_{cr}, and K_{cr} for a broad range of physical stack height and F_m values.

It should be noted that in the extremization algorithm employed for the computation of the above critical conditions, the following constraints on the value of wind speed were incorporated:

for stability Class A — $1 < U < 3$ m/s,
for stability Class B — $1 < U < 5$ m/s,
for stability Class C — $1 < U$,
for stability Class D — $1 < U$,
for stability Class E — $2 < U < 7$ m/s,
for stability Class F — $1 < U < 3$ m/s.

The above constraints reflect the maximum ranges of wind speed for each stability class as derived from Pasquill's (1961) key to stability categories, and also from the modified keys using the radiation and wind speed, as well as the lapse rate and wind speed criteria (IAEA 1980). Their imposition serves the purpose of ensuring that only credible wind speed and stability class combinations are generated by the extremization algorithm.

The constraints reflect also a lower bound in the values of U of 1.0 m/s, common to most Gaussian dispersion models, imposed in order to safeguard against overestimates in the value of C_{cr} caused by the unaccounted meander in the wind direction under very calm conditions.

PRESENTATION AND USE OF THE MODEL RESULTS

The calculated K_{cr} values for all cases are listed in Table 1. Those for C_{cr}, U_{cr}, x_{cr} are plotted as functions of H and F_m in three separate graphs for each combination of area type (urban or rural) and dispersion assumption (buoyancy- or no-buoyancy-induced dispersion). As there are four such combinations possible, a total of 12 graphs would be normally required. It was found, however, that the assumption of no-buoyancy-induced dispersion over the buoyancy-induced one did not produce noticeable differences in the case of urban areas. This observation reduces the number of required graphs to nine.

Table 1. Critical Stability classes for point sources with momentum-dominated plum rise.

	Prevailing K_{cr}
Urban Areas:	
H < 45m	C
30m < H < 100m	A,B,C
100m < H	A,B
Rural Areas:	
H < 15m	C
15m < H < 30m	A,C
30m < H	A

Based on the above, Fig. 1 to 9 along with Table 1 can be used to provide the value of C_{cr}, U_{cr}, x_{cr}, and K_{cr}, for any given combination of urban or rural area with or without buoyancy induced dispersion. Figures 1 to 3 apply to urban areas with or without buoyancy-induced dispersion, Fig. 4 to 5 to rural areas with buoyancy-induced dispersion, and Fig.7 to 9 to rural areas without buoyancy-induced dispersion.

MODEL VALIDATION

RAM version 3.0 dated 85364 (Catalano et al, 1987), a well established U.S. E.P.A. model incorporating all necessary features for the purposes of this study, was used as the reference for validating the predictions of our computer dispersion model.

RAM was further used for validating the computed critical conditions from our combined pollutant dispersion and extremization algorithms. In each test-case RAM computed the ground impact with alternative x, U, and K values. In all cases, the extremization algorithms appeared to have converged into true, globally critical, conditions.

Finally, one of the key conclusions from the analysis of functional dependencies given above, which enabled the presentation of the computed results in the form of simple graphs, was that the physical stack, H, and the momentum plume rise parameter, F_m, were the sole factors affecting the critical impact from any stack. To verify this important point, several stacks with widely different diameters and exit gas velocities were simulated both through our model and RAM. As expected, their computed critical conditions were identical as long as they shared the same H and F_m factors.

EXAMPLE: SO_2 POLLUTION FROM A FERTILIZER PLANT AND MITIGATION OPTIONS

Problem

As an example, a fertilizer plant operating in the outskirts of an urban area and comprising two identical sulphuric acid production units is considered. Both units are equipped with ammonia tail-gas scrubbers and emit via separate stacks. The problem to be solved is to assess whether the SO_2 emissions from these units violate the applicable air quality standards and, if so, what mitigation options are available.

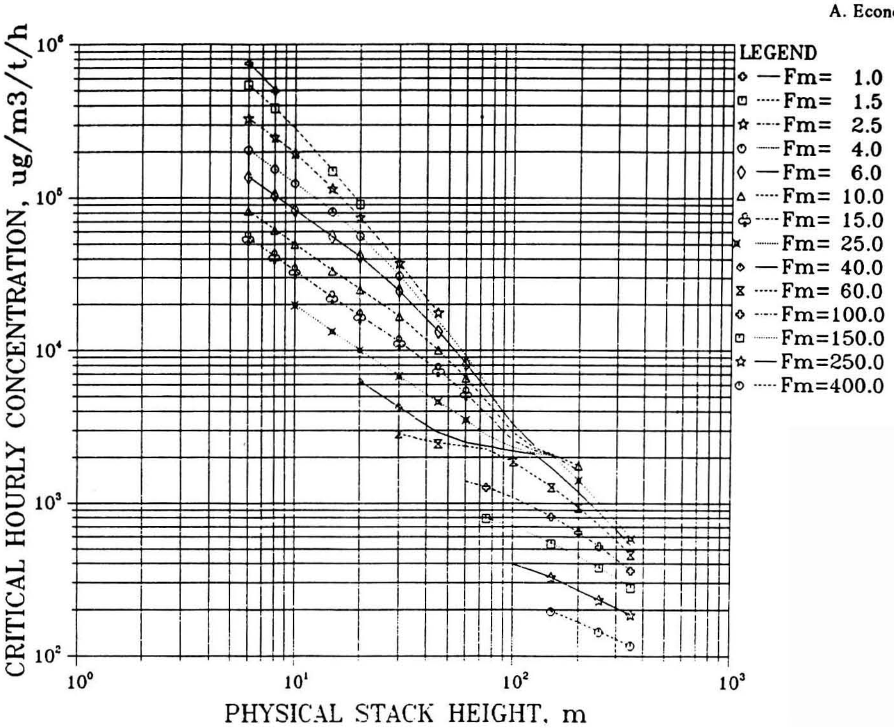


Fig. 1. Critical one-hour-average normalized ground concentration in urban areas.

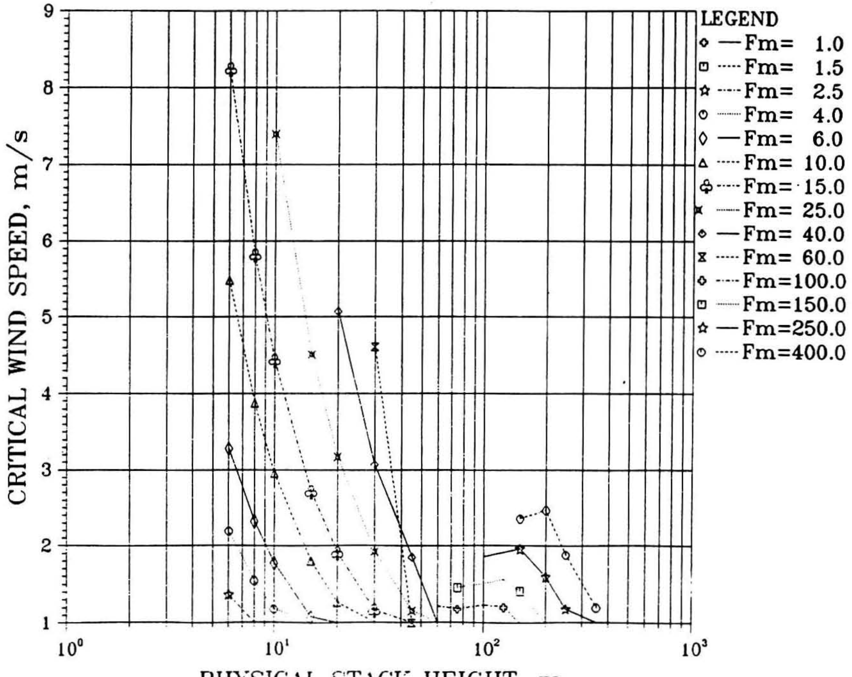


Fig. 2. Critical wind speed in urban areas.

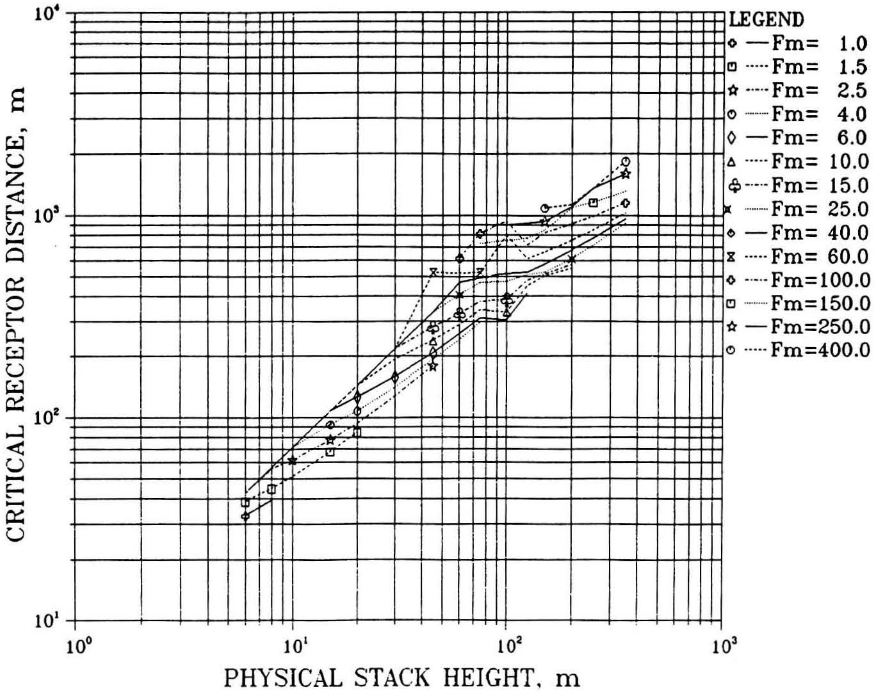


Fig. 3. Critical receptor distance in urban areas.

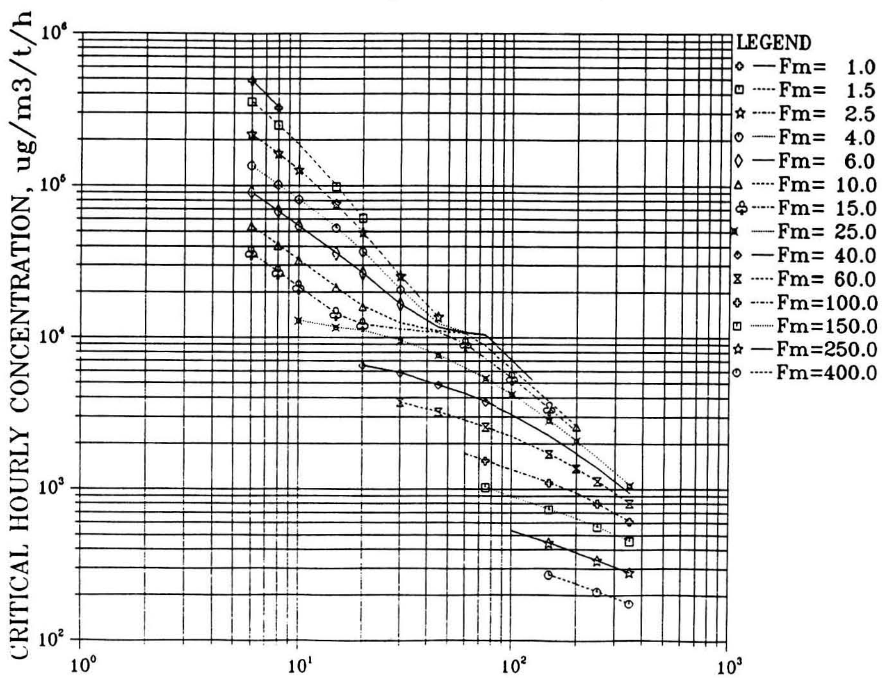


Fig. 4. Critical one-hour-average normalized ground concentration in rural areas with boyancy-induced dispersion.

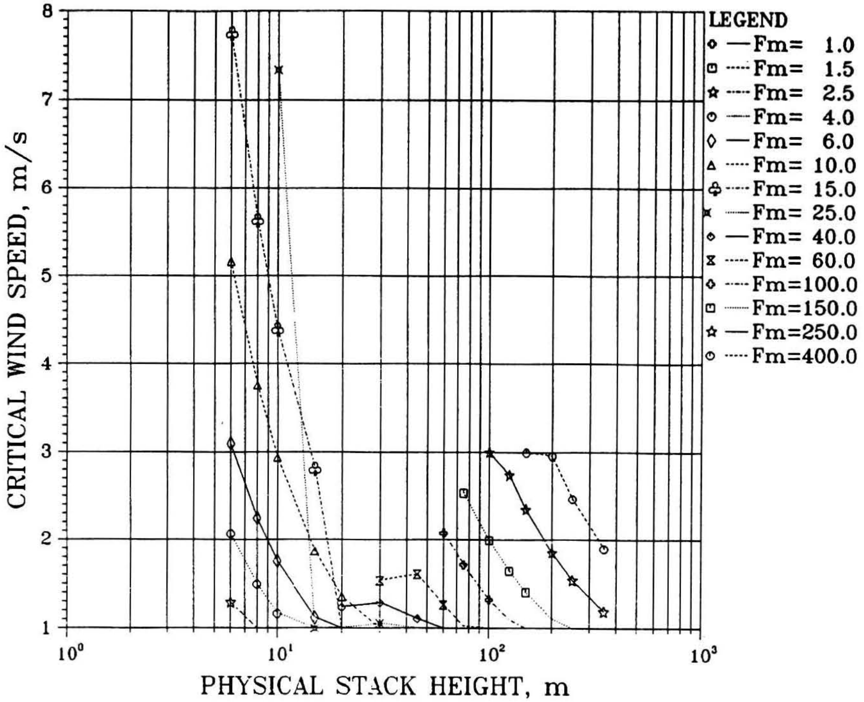


Fig. 5. Critical wind speed in rural areas with bouyancy-induced dispersion.

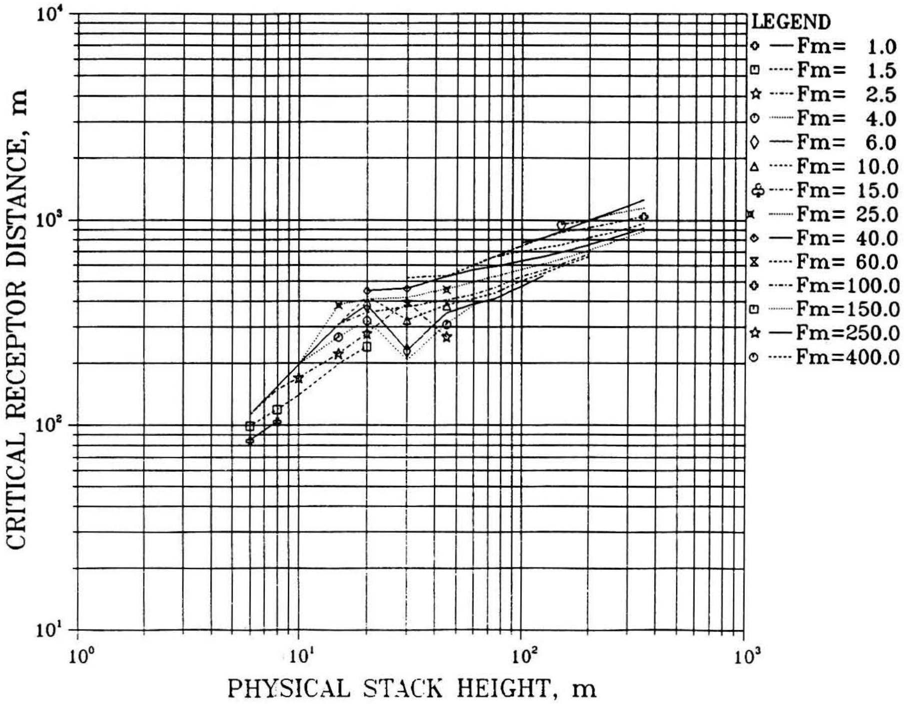


Fig. 6. Critical receptor distance in rural areas with bouyancy-induced dispersion.

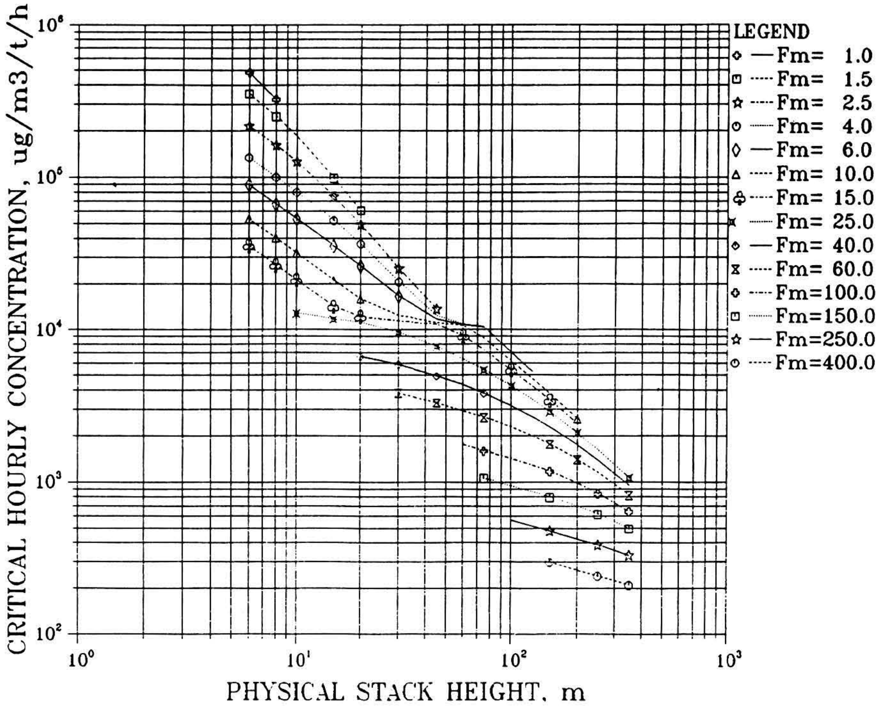


Fig. 7. Critical one-hour-average normalized ground concentration in rural areas without buoyancy-induced dispersion.

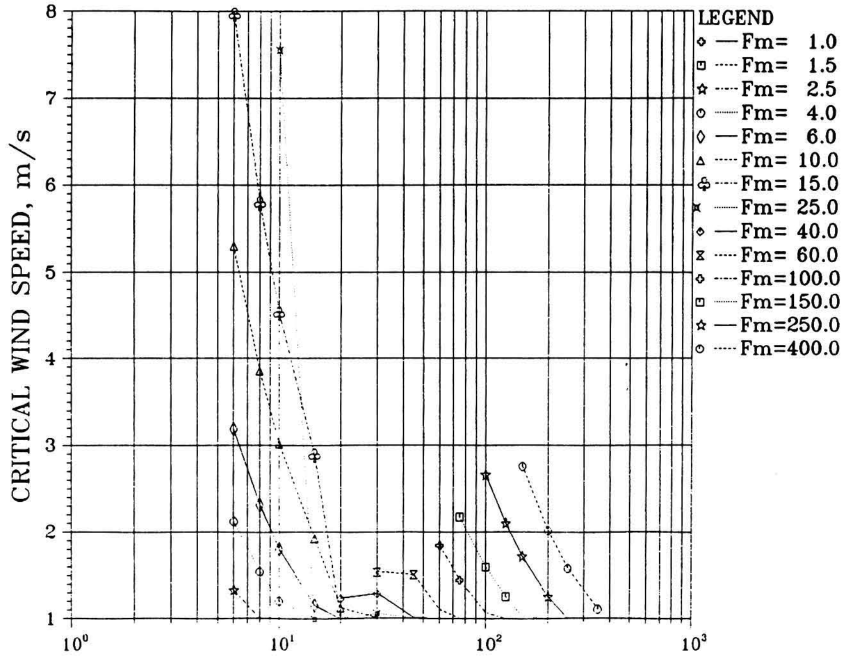


Fig. 8. Critical wind speed in rural areas withoput buoyancy-induced dispersion.

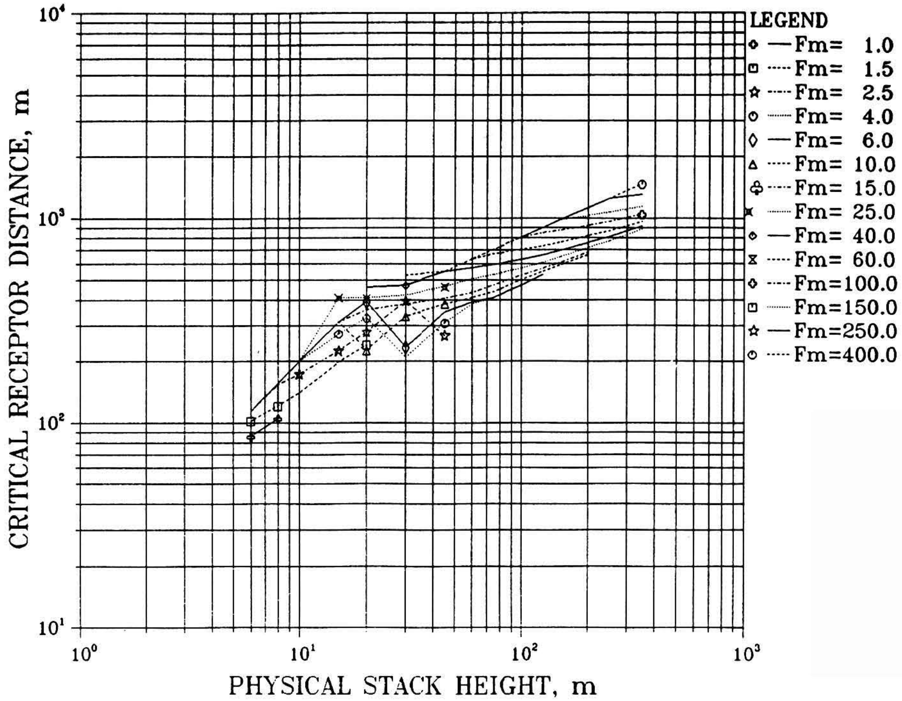


Fig. 9. Critical receptor distance in rural areas without buoyancy-induced dispersion.

In relation to this problem the following data are given:

H	=	76.0 m
D	=	1.44 m
V_s	=	11.27 m/sec
T_s	=	(35 + 273.16) K
T_a	=	(20 + 273.16) K
Q	=	0.140 Mg/h (from both units)

The applicable air quality standard for the hourly concentrations of SO_2 is 350 $\mu g/m^3$ (ψ_{std} = 350).

Solution

The temperature of the tail gas from the scrubbers is not much higher than that of the ambient air and, under the circumstances, it must first be determined whether the plume rise is buoyancy- or momentum-dominated. From Equation (9), one can obtain F_t = 0.89 m^3/s and from Equation (8) ΔT_{cr} = 16.1 K. Since T_s-T_a = 15 K and (T_s-T_a) < ΔT_{cr}, the plume is momentum-dominated.

The problem under consideration is rather typical for existing stacks, and the analysis procedure is similar to the general one described elsewhere for point sources under buoyant plume rise (Economopoulos in press, b).

(1) As the study area is urban, the graphs in Fig. 1 to 3 are applicable. Note that both H and ψ_{std} are specified.

(2) From Equation (12), one obtains F_m = 16.23 m^3/s.

(3) From the graphs in Fig. 1 to 3 and Table 1, one obtains the following for the current situation, where the two sulphuric acid units emit via separate stacks:

C_{cr}	= 3600 $\mu g/m^3/Mg/h$	(Fig. 1)
U_{cr}	= 1.0 m/s	(Fig. 2)
x_{cr}	= 400 m	(Fig. 3)
K_{cr}	= Stability class A, B, or C	(Table 1)

From the equation $\psi = C_{cr}\, Q$, we calculate ψ = 504 $\mu g/m^3$. Thus, the hourly standard of 350 $\mu g/m^3$ may be violated.

(4) The maximum allowed value of C_{cr} can be computed as follows:

$$C_{cr} = \frac{\psi_{std}}{Q} = \frac{350}{0.14} = 2500\ \mu g\ /m^3/Mg/h$$

Using Fig. 1 with the above computed values of C_{cr} and F_m, the minimum stack height required to achieve the desirable air quality standard can be read directly, H = 100 m.

(5) As both H and ψ_{std} are given and the air quality standards are violated, we proceed into the analysis of mitigation options:

(a) One option, as shown in step (4) above, is to increase the height of both stacks from 76 m to 100 m.

(b) A second option would be to reduce the SO_2 emission rates by improving the SO_2 to SO_3 conversion and/or the scrubber efficiencies. The maximum allowable SO_2 emission rate can be computed as follows:

$$Q_{max} = 0.14\ \frac{350}{504} = 0.097\ Mg/h$$

(c) A third option could be to combine the tail gases from both units into one of the existing stacks. Under such conditions, ΔT_{cr} = 20.3 K can easily be calculated from Equations (9) and (8), and thus, the plume rise remains momentum-dominated; F_m = 32.47 m^3/s from Equation (12), and the following from Fig. 1 to 3 and Table 1:

C_{cr}	= 2450 $\mu g/m^3/Mg/h$	(Fig. 1)
U_{cr}	= 1.0 m/sec	(Fig. 2)
x_{cr}	= 450 m	(Fig. 3)
K_{cr}	= Stability class A, B, or C	(Table 1)

Using equation $\psi = C_{cr}\, Q$, one obtains ψ_j = 343 $\mu g/m^3$, and thus, the hourly concentration standard of 350 $\mu g/m^3$ for SO_2 is met.

According to the above analysis, the existing height of stacks appears insufficient to safeguard against violations of the one-hour average SO_2 concentration standard. Alternative mitigation options include increasing the height of both stacks from 76 to 100 m, reducing SO_2 emissions from 0.14 to 0.097 Mg/h, or redirecting the tail gas from both units into a single, 76 m stack. They could also include appropriate combinations of the above measures, which can be analysed through similar procedures. As mentioned earlier, if short-term standards are observed, long-term standards are also expected not to be violated.

DISCUSSION AND CONCLUSIONS

As has been shown, this model combines, through a numerical optimization algorithm, a Gaussian dispersion model with the minimum mixing height model of Benkley and Schulman (1979) as adapted for urban areas by Economopoulos (in press, b). The former computes the dispersion coefficients for urban areas from the correlations of Briggs as reported by Gifford (1976) and derived from the tracer experiments of McElroy and Pooler (1968), the dispersion coefficients for rural areas from the relations of Pasquill (1961, 1974) and Gifford (1961), the standard deviation coefficient for the plume spread during the plume rise from the relation of Pasquill (1976), and the momentum-dominated plume rise from the correlations of Briggs (1969, 1971, 1972, 1973).

Stack downwash, has not been included in the present model as this would interfere with the analysis of functional dependencies and would downgrade unnecessarily the elegance and simplicity of the results. This, however, should have a rather negligible impact in most practical situations.

The model presented applies in the case of relatively unstable pollutants, as the time for a released pollutant to reach the critical receptor spans, in most situations, from a few seconds to a few minutes, while even in the extreme case of very tall stacks the travel time is always less than 30 min. For such short periods, the effects of the chemical reactions are normally insignificant. In cases, however, where the reaction impact needs to be considered, we can use the procedure described earlier on in this paper for estimating C_{cr}, U_{cr}, x_{cr}, and K_{cr}, and proceed to correct C_{cr} from the following relation:

$$(C_{cr})_{corrected} = C_{cr} \exp\left[-0.692\ \frac{t}{t_{1/2}}\right] \quad (23)$$

where

$$t = x_{cr}/U_{cr} \quad (24)$$

The impact of the no-buoyancy-, over the buoyancy-induced dispersion assumption was found negligible for urban areas. In rural areas, the impact becomes moderately significant only in the analysis of very tall stacks with high F_m values (Fig. 4 and 7).

The minimum mixing height relations, introduced in the present model through Equations (17) and (18), affects, as could be expected, the computed critical concentrations and wind speeds of intermediate-height stacks. For example, using the relation L_m = 250U, instead of L_m = 207U, as a mixing height delimiter over urban areas, one obtains lower critical concentrations and critical wind speeds for stacks with heights in the range of 75 to 200 m. The maximum deviation in the computed concentrations (-25 to -27%) is observed for stack heights between 100 to 150 and F_m values between 25 to 40 m^3/s. For short stacks, where dispersion is for all practical purposes under unlimited mixing conditions (L_m far exceeds their effective plume height), as well as for tall stacks, where H_{eff} becomes greater than L_m (and is used instead of L_m), the computed critical conditions are not affected by the form of the L_m relation. It should be noted that from the two minimum mixing height relations used here, that for rural settings, L_m = 90U, has been field-tested and verified by Benkley and Schulman (1979). The other for urban settings, L_m = 207U, was derived by Economopoulos (in press, b) from Benkley and Schulman's model as calibrated with their rural mixing height data. The relation L_m = 250U, used above for sensitivity analysis purposes, is believed to represent an upper bound for the urban minimum mixing height relations.

Observation of the critical distance plots in Fig. 2, 5, and 8 reveals lack of monotonic continuity and noise in the isopleths, similar to that found in buoyant-dominated plumes (Economopoulos in press, b). Step changes in the correlations employed for the calculation of the dispersion parameters and wind speed among the stability classes are thought to be the dominant cause for this.

In conclusion, the present model is best suited for pollutants for which one-hour air quality standard exist, and for areas where interference from other sources is limited. In practice, assumptions can be made enabling the use of the model in most situations. The predictions from this model are as accurate as those from established computer models (e.g., U.S.E.P.A.'s RAM or CRSTER), since the only added simplifying assumption here is that of the no-stack downwash.

The model presented offers an especially fast and accurate way for evaluating critical impacts from single or multiple adjacent point sources, as well as for computing the necessary stack size changes or exhaust gas compounding modifications so as to meet environmental quality criteria. As such, it is useful for regulatory purposes, as it allows accurate definition of minimum stack size requirements as function of the exit gas volume and velocity, the pollutant emission rates, and the hourly concentration standards. It is also useful in environmental management studies (Economopoulos and De Koning 1989), as it offers fast screening of selected point sources and evaluation of the ways to have their impact reduced.

REFERENCES

Benkley, C. W.; Schulman L. L. Estimating hourly mixing depths from historical meteorological data. J. Appl. Meteorol., 18:772-780; 1979.

Briggs, G. A. Plume rise, USAEC Critical Review Series. TID-25075. Springfield, Va.: National Technical Information Service; 1969.

Briggs, G. A. Some recent analysis of plume rise observation. In: H.M. Englund; W.T. Beery, ed. Proc. 2nd International Clean Air Congress, 1971: 1029-1032. New York, NY: Academic Press.

Briggs, G. A. Discussion on chimney plumes in neutral and stable surroundings. Atmos. Environ. 6:507-510; 1972.

Briggs, G. A. Diffusion estimation for small emissions. Contribution File No. (Draft) 79. Oak Ridge, TN: Atmos. Turb. and Diff. Lab.; 1973.

Briggs, G. A. Plume rise predictions. In: Duane A. Haugen, ed. Lectures on air pollution and environmental impact analysis. Chapter 3. Boston, MA: Amer. Meteorol. Soc.; 1975.

Catalano, J.A.; Turner D.B.; Novak J.H. User's guide for RAM. EPA/600/8-86/041. Research Triangle Park, NC 27711: U.S. Environmental Protection Agency; 1987.

Economopoulos, A. P. In: De Koning, H.W., ed. Management and control of the environment. WHO/PEP/89.1. Geneva: World Health Organization; 1989.

Economopoulos, A. P. On the dispersion of traffic and space heating emissions in urban settings. J. Air & Waste Manage. Assoc. 59. (In press, a)

Economopoulos, A. P. A Model for the critical hourly concentration, receptor distance and meteorological conditions from point sources with thermal plume rise. J. Water, Air, Soil Pollut. (In press, b)

Gifford, F. A. Uses of routine meteorological observations for estimating atmospheric dispersion. Nucl. Saf. 2:47-51; 1961.

Gifford, F.A. Turbulent diffusion-typing schemes: A review. Nucl. Saf. 17:68; 1976.

IAEA (International Atomic Energy Agency). Atmospheric dispersion in nuclear power plant siting. A safety guide, safety series No. 50-SG-S3. Vienna: IAEA; 1980.

McElroy, J.L.; Pooler F. St. Louis dispersion study, Vol II - Analysis. National Air Pollution Control Administration. Publ. No. AP-53, U.S. Dept of Health, Education and Welfare, Arlington, VA; 1968.

Pasquill, F. The estimation of the dispersion of windborne material. Meteorol. Mag. 90:33-49; 1961.

Pasquill, F. Atmospheric diffusion. London: D. Van Nostrand Company Ltd.; 1974.

Pasquill, F. Atmospheric dispersion parameters in Gaussian plume modeling. Part II: Possible requirements for change in the Turner workbook values. EPA-600/4-76-030b. Research Triangle Park, NC: U.S. Environmental Protection Agency; 1976.

Environment International, Vol. 18, pp. 87 - 93, 1992

0160-4120/92 $5.00 +.00

CHARACTERIZATION OF ATMOSPHERIC DUST OF SICHUAN, CHINA BY X-RAY ANALYSIS AND COMPARISON WITH JAPANESE SAMPLES

Tsutomu Fukasawa, Masaaki Iwatsuki, and Tsugio Fukasawa
Department of Applied Chemistry, Faculty of Engineering, Yamanashi University, Takeda-4, Kofu-shi, 400 Japan

Zuce Liu
Department of Applied Chemistry, Chengdu University of Science and Technology, Chengdu, Sichuan, China

Shi-Sen Zhang
Department of Environmental Science and Engineering, Chengdu University of Science and Technology, Chengdu, Sichuan, China

EI 9003-030 (Received 12 March 1990; accepted 13 July 1991)

This paper describes the characterization of some atmospheric dusts collected in Chengdu and Dukou of Sichuan Province, China, and compares them with samples from Tokyo and its vicinity. The samples were fractionated with heavy liquids, followed by ordinary x-ray diffraction and fluorescence analyses. Individual particles were further analyzed using an x-ray microdiffractometer with a position sensitive proportional counter. Dukou's dust fall was characterized by high-temperature products and by large amounts of magnetite (Fe_3O_4) and hematite (Fe_2O_3). Chengdu's sample was characterisized by large contents of gypsum ($CaSO_4 \cdot 2H_2O$) and the lightest fraction of <2.0 g/cm^3 including carbonaceous substance and some epsomite ($MgSO_4 \cdot 7H_2O$). It resembled the sample of Chiba (Japan) in the amounts of gypsum and epsomite, and it was similar to the samples of Tokyo in the large proportion of the <2.0 g/cm^3 fraction. In addition to quartz and iron oxides, kaolin mineral and mica were detected in Chengdu, while plagioclase, chlorite, mica, and sodium chloride were detected in Japan. The origins of the pollutants are discussed.

INTRODUCTION

Investigators in Japan and China have a common interest in the air pollution in the Sichuan Basin, China, with its unique climate characterized by cloudy skies for almost the entire year and the recent occurrence of acid rain (Zhao et al. 1988). Although several studies have been carried out on pollutants such as metallic elements, water-soluble ions, and polycyclic aromatic hydrocarbons in airborne particles collected in the Sichuan Basin, no study on their mineralogical components has so far been found.

In Japan, studies have characterized airborne particles collected in Tokyo and its vicinity, using x-ray diffraction (XRD) analysis combined with heavy-liquid separation, and elucidated their mineralogical components. These studies have provided important information on the origin of pollutants. (Fukasawa et al. 1980). The XRD and x-ray fluorescence (XRF) analyses were applied to airborne particles collected size-fractionally by an Andersen cascade impactor with eight stages and used to construct distribution curves of compounds (minerals) or elements versus particle size for environmental studies (Fukasawa et al. 1983; Iwatsuki et al. 1984). Chemical states and acid-extractivities of elements in some airborne particles were elucidated by applying x-ray analysis and heavy-liquid separation to the decomposition residues after ashing, acid-treatment, and flux fusion (Fukasawa and Iwatsuki 1985). Recently, Iwatsuki and Fukasawa (1991) showed that the x-ray microdiffractometer was useful for the analysis of individual particles in atmospheric dust.

The purpose of the present study was to obtain information on mineralogical components and density distributions of dust fall and airborne particles collected in Sichuan Province and to reveal their characteristics by comparing them with the Japanese samples.

The Chinese authors carried out the sample collection in China and the analysis of Chengdu's dust fall, and the Japanese authors did the others. The results observed here were compared with each other and with those observed so far from the Japanese samples.

EXPERIMENTAL

Samples

Table 1 shows the locations, times, and methods for sample collection in China and Japan.

The dust fall sample CDD1 was collected at Dukou (Sichuan). Dukou is located in the southernmost mountain area about 500 km from Chengdu; it has iron and other manufacturing plants nearby. The samples CCD1 and CCD2 were collected in the urban and south suburban areas, respectively, of Chengdu, the capital of Sichuan Province in the Sichuan Basin. These samples were collected in a glass cylinder 15 cm in diameter and 30 cm in height, which was supported by a tripod 1 m in height and placed on the roof of a tall building. All water in the collected samples was removed by evaporation before the study.

Table 1. Samples.

No.*1	Location		Year	Collected by
CDD1	China	Dukou	1987	Glass cylinder (15cm i.d.,30cm high) [Dust fall]
CCD1		Chengdu(urban)	1986	
CCD2		Chengdu(suburban)	1986	
CCM1		Chengdu(urban)	1988*2	Middle-volume sampler (125mm diameter glass fiber filter used)
CCM2		Chengdu(urban)	1988*3	
CCM3		Chengdu(urban)	1988*4	
JTB1	Japan	Tokyo(government office)	1973	Air cleaner (bag filter used)
JTB2		Tokyo(business)	1975	
JYB1		Yokohama(business)	1974	
JCB1		Chiba(industrial)	1974	
JKA1		Kofu(residential)	1982	Andersen cascade impactor(8 stages)
JKA2		Kofu(residential)	1982	

*1 Sample notation: The first letter indicates the country; the second letter the city where the sample was collected; the third letter the dust type or sampling media.
*2 Collected from 16:00 to 22:30, October 22.
*3 Collected from 8:50 to 13:30, October 23.
*4 Collected from 16:15 to 22:15, October 23.

The samples of Chengdu, CCM1, 2, and 3, were collected using a middle-volume sampler equipped with a glass fiber filter on the roof of a tall building in an urban location.

The samples from Tokyo (JTB1, government office district, and JTB2, business district); Yokohama (JYB1, business district with a nearby industrial district); and Chiba (JCB1, industrial district) were collected in bag filters by air cleaners on the roofs of tall buildings. These samples were ground and homogenized before use (Fukasawa et al. 1980).

The samples from Kofu (JKA1 and 2) were collected size-fractionally by an Andersen cascade impactor consisting of eight stages of removable aluminum plates (80 mm diameter) covered with Nuclepore filters (made of polycarbonate, from Nuclepore Corp.) as collecting media (Fukasawa et al. 1983).

Heavy-liquid separation

Samples were first fractionated to six parts having different densities using heavy liquids as follows: A 100-mg or 200 mg sample was shaken with carbon tetrachloride in a 100 mL flask to remove solvent-soluble substances and filtrated out onto a 25 mm diameter membrane filter (MF-Millipore filter, made of mixed esters of cellulose, HA-type, 0.45 μm pore, from Millipore Corp.). After washing with carbon tetrachloride, the sample was transferred to a 10-mL centrifuge tube, where carbon tetrachloride of 8 mL was added as the first heavy liquid, and then the sample was subjected to ultrasonic waves in an ultrasonic cleaner unit. After centrifugation, the float was filtered off along with the upper 4 mL of the heavy liquid onto a 25 mm diameter membrane filter and washed with carbon tetrachloride. For the successive separation of the sediment, methylene iodide and carbon tetrachloride were added to the sediment in the residual heavy liquid of 4 mL, so as to prepare 8 mL of heavy liquid of a greater density. The procedure described was repeated. The final sediment was treated in the same manner as the floats. All the fractions with different densities were weighed after expelling the solvent and subjected to x-ray analyses. The results were used to construct histograms of weight percentage or an XRD or XRF line intensity vs. density.

XRD analysis

Rigaku x-ray diffractometers were used under ordinary conditions. A copper-anode x-ray tube was used for the Chengdu dust fall (CCD1 and 2) and an iron tube used for others. Sample mounting was as follows. The unfractionated ground sample, which could be used in a larger quantity, was packed into a hollow that was made on a nondiffracting quartz plate. A 16 mm diameter fractionated sample (on a 25 mm diameter membrane filter) or a 25 mm diameter sample (which was a cut piece of a glass fiber filter with dust collected by a middle-volume sampler) was held between a standard aluminum sample holder with a hole of 15 × 20 mm and an aluminum square plate (0.3 mm thick) with a 23 mm diameter irradiation window.

A Debye-Scherrer camera also was used in China for the analysis of a small sample containing heavy minerals.

The analytical results of the Japanese samples taken from air cleaners had also been obtained by the same heavy-liquid separation and x-ray analyses as described above (Fukasawa et al. 1980).

X-ray microdiffraction (XRMD) analysis

A Rigaku x-ray microdiffractometer, which consists of a curved PSPC and a three-circle goniometer, was used with a high-power x-ray generator of rotary copper-anode type excited at 40 kV and 150 mA. Individual dust particles were sorted depending on color, shape, etc. under a microscope using a needle of magnetized stainless steel or copper, and attached with rubber cement onto the tip of a copper or aluminum wire, which was attached to a hand-made brass sample holder. After being set on the goniometer head, the particle was irradiated with a collimated x-ray beam of 100 μm, under a three-dimensional motion (i.e., rotation around the ϕ-axis, and oscillation of -30° to +30° around the χ–axis and oscillation of 20° to 60° around the ϖ-axis), to give a smooth and reproducible diffraction pattern. The x-ray diffraction pattern was accumulated for 600 s into a multichannel analyzer, and printed out after data processing.

XRF analysis

A Shimadzu VF-320A x-ray spectrometer was used under conventional operating conditions. The sample collected onto a glass fiber filter of 125 mm diameter was cut to a 50 mm diameter size, and held in a Teflon sample holder for analysis. Other samples on membrane filters were sandwiched between two pieces of Mylar film (made of polyethylene terephthalate, from E.I. du Pont de Nemours & Co.) and mounted on the sample holder.

RESULTS AND DISCUSSION

Density distribution

Figure 1 shows a comparison of weight percentages vs. density histograms of the samples taken in China and Japan.

The 1.6 - 2.0 g/cm^3 fraction of the Dukou's sample was as much as 47%, it decreased to 21% for the same ground sample. Its >3.1 g/cm^3 fraction constituted 32% of the sample corresponding to the ground sample constituting 23%. Grinding may have destroyed some pores in the fly ash particles and also combinations among different minerals resulting in a different distribution. In any event, Dukou's dust fall was characterized by much larger amounts of heavy minerals, differing from all other samples. On the other hand, Chengdu's sample was characterized by the <2.0 g/cm^3 (lightest) fraction constituting 45% including large amounts of carbonaceous substances, and the >3.0 g/cm^3 fraction constituting as little as 2%.

Characterization by X-ray analysis

Dukou's dust fall. The ordinary XRD analysis of Dukou's dust fall and its fractions separated with heavy liquid, showed that Dukou's dust fall contains magnetite (Fe_3O_4) and hematite (Fe_2O_3) as the major crystalline substances in the heaviest fraction of a large amount (refer to Fig. 1), and α-quartz (SiO_2)

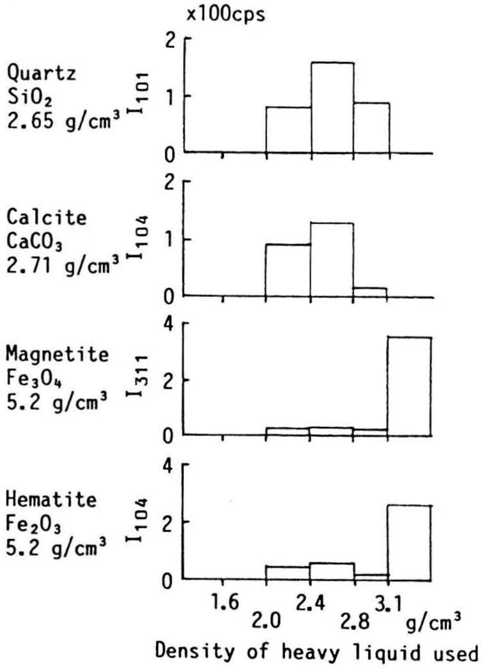


Fig. 2. Histograms of XRD intensities of identified substances in Dukou's dust fall.

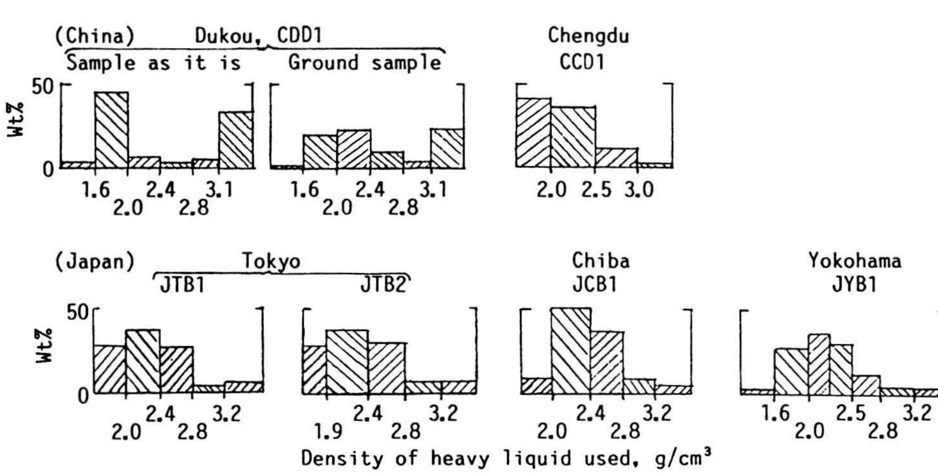


Fig. 1. Density distribution of Chinese dust fall and Japanese airborne particles (ground).

and calcite ($CaCO_3$) as the major crystalline substances in the fractions of moderate densities. Figure 2 shows the histograms of XRD line intensities of the minerals vs. density. These histograms resembled those of XRF line intensities of the main elements vs. density constructed from the results of XRF analysis of each fraction (which are omitted here). Table 2 summarizes substances identified by XRMD analyses of particles in Dukou's dust fall. It shows that each of the major substances described above existed in some different states. The XRMD analyses also allowed the distinct identification of minor constituents, even a particle as small as about 0.03 μg, which was calculated as size multiplied by density: mullite ($Al_6Si_2O_{13}$), phlogopite [$KMg_3(Si_3Al)O_{10}(OH)_2$], periclase (MgO), and sphered particles (containing magnetite, hematite, mullite, or glass only) were detected.

Chengdu's samples. The XRD patterns of three samples (CCM1-3) of airborne particles, which were collected at the same place, but at a different time, were similar to each other and showed only the presence of gypsum ($CaSO_4 \cdot 2H_2O$) and α-quartz. The XRF analyses of the three samples also showed similar results to each other. These results indicate that there were no differences among these samples.

The XRD patterns of Chengdu's dust fall, which was collected in a larger quantity, suggested the presence of some amounts of epsomite, kaolin mineral [$Al_2Si_2O_5(OH)_4$], and mica, in addition to quartz and gypsum. Then, the fractionation of the dust fall using the heavy-liquids and the XRD analyses confirmed the minor components described above, and further detected magnetite and hematite in the heaviest fraction of a smaller amount. Figure 3 shows the histograms of XRD line intensities of the minerals vs. density. The histograms were also supported by those of XRF line intensities of their main elements vs. density (which are omitted here). Figure 3 shows that the dust fall included epsomite ($MgSO_4 \cdot 7H_2O$) as a main crystalline component in the lightest fraction in addition to a large amount of carbonaceous substance. It also included large amounts of gypsum, quartz, and some mica as main components in the moderate fractions of 2.0 - 3.0 g/cm^3, and iron oxides, such as magnetite and hematite, in the heaviest fraction at a smaller quantity.

Table 2. Mineralogical components identified by XRMD analysis of dust fall particles in Dukou.

No.	Identified substance	Amount	Color	Trans-parency	Shape	Size(μm)	Density (g/cm³)
1.	Amorphous carbon	Large	Black	Opaque Glossy	Irregular lump	10-1000	1.6-2.0
2.	Fly ash containing mullite or glass only	Small	Colorless or pale yellow	Trans-lucent	Sphere	20- 200	2.0-2.4
3.	Quartz	Medium	Colorless or pale yellow	Trans-lucent	Grain	10- 400	2.4-2.8
4.	Calcite	Medium	White	Opaque	Aggregate	10- 500	2.4-2.8
		Small	Colorless	Trans-lucent	Grain	20- 200	2.4-2.8
5.	Phlogopite	Small	Gold	Opaque Glossy	Plate	500x600x100	2.4-2.8
6.	Mullite	Small	White	Opaque	Lump	300x100x100	2.4-2.8
7.	Periclase	Small	White	Opaque	Mixed aggregate	100	2.4-2.8
8.	Fly ash containing magnetite	Medium	Black	Opaque Glossy	Sphere	20- 500	>3.1
9.	Fly ash containing hematite	Medium	Brownish black	Opaque Glossy	Sphere	20- 500	>3.1
10.	Magnetite>Hematite	Large	Black	Opaque	Grain Fragment	10- 400	>3.1
11.	Hematite>Magnetite	Large	Redish black	Opaque	Aggregate	10- 800	>3.1

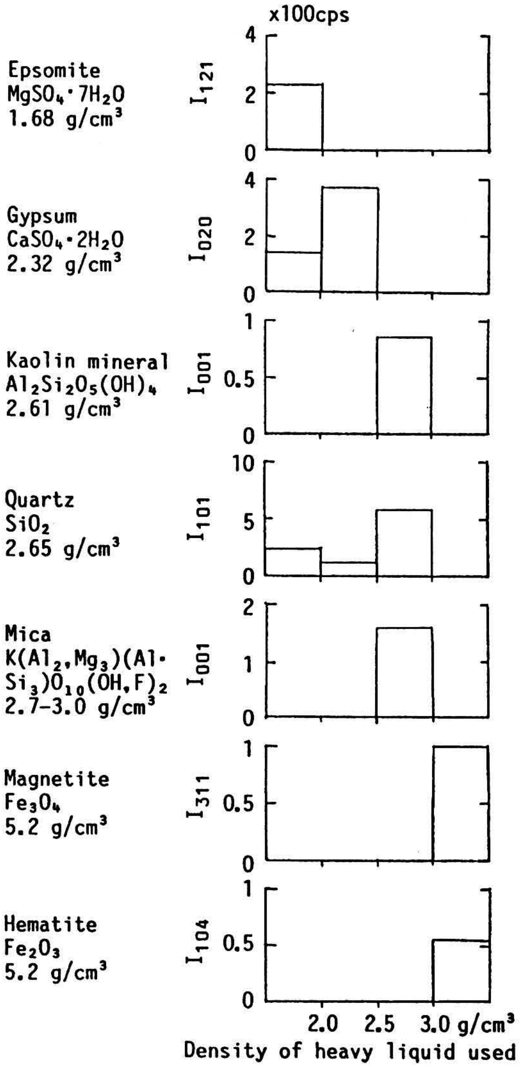


Fig. 3. Histograms of XRD intensities of identified substances in Chengdu's dust fall (relative intensity by Debye-Scherrer camera).

Comparison between pollutants in China and Japan and their origin

Table 3 compares detected substances in the samples collected in China and Japan.

Dukou's dust fall (CDD1) was distinctly different from other samples and characterized by a great deal of the >3.0 g/cm^3 fraction containing magnetite and hematite as main components and high temperature products like sphered particles, mullite, and others. It suggests great influence from iron and other manufacturing plants located in the Dukou area.

Chengdu's dust fall (CCD1, 2) was characterized by a large amount of gypsum, a larger amount of the lightest fraction including carbonaceous substance, some epsomite, in addition to kaolin mineral, and mica of probably earth origin. It was similar to Chiba's sample (JCB1), though hemihydrate gypsum ($CaSO_4 \cdot 0.5\ H_2O$) detected in Chiba's sample was not detected in Chengdu's. Gypsum in Chengdu's samples seems to have been produced by the reaction of SO_2, mainly from the combustion of coal with high sulfur contents and lime, a popular wall paint for construction. On the other hand, the Chiba area had a power plant where lime was used for the flue gas desulfurization to prepare gypsum. All the samples except Dukou's dust fall included some sulfates like gypsum, hemihydrate gypsum, ammonium sulfate, or epsomite which were probably attributed to SO_2 pollution. Sodium chloride in the sample of Tokyo and Yokohama may be attributed to the nearby sea. In addition to quartz and the iron oxides, the following minerals, which were probably earth origin, were detected: plagioclase, chlorite, and mica in Japan; and kaolin mineral and mica in Chengdu.

The quantities of dust fall were about 97 - 124 Mg/km^2·y (1986) in the Chengdu area. In Japan, dust fall decreased rapidly from about 1967 to 1975, and slowly since about 1976 as follows: 188 (1970), 110 (1974), 43 (1983), and 56 (1987) Mg/km^2·y in the Tokyo district; 95 (1970), 65 (1975), 66 (1983), and 56 (1987) Mg/km^2·y in the Yokohama district; 85 (1971), 52 (1975), 50 (1983), and 48 (1987) Mg/km^2·y in the Chiba district; and 42 (1973), 30 (1975), 14 (1983), and 16 (1987) Mg/km^2·y in the small Kofu basin, which contains only a few small industries. The dust pollution in the Chengdu area seems to be about two to three times the present amount in Japan, although the Yokohama and Chiba districts have large iron manufacturing and other plants nearby.

The results described above suggest that the atmosphere in Dukou may be improved by clean-up of the industrial plants. Similarly, the atmosphere in the Chengdu area may be improved by the pollution abatement at the coal combustion plants.

Table 3. Comparison among substances detected in samples collected in China and Japan.

Sample No.	CDD1		CCD1,2	CCM1-3	JTB1	JTB2	JYB1	JCB1	JKA1	JKA2
Location	Dukou		Chengdu	Chengdu	Tokyo	Tokyo	Yokohama	Chiba	Kofu	Kofu
Method*	1	2	1	3	1	1	1	1	4	4
NH_4Cl	-	-	-	-	-	-	-	-	2+	-
$MgSO_4 \cdot 7H_2O$	-	-	2+	-	-	-	-	+	-	-
$(NH_4)_4(NO_3)_2SO_4$	-	-	-	-	-	-	-	-	+	-
$(NH_4)_2SO_4$	-	-	-	-	-	-	-	-	3+	+
Carbonaceous	M	4+	L	L	M	M	M	S	S	S
NaCl	-	-	-	-	2+	+	3+	-	-	-
$CaSO_4 \cdot 2H_2O$	-	-	4+	4+	3+	3+	4+	5+	-	-
$CaSO_4 \cdot 0.5H_2O$	-	-	-	-	-	-	-	3+	-	-
Kaolin mineral	-	-	+	-	-	-	-	-	-	-
Quartz	3+	3+	4+	4+	5+	5+	5+	5+	5+	5+
Plagioclase	-	-	-	-	2+	2+	2+	3+	2+	2+
Calcite	3+	3+	-	-	2+	+	-	-	+	+
Chlorite	-	-	-	-	2+	+	-	+	-	-
Mica	-	+	2+	-	2+	+	-	+	-	-
Mullite	-	+	-	-	-	-	-	-	-	-
Periclase	-	+	-	-	-	-	-	-	-	-
Magnetite	4+	4+	+	-	2+	+	2+	2+	-	-
Hematite	4+	4+	+	-	2+	+	+	2+	-	-

* 1: Ordinary XRD anal. of sample fractionated with heavy liquid;
2: XRMD anal. of individual particles;
3: Ordinary XRD anal. of sample collected by middle-volume sampler;
4: Ordinary XRD anal. of sample collected by Andersen sampler.
Number of +: Detected XRD intensity approximately propotional to amounts. L>M>S: Approximate quantity estimated from fractionation with heavy liquid and/or ashing

Acknowledgment — This study has been supported by a grant under the Mombusho International Science Research Program.

REFERENCES

Fukasawa, T.; Iwatsuki, M.; Kawakubo, S.: Miyazaki, K. Heavy-liquid separation and x-ray diffraction analysis of airborne particulates. Anal. Chem. 52: 1784-1787; 1980.

Fukasawa, T.; Iwatsuki, M.; Tillekeratne, S.P. X-ray diffraction analysis of airborne particulates collected by an Andersen sampler. Compound distribution vs. particle size. Environ. Sci. Technol. 17: 596-602; 1983.

Fukasawa, T.; Iwatsuki, M. Chemical treatment and characterization of airborne particulates. J. Japan Soc. Air Pollut. 20: 23-32; 1985.

Iwatsuki, M.; Fukasawa, T. A state analysis of atmospheric dust by an x-ray microdiffractometer and an x-ray microanalyzer. J. Japan Soc. Air Pollut.; 1991. (In press)

Iwatsuki, M.; Tillekeratne, S.P.; Fukasawa, Tsug.; Fukasawa, T. X-ray analysis of airborne particulates collected by an Andersen sampler. Compound and elemental distribution vs. particle size of laboratory particulates. Environ. Sci. Technol. 18:818-822; 1984.

Zhao, D.; Xiong, J.; Xu, Y.; Chan, W.H. Acid rain in southwestern China. Atmos. Environ. 22:349-359; 1988.

Environment International, Vol. 18, pp. 95 - 101, 1992
Printed in the U.S.A.

0160-4120/92 $5.00 +.00

INDOOR RESIDENTIAL NITROGEN DIOXIDE CONCENTRATIONS IN BAHRAIN

Ismail M. Madany
Arabian Gulf University, P.O. Box 26671, State of Bahrain

Sami Danish
Bahrain Center for Studies and Research, State of Bahrain

EI 9104-126M (Received 9 April 1991; accepted 29 August 1991)

A total of 128 passive diffusion tube samplers have been used to measure the average concentrations of nitrogen dioxide inside and outside of 32 homes in Bahrain. The tubes were placed for a period of 14 days. Nitrogen dioxide in the kitchen, hall, bedroom, and outdoors averaged 52.3, 22.1, 15.2, and 26.0 $\mu g/m^3$, respectively. The overall mean of the indoor concentrations was 29.8 $\mu g/m^3$, and the mean indoor/outdoor ratio was 1.2. A significant positive correlation was found between the concentrations of NO_2 in the kitchen and the number of meals cooked per week. In 6% of the houses, the average kitchen NO_2-levels were higher than the U.S. National Ambient Air Quality Standard of 100 $\mu g/m^3$. All houses had liquefied petroleum gas (LPG) cookers with the exception of one which used an electric cooker. The mean levels of NO_2 in this house were 14.5, 10.5, 11.5, and 28.2 $\mu g/m^3$ in the kitchen, hall, bedroom, and outdoors. The results of the study show that indoor sources of NO_2 contribute more than outdoor sources to the overall concentrations of NO_2 in the houses in Bahrain.

INTRODUCTION

Air pollution has been traditionally associated with outdoor air pollution and industrial occupational exposure, and concern over the adverse health consequences of air pollution has always focused on outdoor and occupational exposure. Only recently, however, increasing attention has been drawn to the quality of air in nonindustrial indoor environments, such as private residences, offices, schools, and commercial and public buildings. This is reflected by the numerous studies and reviews which have been published regarding the various aspects of indoor air quality (Meyer 1983; Sherwood et al. 1987; Spengler et al. 1983).

Several factors have contributed to this widespread concern:

(1) People in Bahrain and in many countries in the world spend at least 20 h each day in indoor environments.

(2) Policy towards energy conservation by constructing tighter buildings affected indoor air quality,

(3) awareness of the presence of various chemicals in indoor environments and recognition of the potential impacts of exposure to these pollutants, and

(4) the need to understand total exposure to pollutants which includes both the outdoor and indoor environments.

There are many sources of indoor air contaminants including various outdoor sources, gas cookers, gas hot water heaters, gas or kerosene space heaters, building and furnishing materials, and smoking. Numerous investigations have documented that the concentration of some pollutants, such as nitrogen dioxide may be substantially greater indoors than outdoors in homes that have unvented combustion appliances (Spengler et al. 1979; Moschandreas et al. 1978; Palmes et al. 1977). This observation has raised concern about the health implications of exposure to NO_2.

Some recent studies have found the association of respiratory illness in primary school children living in inner city areas of England with the combined use of gas cookers and kerosene heaters in the home (Melia et al. 1979; Melia et al. 1982; Melia et al. 1988).

In the Arabian Gulf countries, and in the state of Bahrain in particular, not much attention has been given to outdoor air pollution, and virtually no concern has been raised with respect to the quality of indoor environments.

With regard to outdoor air only, an automated mobile air monitoring unit is employed to monitor nine air pollutants in certain areas in Bahrain (Madany and Danish 1988), and no work has been carried out regarding the quality of indoor air. The objectives of this investigation were to assess nitrogen dioxide levels in 32 homes in the state of Bahrain, and to report spatial variations in nitrogen dioxide concentrations within and between homes by installing three passive diffusing samplers in each home and one outside the home. This study will document the first data on the quality of indoor air in Bahrain with respect to NO_2.

MATERIALS AND METHODS

Sample selection and sampling protocol

The 32 residential houses which were selected in this study represented all populated areas in Bahrain. Note that the area south of Bahrain was not included in the study because it is not inhabited.

The residents of the houses participating in this investigation were provided with detailed information sheets that described the objectives of the study and the procedures to follow along with a questionnaire. The questionnaire included information regarding factors influencing indoor nitrogen dioxide levels, such as area of residence; vicinity of heavy traffic; smoking habit (smoker or nonsmoker); presence of equipment using gas-like gas cookers or water heaters; number of meals cooked per week in the house; and how often windows are open for ventilation and if a mechanical ventilation system is used.

Three NO_2 diffusion tubes were installed in each house, in the kitchen, bedroom, and hall (living room). In the kitchen, the tube was placed against a wall approximately 1.5 m above the floor and 3 m from the stove. In the bedroom and hall, it was placed in a wall away from windows and approximately 1.5 m above the floor. The tubes were exposed for a period of about 14 d. In addition, diffusion tubes were installed outside the houses.

Instrumental and analytical methods

The NO_2 diffusion tubes used in this investigation were supplied and analyzed by Gradko International Limited of Winchester, UK. These have been fully described and evaluated elsewhere (Palmes et al. 1976, 1977; Blacker 1973; Levaggi et al. 1973; Atkins et al. 1978). The acrylic tubes were 7.2 × 1.1 cm in diameter and fitted with airtight polythene end-caps. Three acid-cleaned stainless steel mesh discs were soaked in 50% v/v triethanolamine (TEA)/acetone solution and, after allowing the acetone to evaporate, fitted inside one end of the tube. During exposure, the polythene end-cap at the opposite end of the tube to the mesh collector was removed and the tube mounted vertically, with the open end pointing downwards.

The nitrogen dioxide absorbed by the collectors was determined colorimetrically as NO_2. A mixed reagent was prepared consisting of the following materials:

(1) 1 mL of distilled water;

(2) 1 mL of sulfanilamide reagent prepared by adding 2 g sulfanilamide to 5 mL concentrated phosphoric acid and diluted to 100 mL with distilled water; and

(3) 0.1 mL of N-1-naphthylethylene-diamine-dihydrochloride (NEDA) reagent prepared by dissolving 70 mg NEDA in 50 mL distilled water.

After adding 2.1 mL of the mixed reagent to each tube, the tubes were agitated and left for 20 min for the reaction to proceed. In solution, the nitrite ion diazotizes sulfanilamide, and the resulting salt is coupled with NEDA to give a pink azo dye. The absorbance was measured at 540 nm using a spectro-photometer. A range of standards was prepared from Analar sodium nitrite and a calibration curve was prepared from the standards. Using the quantities of NO_2 found in the sample tubes, the known sampling rate of the tubes, and the number of hours of exposure, the average levels of NO_2 in the air sampled during the exposure period were calculated.

Quality assurance procedures included two blanks and at least one replicate sample for every 15 samples. The blanks included laboratory and field blanks.

The statistical method used to assess the differences between the means of NO_2 levels was the student's t-test. The correlation coefficient between various variables was calculated using Pearson's (r) values, and the student's test was employed to estimate the significance of these values.

RESULTS AND DISCUSSION

In only 32 of the original 37 houses selected for the study, the residents agreed to participate. The total number of tubes used in the investigation, excluding the blanks was 128 tubes. Ninety-six tubes were placed in the houses and 32 tubes were placed outdoors. Of the 32 participating households, only one used an electric cooker; the rest had liquefied petroleum gas (LPG). In Bahrain, LPG is more convenient to use, readily available, and cheap; thus, approximately 95% of the Bahraini people use LPG for cooking purposes. All households in the present study used electric water heaters.

The results of the present investigation are demonstrated in Table 1. The table shows the average levels of NO_2 at each of the 32 houses and in the bedroom, hall, kitchen, and outdoors. The mean of the levels of NO_2 at each of the three sites indoors show that levels tended to be highest in all the kitchens, except with house number 20. The values were 52.3 $\mu g/m^3$ in the kitchen, 22.1 $\mu g/m^3$ in the hall, and 15.2 $\mu g/m^3$ in the bedroom. The difference between the means of NO_2 levels in the kitchen and hall was significant ($p < 0.001$), and also between the means of NO_2 levels in the hall and bedroom ($p < 0.01$). The level of NO_2 in the kitchen of the house with the electric cooker was measured to be the lowest (14.5 $\mu g/m^3$).

Analyses were conducted to find out the effect of various factors, such as the number of meals cooked per week, area of residence, vicinity of heavy traffic, and smoking habits, which may have been related to the NO_2 level. In these analyses, a statistically significant correlation was found between the levels of NO_2 in the kitchen and the number of meals cooked per week in the house ($r = 0.56$, $p < 0.001$). However, with respect to the other factors, no statistically significant variations were found in the NO_2 concentrations. Also, no correlation was found between NO_2 levels in the kitchen and in the hall ($r = -0.04$).

The overall mean of the concentrations of NO_2 at each of the 32 sites outdoors was measured to be 26.0 $\mu g/m^3$, and ranged from 16.1 to 47.0 $\mu g/m^3$ as demonstrated in Table 1. It can be seen from the table that the mean outdoor NO_2 value is lower than the overall mean indoor value of 29.8 $\mu g/m^3$. The correlation between the outdoor NO_2 values and the corresponding mean indoor values was not important ($r = 0.17$). Table 2 provides the ratios of the NO_2 levels in the kitchen, hall, bedroom and the whole house (indoors) to that of the NO_2 outdoors. The ratios are 2.2, 0.8, 0.6, and 1.2, respectively.

The aim of this investigation was to provide information regarding the quality of indoor air in an arid climate such as Bahrain, by measuring nitrogen dioxide levels inside the houses, and to study the factors which might influence the concentration of NO_2.

It was apparent from our results that indoor NO_2 concentrations markedly vary within and between houses. Kitchen NO_2 levels were the highest, then the hall, and the lowest NO_2 values were measured in the bedroom. These results are expected due to the use of LPG cookers in the kitchen, which is usually the only source of NO_2 in the houses in Bahrain. Our data are consistent with the literature which has reported that NO_2 concentrations vary spatially within homes, with kitchen levels being generally the highest compared with the living room and bedroom (Spengler et al. 1983; Boleij et al. 1982; Atkins et al. 1978; Melia et al. 1990).

In our study, the elevated levels of NO_2 in the kitchen were found to be significantly correlated to the reported number of meals cooked per week. However, Marbury et al. (1988) reported that the number of meals cooked per week was not associated with the NO_2 concentrations.

All houses in the present investigation used LPG for cooking, with the exception of house number 13 which used an electric cooker. This house measured the lowest NO_2 value in the kitchen, and low values in the hall and bedroom (Table 1). Although no decisive conclusion could be made regarding this observation due to the low number of houses with electric cookers, such observation was confirmed by others who reported significantly higher NO_2 levels in dwellings with gas stoves than those with electric stoves (Palmes et al. 1977; Atkins et al. 1987; Melia et al. 1990; Spengler et al. 1983; Parkhurst et al. 1988).

Table 1. Nitrogen dioxide concentrations in the 32 Bahrain houses and outdoors.

	NO_2 Concentration ($\mu g/m^3$)			
House number	Bedroom	Hall	Kitchen	Outdoor
1	26.5	30.8	36.8	21.8
2	18.6	21.8	36.5	35.9
3	10.3	11.7	31.0	21.8
4 (c)	20.7	54.3	57.9	26.4
5	11.8	13.9	22.9	18.0
6	6.0	10.0	141.2	18.0
7 (b)	10.0	21.1	35.7	35.9
8	4.5	10.9	22.4	28.2
9 (c)	20.1	34.2	52.3	35.9
10	19.6	27.6	52.8	37.8
11 (b,c)	13.5	22.0	34.0	37.8
12	7.0	13.3	32.5	16.1
13 (a)	11.5	10.5	14.5	28.2
14 (c)	19.6	20.1	74.3	29.3
15	10.0	24.4	52.5	16.7
16	6.0	18.0	78.0	20.3
17 (c)	12.4	15.2	88.5	16.7
18	13.7	14.9	27.8	16.7
19 (b,c)	20.9	27.4	60.0	37.8
20 (b)	22.9	38.5	29.9	21.8
21 (b)	7.9	11.3	91.2	18.0
22	19.7	32.1	75.8	37.8
23 (c)	21.1	28.6	58.3	37.8
24	12.8	21.0	51.9	20.3
25	11.3	15.4	42.9	20.3
26	24.3	39.9	66.7	28.2
27	18.2	22.6	28.6	28.2
28 (c)	17.7	15.4	2.6	18.0
29	9.6	13.7	118.4	20.9
30	13.9	10.7	29.7	20.3
31 (c)	17.7	20.3	69.6	47.0
32	26.3	36.7	32.0	16.
Average (SD)	15.2(6.1)	22.1(10.4)	52.3(28.4)	26.0(8.6)
Average(indoor)(SD)		29.8(10.3)		

(a) house with electric cooker.
(b) smoking residents.
(c) heavy traffic area.

Table 2. Indoor/outdoor ratio of NO_2 concentrations in bedroom (B), hall (H), and kitchen (K).

	Indoor / outdoor ratio			
House No.	B/O	H/O	K/O	I/O[a]
1	1.2	1.4	1.6	1.4
2	0.5	0.6	1.0	0.7
3	0.4	0.5	1.4	0.8
4	0.7	2.0	2.2	1.7
5	0.6	0.8	1.3	0.9
6	0.3	0.5	7.8	3.0
7	0.3	0.6	0.9	0.6
8	0.1	0.4	0.8	0.4
9	0.5	0.9	1.5	0.9
10	0.5	0.7	1.4	0.9
11	0.4	0.6	0.9	0.6
12	0.4	0.8	2.0	1.1
13	0.4	0.4	0.5	0.4
14	0.7	0.7	2.5	1.3
15	0.6	1.5	3.1	1.7
16	0.3	0.9	3.8	1.7
17	0.7	0.9	5.3	2.3
18	0.8	0.9	1.6	1.1
19	0.5	0.7	1.6	0.9
20	1.1	1.8	1.4	1.4
21	0.4	0.6	5.1	2.0
22	0.5	0.8	2.0	1.1
23	0.6	0.7	1.5	0.9
24	0.6	1.0	2.5	1.4
25	0.5	0.7	2.1	1.1
26	0.9	1.4	2.4	1.5
27	0.6	0.8	1.0	0.8
28	0.9	0.8	1.5	1.1
29	0.4	0.6	5.7	2.3
30	0.7	0.5	1.5	0.9
31	o.4	0.4	1.5	0.8
32	1.6	2.2	1.9	1.9
Average(SD)	0.6(0.3)	0.8(0.4)	2.2(1.6)	1.2(0.6)

(a) mean indoor (house) / outdoor.

The overall mean NO_2 value for all the 32 houses was 29.8 $\mu g/m^3$ (SD = 10.3; range = 12.1 - 52.4) as presented in Table 1. Some factors might appear to explain some of this NO_2 variance. Houses number 4, 9, 14, 17, 19, 23, and 31 which have mean NO_2 values of 44.3, 35.5, 38.0, 38.7, 36.1, 36.0, and 35.8 $\mu g/m^3$, respectively, were located in heavy traffic areas. However, other houses (Nos. 11, 28) which were also located in heavy traffic areas did not show elevated mean NO_2 levels. House number 6 has the highest mean NO_2 level (52.4 $\mu g/m^3$) due to high levels of NO_2 in the kitchen (141.2 $\mu g/m^3$) which is located in a poorly ventilated basement of the house. Only two houses (Nos. 20, 21) out of five with smoking residents showed high mean levels of NO_2, and one of the two houses had NO_2 values of 91.2 $\mu g/m^3$ in the kitchen. Thus, no definite conclusion could be drawn regarding the effect of smoking on the variation of indoor NO_2 levels.

The overall mean of the outdoor concentration of NO_2 was 26.0 $\mu g/m^3$ (SD = 8.6; range = 16.1 - 47.0). This is similar to the results obtained from a mobile air monitoring station in Bahrain which reported an average value of 28.8 $\mu g/m^3$ (Madany and Danish 1988). Table 2 presents ratios of NO_2 concentrations in the kitchen, hall, bedroom, and the whole house (indoors) to that of NO_2 levels outdoors. Generally, the indoor/outdoor ratio of NO_2 levels is lower than unity in houses in which there are no major indoor sources, and greater than unity in houses with indoor sources such as gas stoves (DNHW 1987). The data show that the mean kitchen/outdoor and indoor/outdoor ratios are higher than bedroom/indoor and hall/indoor ratios, 2.2 and 1.2, respectively. This suggests that indoor sources of NO_2 (major source being an LPG cooker) contribute more than outdoor sources to the overall concentrations of NO_2 in the houses in Bahrain.

The indoor NO_2 concentrations presented in this investigation are somewhat lower than those reported for homes with NO_2 sources in other part of the world. In a study using diffusion tube samplers for one-week sampling times in winter in England, Goldstein et al. (1979) reported a mean across 428 homes with gas stoves of 202 $\mu g/m^3$ and a mean of 32 $\mu g/m^3$ in homes without gas stoves, while ambient concentrations were about 35 $\mu g/m^3$. Atkins et al. (1978) in England, reported mean kitchen, living room, and bedroom NO_2 concentrations of 103.4, 50.8, and 41.4 $\mu g/m^3$, respectively, with gas cooking, and 16.9, 11.2, and 9.4 $\mu g/m^3$, respectively, with electric cooking. Recently, Melia et al. (1990) reported mean kitchen, living room, and bedroom NO_2 levels in winter in England of 69.4, 45.8, and 45.3 $\mu g/m^3$, respectively with gas, and 39.6, 32.1, and 38.9 $\mu g/m^3$, respectively, with electric cooking. Boleij et al. (1982) reported weekly mean levels across 175 Dutch houses in winter in kitchen, living room, and bedroom of 115, 54, and 43 $\mu g/m^3$, respectively, whereas ambient concentrations varied from 25 to 72 $\mu g/m^3$. Palmes et al. (1977) reported mean kitchen and living room NO_2 levels of 92.3 and 46.8 $\mu g/m^3$, respectively with gas cooking, and 15.6 and 12.7 $\mu g/m^3$, respectively, with electric cooking in New York in spring.

Comparing the results reported here with the annual U.S. National Ambient Air Quality Standard (NAAQS) and Canada's Acceptable Long-Term Exposure Range (ALTER) for residential indoor air (DNHW 1987) of 100 $\mu g/m^3$, we find that only two homes (Nos. 6, 29) had mean kitchen concentrations exceeding those standards. This represents about 6% of the total 32 homes sampled, indicating that a non-negligible percentage of the population is exposed to high concentrations of NO_2.

The present study was conducted in December 1990, a winter month in Bahrain. In winter months (November to February), houses are usually more ventilated and electricity consumption decreases; whereas in the prevailing summer months electricity consumption increases by using air conditioning which naturally keeps the house less ventilated. This condition might lead to increasing the level of NO_2 and other pollutants in the house. Therefore, there is a need for another study to provide additional information on NO_2 levels indoors in summer months.

CONCLUSIONS

In the light of the preceding results and discussion, the following conclusions can be drawn:

(1) The survey of the 32 houses in Bahrain has demonstrated that NO_2 concentrations in the kitchens were consistently higher than those in the hall and bedroom. The level of NO_2 in the kitchen of the house with an electric cooker was the lowest.

(2) A statistically significant positive correlation was found between levels of NO_2 in the kitchen and the reported number of meals cooked per week.

(3) Mean indoor NO_2 concentrations in the houses in Bahrain exceeded outdoor concentrations.

(4) Only 6% of the houses had mean kitchen concentrations exceeding the USNAAQS.

(5) Liquefied petroleum gas used in cookers is the major source of indoor NO_2 pollution in the houses of Bahrain.

Acknowledgment — The authors would like to thank the Bahrain Center for Studies and Research for supporting this work and Adel Al-Hussaini for his assistance.

REFERENCES

Atkins, D.H.F.; Healy, C.; Tarrant, J.B. The use of simple diffusion tubes for the measurement of nitrogen dioxide levels in homes using gas and electricity for cooking. AERE - R 9184; Harwell Laboratory, Oxford, England; 1978.

Blacker, J.H. Triethanolamine for collecting nitrogen dioxide in the TLV range. Am. Ind. Hyg. Assoc. J. 34:390-395; 1973.

Boleij, J.S.M.; Brunekreef, B; Lebret, E; Biersteker, K. Indoor NO pollution. In: Schneider, T. and Grant, L., eds. Air pollution by nitrogen oxides. Studies in Environmental Science 21:225-233. Amsterdam: Elsevier Scientific Publishing Company; 1982.

DNHW (Department of National Health and Welfare). Exposure guidelines for residential indoor air quality; April 1987. Ottawa, Canada; 1987.

Goldstein, B.D.; Melia, R.J.W.; Chinn, S.; Florey, C.; Clark, D.; John, H.H. The relation between respiratory illness in primary school children and the use of gas for cooking II: Factors affecting nitrogen dioxide levels in the home. Int. J. Epidemol. 8:339-345; 1979.

Levaggi, D.A.; Siu, W.; Feldstein, M.A New method for measuring average 24-hour nitrogen dioxide concentrations in the atmosphere. J. Air Pollut. Control Assoc. 23:30-33; 1973.

Madany, I.M.; Danish, S. Measurement of air pollution in Bahrain. Environ. Int. 14:49-58; 1988.

Marbury, M.C.; Harlos, D.P.; Samet, J.M.; Spengler, J.D. Indoor residential NO_2 concentrations in Albuquerque, New Mexico. J. Air Pollut. Control Assoc. 38:392-398; 1988.

Melia, R.J.W., Chinn, S; Rona, R.J. Indoor levels of NO_2 associated with gas cookers and kerosene heaters in inner city areas of England. Atmos. Environ. 24 B:177-180; 1990.

Melia, R.J.W.; Chinn, S., Rona, R.J. Respiratory illness and home environment of ethnic groups. Brit. Med. J. 296:1438-1441; 1988.

Melia, R.J.W.; Florey, C. duV.; Morris, R.W.; Goldstein, B.D.; Clark, D.; John, H.H. Childhood respiratory illness and home environment. I. Relations between nitrogen dioxide, temperature and relative humidity. Int. J. Epidemol. 11:155-163; 1982.

Melia, R.J.W; Florey, C. duV.; Chinn, S. The relationship between respiratory illness in primary schoolchildren and the use of gas for cooking I: Results from a national survey. Int. J. Epidemol. 8:333-338; 1979.

Meyer, B. Indoor air quality. Reading, MA: Addison-Wesley Publishing Company; 1983.

Moschandreas, D.; Stark, J.; McFaddem, J.; Morse, S. Indoor air pollution in the residential environment. EPA 600/7-79-228 AB, Washington, D.C.: Geoment, Inc.; 1987.

Palmes, E.D; Gunnison, A.F.; Dimattio, J; Tomczy, C. Personal sampler for nitrogen dioxide. Am. Ind. Hyg. Assoc. J. 37:570-577; 1976.

Palmes, E.D.; Tomczyk, C.; DiMattio, J. Average NO_2 concentration in dwellings with gas or electric stoves. Atmos. Environ. 11:869-872; 1977.

Parkhurst, W.J.; Humphreys, M.P.; Harper, J.P.; Spengler, J.D. Influence of indoor combustion sources on indoor air quality. Environ. Progress 7:257-261; 1988.

Sherwood, B.; Hedge, A.; Wilson, S.; Bass, J.; Rebertson, A. Sick building syndrome: A study of 4373 office workers. Ann. Occup. Hyg. 31:493-504; 1987.

Spengler, J.D.; Duffy, C.; Letz, R.; Tibbitts, T.; Ferris, B. Nitrogen dioxide inside and outside 137 homes and implications for ambient air quality standards and health effects research. Environ. Sci. Technol. 17:164-168; 1983.

Spengler, J.D.; Ferris, B.; Dockery, D. Sulfur dioxide and nitrogen dioxide levels inside and outside homes and the implications on health effects research. Environ. Sci. Technol. 13:1276-1280; 1979.

Environment International, Vol. 18, pp. 103 - 105, 1992
Printed in the U.S.A.

0160-4120/92 $5.00 +.00

A COMPARATIVE STUDY OF Pb, Cu, AND Cr IN ROADSIDE SEDIMENTS IN METROPOLITAN LAGOS AND BENIN CITY, NIGERIA

A. E. Ihenyen
Nigerian Institute for Oceanography, P.M.B. 12729, Victoria Island, Lagos, Nigeria

EI 9011-210M (Received 30 November 1990; accepted 29 April 1990)

The effect of motor vehicle emissions containing the trace elements Pb, Cu, and Cr in surface sediments is investigated along motor routes in metropolitan Lagos and Benin City in southwestern Nigeria. The results of analyses of 85 sediment samples from roadside drains, 60 from metropolitan Lagos and 25 from Benin City, show clear differences in pollution levels between the two cities. There are proportionately high Pb, Cu, and Cr concentrations in sediments along high density motorways in both cities considered while lower trace metals are found along medium and light density motorways. However, there are higher levels of trace metal enrichment in Benin City than in Lagos. In particular, high levels of Pb (480-5112 µg/g, mean: 1207±35) are found in sediments along high density motorways in Benin City in comparison to 221-1252 µg/g (mean: 540±82) recorded for Lagos samples. The generally higher trace metal concentrations in Benin City are inferred to result from very poor municipal drainage systems.

INTRODUCTION

Great concern has been expressed, especially in developed countries, about the role and fate of trace metals derived from industries, mining, traffic, and household sources in the environment. In the recent past, there has been a tremendous increase in the number of motor vehicles in Nigeria. Airborne metal particulates like Pb, Cu, and Cr have been attributed to motor vehicle emissions. For example, Pb occurs as lead tetraethyl, an important additive to petrol; its effect on soil and vegetation has been studied by Cannon and Bowles (1962), Daines et al. (1970), Ihenyen (1987), and Ndiokwere (1984). Cr is a component of chrome plating of many motor vehicles while Cu is a common constituent of piping and other engine parts (Ndiokwere 1984; Lagerwerff and Specht 1970). WHO (1972) and Shubert (1974) have documented the toxic effects of some heavy metals when ingested or inhaled.

This work undertakes the study of heavy metal pollution levels arising from motor vehicle emissions, employing the distribution of Pb, Cu, and Cr in the sediment of roadside drains along intra- and intercity motorways in two cities, metropolitan Lagos and Benin, both situated in southwestern Nigeria. Most of these motorways lack efficient drainage systems, so that highway runoffs are deposited directly in the immediate surroundings. Fruits and leafy vegetables sometimes grown in these flood neighbourhoods may contain a significant proportion of heavy metals.

Lagos, the former capital city of Nigeria, is a city with a high number of motor vehicles and human activities. It has a population of about 3.4 million, and many industries dot the periphery. However, Lagos, unlike most big cities of developed countries, lacks efficient drainage systems. Emissions from motor exhausts and effluents from households and industries are discharged directly into the immediate environment which, in some cases, may be farmed.

In contrast, Benin City is a medium-sized town with a population of about 375 400 inhabitants. It is situated on the eastern corner of southwestern Nigeria and forms an important gateway between Lagos and the eastern and northern states of Nigeria. Industrialisation is low and any elevation in heavy metals concentrations of roadside sediments would be attributable more to emissions from motor vehicles and effluents from households. The municipal drainage system is very poor.

This study aims to compare the levels of petroleum-related heavy metal pollutions between the two cities studied and to determine the relation between the volume of traffic and the efficiency of drainage systems.

MATERIALS AND METHODS

Sediment samples were collected from roadside drains along major traffic routes in both cities in 1986. In Lagos, where estimated background data are not available, sediments were also collected from areas about 50m from motor vehicle routes along intercity ways in order to estimate natural background levels. The motorways were classified into (1) heavy density, (2) medium density, and (3) light density motorways. In Lagos, heavy density motorways carry more than 200 000 vehicles per day; medium density 50 000 - 100 000 vehicles; and light density motorways fewer than 10 000 vehicles. In Benin City, these routes support about 50 000, 20 000 - 30 000, and fewer than 5000 vehicles per day, respectively.

There are no official figures on the volume of traffic per day. Traffic densities along the routes considered were estimated by counting the number of motor vehicles at peak and low traffic periods along representative routes of the three categories of motorways for one hour each. The resulting average traffic volumes were projected over the period between 06:00 and 19:00 h, which represents high industrial activities.

The number of samples was 85, 60 from Lagos metropolis and 25 from Benin City. The collected samples were oven dried at about 100° C and fractions less than 63 μm used for analyses. According to the method of Herman (1976), 0.25g of powdered sediments were digested with 5ml concentrated HNO_3 (AnalaR) . Trace element composition was determined by Atomic Absorption Spectroscopy, Pye Unicam 2900, using laboratory standards (E. Merck, Darmstadt). Reagent blank determination was carried out. Standard analytical error was about 5%.

Table 1. Trace metal concentrations (μg/g dry wt.)in roadside sediments along high, medium, and light density motorways.

CITY	METAL	HIGH DENSITY	MEDIUM DENSITY	LIGHT DENSITY	BACKGROUND LEVEL
Lagos	Pb range	221 - 1251	235 - 331	176 - 368	83
	mean	540 ± 82	245 ± 24	242 ± 24	
	Cu range	31 - 95	38 - 74	23 - 51	33
	mean	53 ± 15	48 ± 3	40 ± 8	
	Cr range	85 - 101	77 - 100	86 - 102	88
	mean	95 ± 7	92 ± 12	96 ± 7	
Benin	Pb range	480 - 5112	238 - 530	180 - 296	12
	mean	1207 ± 35	394 ± 18	258 ± 16	Ndiokwere 1984
	Cu range	29 - 258	33 - 59	28 - 39	15
	mean	107 ± 10	47 ± 7	33 ± 8	
	Cr range	76 - 131	85 - 111	83 - 106	6
	mean	111 ± 53	97 ± 10	97 ± 10	

RESULTS AND DISCUSSION

The results of spectrophotometric analyses on the roadside sediments from metropolitan Lagos and Benin City are summarized in Table 1. In general, sediments from Benin City show a higher level of heavy metal concentrations than samples from Lagos. Also, there are clear gradational decreases in heavy metal concentrations along heavy, medium, and light density motorways in both cases. There is, however, an exception to this trend in the distribution of Cr in the Lagos samples. The highest concentrations are found along light density motorways which incidentally are situated in residential areas. Estimated background levels are rather high, probably due to the proximity of the sites to motorways.

Results in Table 1 separate pollution levels for Pb and Cu in sediments from metropolitan Lagos into two main subdivisions: (1) high pollution levels along high density motorways, and (2) lower pollution levels along both medium and light density motorways. In contrast, Cr does not show a similar distribution pattern like that recorded for Pb and Cu above. Rather, the highest concentrations are found in sediments along light density motorways which are also situated in residential areas. Input through effluents from household waste waters is inferred to account for the elevated Cr concentrations. It is seen from this study that heavy pollution from Pb occurs along high, medium, and light motorways while heavy Cu pollution occurs only along high density motorways; Cr pollution is moderate along all routes.

In contrast, the levels of heavy metals found in roadside sediments in Benin City are considerably higher than those noted in samples from Lagos. For example, there is a high Pb concentration along high density motorways in Benin City (1207±35 μg/g) as compared with 540±82 μg/g in metropolitan Lagos. Pb levels are, however, much lower (394±18 and 258±16 μg/g, respectively) along both medium and light density motorways. There is, therefore, no doubt that the elevated Pb values along high density motorways are directly associated with emissions from motor vehicles which run on leaded petrol.

The concentrations of Cu and Cr along high, medium, and light roadways show a distribution pattern similar to those obtained for Pb. It can be concluded that the occurrence of a similar distribution pattern is linked to an identical source of input. A comparison with background levels (Ndiokwere 1984) shows that Pb and Cr are heavily polluted along all routes while Cu is heavily polluted along high density motorways, but moderately polluted along medium and light density motorways.

A careful comparison of pollution levels in sediments of metropolitan Lagos and Benin City shows that although Lagos motorways carry a larger volume of traffic, roadside sediments in Benin City have higher concentrations of Pb, Cu, and Cr. For example, the statistical mean of Pb along high density motorways in Lagos and Benin City are 540±82 μg/g and 1207±35 μg/g respectively, representing a ratio of 1:2. The ratio is also true for Cu. However, this ratio is approximately 1:1 for Cr. It is inferred that the generally higher trace metal concentrations in sediments in Benin City may be attributable to the very poor municipal drainage system because both cities are founded on the same geological formation, the Benin Formation. This unhealthy development can be remedied by the introduction of unleaded petrol to the transport industry and by providing an adequate municipal drainage system particularly in Benin City.

CONCLUSION

Evidence adduced from this chemical study on sediments from roadside drains show that Pb pollution in metropolitan Lagos, and Pb and Cr pollution in Benin City are high along all routes considered. However, sediments in Benin City are more polluted than in Lagos, although motorways in Lagos sustain a larger volume of traffic. This development is inferred to be attributable to the poor municipal drainage systems in Benin City.

REFERENCES

Cannon, H.L.; Bowles, J.M. Contamination of vegetables by tetraethyl lead. Science 137:765-766; 1962.

Daines, H.R.; Motto, H.; Chilko, D.M. Atmospheric lead: Its relation to traffic volume and proximity to highways. Environ. Sc. Technol. 4:318-322; 1970.

Herman, A.G. Praktikum der Gesteinanalyse: Chemisch instrumentelle Methode zur Bestimmung der Hauptkomponente. Berlin: Springer Verlag; 1976.

Ihenyen, A.E. Heavy metal pollution studies in coastal environments. Annual Report. Nig. Institute for Oceanography. 1987:44-45. Available from: Nigerian Institute for Oceanography, Lagos.

Lagerwerff, J.V.; Specht, A.W. Contamination of roadside soil and vegetables with Cd, Ni, Pb, and Zn. Environmental Sc. Technol. 4:583-586; 1970.

Ndiokwere, C.L. A study of heavy metal pollution from motor vehicle emissions and its effect on roadside soils, vegetables, and crops in Nigeria. Environ. Sc. Technol. (Series B) 7:35-42; 1984.

Shubert, J. Heavy metal-toxicity and environmental pollution. In: Dhar, S.K., ed. Metal ions in biological systems. New York:Plenum; 1972.

World Health Organization. Health hazards of the human environment. Available from: WHO, Geneva; 1972.

Environment International, Vol. 18, pp. 107 - 108, 1992
Printed in the U.S.A.

0160-4120/92 $5.00 +.00

LETTERS TO THE EDITOR

SOIL LEAD CONCENTRATIONS AND PREVALENCE OF HYPERACTIVE BEHAVIOR AMONG SCHOOL CHILDREN IN OTTAWA, CANADA; A RESPONSE

Dear Editor:

Several aspects of this report (Ericson and Mishra 1990) deserve further attention.

(1) The reported soil lead values, up to 75 ppm (mg/kg), are all within the natural range and do not demonstrate lead contamination. For example, rural Ontario soils typically range from 5 to 360 ppm (mg/kg) (Rinne et al. 1986; Stokes 1990; Nriagu 1986), although urban soils are often much higher, over 1000 ppm (mg/kg).

(2) The statistical analysis on page 255 shows several correlation coefficients which are claimed to be significant, but fall short of a $p = 0.05$ level. The r value of 0.50 from the subset of schools is claimed to be significant at the $p = 0.05$ level, but a coefficient of 0.55 would be required. Also, for the entire data set, the r value of 0.32 is claimed as significant, but an r of 0.35 would be required to achieve significance.

The regression equation ($y = 0.12 \times +10.66$), the standard error of the lead coefficient is so high (0.06), that the confidence interval includes zero. The fit of this line to the data is not significant ($F = 3.49$, $p = 0.07$) and could be rejected in favor of a line with zero slope.

The conclusions that lead in soil shows contamination and that the amounts of lead are related to the prevalence of hyperactivity (the y above) are not supported. Indeed, the null hypothesis, that lead and hyperactivity are independent, is not refuted by the descriptive report.

Much higher lead levels have been reported to be associated with hyperactivity and many other adverse outcomes, as is noted. However, at the lead levels reported here, there is no evidence to support this claim. Our recent studies in which lead body burdens of Chinese children have been compared to their classroom behavior has also failed to support this claim (Rabinowitz et al. 1990). We too found a bivariate association. Among the 42 of 234 boys who were rated by their teachers as being impulsive and hyperactive, when classified by the lead content of the interior dentine of their shed incisors, the χ^2 for the trend is significant, <0.01. For example, 4 of the 53 boys with very low lead levels (<2.9 µg/g) were hyperactive compared to 14 of the 56 with much higher lead levels (>5.6 µg/g). However, when other risk factors are considered (notably gender, age, lengthy hospitalization, and family size). the predictive strength of any lead term decreases. Logistic models of hyperactivity, although significant (model χ^2 21.3, $p < 0.001$), are not improved by adding lead terms (change in model χ^2 2.2, $p > 0.3$).

Interestingly, at these lower lead exposure levels, another test of mental function does show lead associated trends, Raven's Colored Progressive Matrices Test. This language-free intelligence test involves visuo-spatial analogy tasks.

Michael Rabinowitz
Marine Biological Laboratory
Woods Hole, MA 02543

REFERENCES

Ericson, J.E.; Mishra, S.I.; Soil lead concentrations and prevalence of hyperactive behavior among school children in Ottawa, Canada. Environ. Int. 16:247-256; 1990.

Nriagu, J. Pathways, cycling, and transformation of lead in the environment. In: Stokes, P., ed. Commission on Lead in the Environment. Ottawa, Canada: Royal Society of Canada; 1986.

Rabinowitz, M.; Wang, J.D.; Soong, W.T. Lead and classroom performance at seven primary schools in Taiwan. In: Lin, R.S., ed. Health, environment and social change. Cambridge, MA: Harvard University Press; 1991.

Rinne, R.J.; Linzon, S.; Stokes, P. Clean up of lead contaminated sites—the Ontario experience. Trace Subst. Environ. Health. 20:308-320; 1986.

Stokes, P. Lead in soils: Canadian case studies and perspectives. Environ. Geochem. Health Suppl. Monograph Series 4, Vol. 9:131-141; 1988.

SOIL LEAD CONCENTRATION AND PREVALENCE OF HYPERACTIVE BEHAVIOR AMONG SCHOOL CHILDREN IN OTTOWA, CANADA; A RESPONSE TO CRITICISM

Dear Editor:

Several points addressed in the Letter to the Editor (Rabinowitz 1991) deserve comment:

(1) The reported soil lead values up to 75 ppm (mg/kg) may be within the natural range for rural Ontario soils. However, the values do show spatial patterns conforming to major transportation routes and the history of urban development and land use in Ottawa. These patterns may be best explained by anthropogenic inputs to natural soil horizons. Secondly, urban soil lead tends to be sampled in the upper centimeter. Whereas, the samples in this pilot study were collected 2-4 cm below the surface which may account for their low level. Comparison between surface and subsurface sampling may not be warranted in this case. Thirdly, arguments favoring comparison of Pb concentrations may not be as accurate as using Pb isotopic concentrations. In subsequent studies of Ottawa soil level it will be important to use Pb isotope analysis to discriminate between anthropogenic inputs and natural soil lead.

(2) The statistical analysis on page 255 has been examined and stands as reported. We share concerns with Rabinowitz (1991) involving the robustness of the association between soil lead and hyperactivity.

The major concern of our study was the issue of catchment whether the location of the school conformed to the centroid of student residences. In our pilot study, we did not have the resources or information to test the correlation between soil lead and % hyperactivity grouped by residential zones. School location had to suffice. For example, on page 253, the east view of the prevalence of hyperactivity on Figure 2A shows a topographical "ridge" running northeast-southwest in the central part of Ottawa. In the same view (Figure 2B) the "ridge" of soil lead is parallel and displaced to the south of the hyperactivity "ridge." The lack of concordance between these two patterns did affect the association of the hyperactivity and soil lead as measured at the school locations. A reanalysis of these data grouped by residence, if data are available, may improve the association between soil lead and prevalence of hyperactivity.

The significance of the statistical analysis should be weighed with general and specific spatial pattern analysis. Clearly, there are demographic patterns of hyperactivity in the Ottawa schools (Trites 1979) as well as demographic patterns of soil lead. We would like to understand why prevalence of hyperactivity is so distributed in Ottawa.

(3) It is interesting that the study of the Chinese children (Rabinowitz et al. 1991) does show lead associated trends using the Raven's Color Progressive Matricies Test rather than those variables using teacher rating of impulsive and hyperactive behavior. Factors involving hyperactivity are multi-causational and include biological variables such as genetic, neurotransmitters, nutritional variables such as intake of chemicals; and psychosocial variables such as socio-economic status (Whalen 1989). Future "high lead" versus "low lead" arguments must be considered relative to the extremely elevated typical levels of body burden lead of contemporary industrialized people which exceed natural levels by a factor of approximately 1000 (Patterson et al. in press).

Jonathon E. Ericson
and
Shiraz Mishra
Program in Social Ecology
University of California, Irvine
Irvine, CA 92717

REFERENCES

Patterson, C.C., Ericson, J. E., Manea-Krichten, M.; Shirahata, H. Natural skeletal levels of lead in Homo Sapiens sapiens uncontaminated by technological lead. Sci. Total Environ.: in press.

Rabinowitz, M. Soil lead concentrations and prevalence of hyperactive behavior among school children in Ottawa, Canada: A response. Environ. Int. 17:000-000 1991.

Rabinowitz, M.; Wang, J.D.; Soong, W.T. Lead and classroom performance at seven primary schools in Taiwan. In: Lin, R.S., ed. Health, environment and social change. Cambridge, MA: Harvard University Press, 1991.

Trites, R.L., ed. Hyperactivity in children: Etiology, measurement, and treatment implications. Baltimore: University Park Press; 1979.

Whalen, C.K. Attention deficit and hyperactive disorders. In: Ollendick, T.H.; Hersen, M., eds. Handbook of child psychopathy (2nd edition). New York: Plenum Press, 1989:131-169.

Environment International, Vol. 18, pp. 109 - 114, 1992
Printed in the U.S.A.

0160-4120/92 $5.00 +.00

BOOKS

Agriculture and Fertilizers. Oluf Chr. Bøckman et al. Norsk Hydro, Oslo, Norway; 1990. 245 pp. (ISBN 82-90861-01-X) £5.00 softcover.

A growing number of people, particularly in the industrialized nations, is alarmed over threats to nature, to the environment, and ultimately to man as a result of prevailing agricultural, industrial, and social practices. Environmental protection is on the agenda throughout the world. The issues relating to agriculture and the environment are very complex. There exists a large body of scientific knowledge in this field. The public debate does not always reflect these insights. It is of the utmost importance to use what is known, and to seek new knowledge where needed. This book has been prepared by Norsk Hydro's Agricultural Group. As a producer of 12 million tonnes of fertilizer annually, Norsk Hydro has an obvious interest in the future of agriculture. The purpose of the book is to provide factual information about the environmental aspects of modern agriculture, with an emphasis on the issues relating to fertilizer use. The information is drawn from the scientific literature and the text has been reviewed by independent reviewers. This volume is recommended as a desk copy.

Cancer Risk Assessment. Samuel C. Morris. Marcel Dekker, Inc. New York, N.Y.; 1990. 408 pp. (ISBN 0-8247-8239-9) hardcover.

Cancer assessment draws on many subareas of biology, chemistry, physics, engineering, and the social sciences. For an assessment to work well, the effort must be truly interdisciplinary. This book shows how the disciplines relate to the field and each other—outlining procedures in which experts combine their efforts for more accurate results. It provides tables of Poisson confidence limit factors for varying uncertainty levels...cancer incidence and mortality statistics for the United States and internationally...a detailed summary of current practices and future trends, and extensive references for in-depth comprehension of specific areas. This book is recommended as a desk copy and as a library reference.

Conceptual Basis for Calculations of Absorbed-Dose Distributions. National Council on Radiation Protection and Measurements, Bethesda, Md; 1991. 234 pp. (ISBN 0-929600-16-9) softcover.

In external or internal irradiation, the absorbed radiation dose is usually non-uniform in any structure and, in particular, in the human body. This non-uniformity is to be distinguished from the stochastic variations that exist even in regions where the dose is uniform and that are the subject of microdosimetry. For all absorbed-dose calculations, there is a source of radiation and a receptor of some of the energy of this radiation, with or without intervening material between the source and receptor. The calculation of absorbed-dose distributions requires specification of the sources and receptors, characterization of their geometrical relationships and consideration of the physical interactions of the radiations involving attenuation, scattering, and the production of secondary radiations. All these processes are considered in the basic transport equation, the general theorems and properties and the methods of solution of which are described in the transport theory. The report is a systematic presentation, discussion, and compilation of all the concepts involved. It contains some complicated mathematics that will be of interest to the mathematically knowledgeable, but that should not discourage those not mathematically inclined. The text of the report contains detailed explanations of all the concepts and of the consequences of the equations so that, even omitting the mathematics, a broad and comprehensive understanding can be obtained of what is entailed in the calculation of an absorbed-dose distribution. This report is highly recommended as a desk copy and as a library reference.

Desalination and Water Re-use. Miriam Balaban, ed. Hemisphere Publishing Corporation, Bristol, PA; 1991. 4 Vol., 1 674 pp. (ISBN 1-56032-234-9) hardcover.

These four volumes constitute the Proceedings of the Twelfth International Symposium on Desalination and Water Re-Use sponsored by the European Federation of Chemical Engineering in conjunction with the International Desalination Association (IDA). The 1991 conference organized by the Institution of Chemical Engineers in the United Kingdom and hosted by the Government of Malta is sponsored jointly by the European Society of Membrane Science and Technology, the American Institute of Chemical Engineers, the European Desalination Association, and the Academy of Sciences of the USSR. Topics covered during the symposium included economics, membrane and evaporative processes, reverse osmosis, solar processes, fouling and scaling, waste water treatment, synthesis and properties of membranes, electrodialysis, and material requirements.

Environment and Health. Daniel W. Bromley. Blackwell Publishers, Oxford, UK; 1991. 247 pp. (ISBN 1-55786-087-4) £35.00 hardcover.

In this book, Daniel Bromley presents an operational theory of rights, property, and property rights with the intent of informing economic analysis and public debate about natural resource and environmental problems. He argues that externalities, efficiency, equity, the commons, or intertemporal equity cannot be properly understood without first being clear about the property relations defining the legal relationships among various users. This leads to a detailed treatment of property rights and property regimes in natural resource management, clarifying in particular the unfortunate confusion between "common property resources" and "open access resources" that has plagued scholarship and policy for nearly four decades. The author explores a number of applications of the theory, but his prime concern is to demonstrate a conceptual approach to the analysis of property relations concerning natural resources that transcends particular examples and can provide general illumination of the abiding policy issues in natural resource and environmental management.

Environmental Health in Urban Development. Report of a WHO Expert Committee, World Health Organization, Geneva, Switzerland; 1991. 65 pp. (ISBN 92 4 1208074) Sw.fr. 11.-/US $9.90, softcover.

This report assesses what can be done to alleviate the many severe health problems associated with urban environments, where the living conditions of hundred of millions of people adversely affect their health, cause misery, and have potentially catastrophic social consequences. Recommendations and advice respond to the urgent need for an integrated approach to urban development that takes into account all the environmental factors that affect human health and well-being. Particular emphasis is placed on informal settlements, slums, and shanty-towns, where the most serious health problems are found. It is recommended as a desk copy.

Evaluation of Environmental Data for Regulatory and Impact Assessment. S. Ramamoorthy and E. Baddaloo. Elsevier Science Publishers, Amsterdam, The Netherlands; 1990. 466 pp. (ISBN 0-444-88530-7) US$ 171.50/Dfl.300.00 hardcover.

This book deals with the evolution of analytical methodologies to the current state-of-the-art techniques, quality assurance/quality control of data acquirements, and testing procedures for screening of toxic chemicals including their hazard identification, persistence, and fate processes in the environment. The models currently employed in environmental impact assessment and risk assessment are also discussed in detail. Public involvement and participation in regulatory decision-making processes are also described. This book is intended for managers and scientists involved in environmental management and research of toxic chemicals in the environment.

The Genetic Revolution. Bernard D. Davis, M.D., ed. The Johns Hopkins University Press, Baltimore, Md; 1991. 295 pp. (ISBN 0-8018-4239-5) $15.95 softcover; $45.00 hardcover.

Remarkable advances in molecular genetics have brought benefits ranging from more flavorful tomatoes to inexpensive human insulin produced in bacteria. But not everyone welcomes the inevitable "genetic revolution." Perhaps because experts and the general public belatedly recognized that the benefits of other technologies have come at great cost—pollution of the environment, exhaustion of natural resources, even damage to the atmosphere—many assumed that similarly unintended and unforeseen harmful consequences are inevitable for biotechnology. What monsters and disasters, they wonder, will accompany the miracles of this latest advance? This book addresses such fears with clear explanations of molecular genetics, its practical applications in biotechnology, its legal implications, and its surprising historical context. To ensure that all sides of the debate are heard, Davis has chosen outstanding contributors with a wide range of viewpoints—from apprehensive to enthusiastic—and a variety of backgrounds, including political science, law, and government regulation, as well as biology and medicine. With the latest information on the likely impact of genetic engineering in agriculture, animal husbandry, ecology, and medical research and practice, the book introduces scientific facts and informed opinions to an emotional and often confusing public discussion. It is highly recommended as a desk copy.

Green Futures for Economic Growth. Terry Barker, ed. Cambridge Econometrics, Cambridge, UK; 1991. 137 pp. (ISBN 0-9516638-0-1) softcover.

The nature of environmental policy is changing. There is a distinct shift from the wholesale emphasis on "command-and-control" approaches (CAC) to approaches based on market-based instruments (MBI). CAC is typified by the traditional standard-setting approach based on ambient concentration limits or "best available technology". Basically, CAC says that a polluter can emit waste up to a point, and then no more. The limit may be set by ambient thresholds or by what is as "reasonable" to expect a polluter to do, given the available technology. The MBI approach is different. It allows pollution so long as the polluter pays the price of using up the valuable services of the environment, services which have hitherto been regarded as underpriced (and hence over-used). A typical MBI is an environmental tax, proportional to the amount of damage done. Such a tax induces the adoption of cleaner and cleaner technology in an effort to minimise the tax burden. In so far as some of the cost is passed on to the consumer, the consumer also receives a signal in the market place that a given produce is polluting and therefore expensive. There is no need for a significant sacrifice of "lifestyle", but the use of MBIs will alter the pattern of technology and consumption in the economy, and hence the way we grow. Essentially, the economy becomes restructured, away from a composition biased towards "high waste" goods and towards a "low waste" structure. The emphasis is on efficient environmental policy: achieving environmental goals at least cost. This is an important objective, neglected in the past, and vital in an age where, rightly, environmental controls are tightening and being extending to the "new" challenges such as global warming. The current book discusses how the various reforms will impact the economy, employment and competitiveness, and the low income groups. For that matter, we know little about the impacts of past CAC policy. This volume is highly recommended as a desk copy.

Hazardous Waste Incineration Calculations. Joseph P. Reynolds et al. John Wiley & Sons, Inc. New York, NY; 1991. 249 pp. (ISBN 0-471-50782-2) hardcover.

The engineering profession management of hazardous wastes, with particular emphasis on control by incineration is being considered by an increasing number of engineers. This book, plus the software contained on the computer diskette, represent an attempt to help meet these challenges. It consists of four main parts. Part 1 contains almost 100 problems dealing with hazardous waste incineration and related areas (e.g., quenchers, air pollution control equipment, risk analysis, etc.) and Part 2 contains detailed solution to these problems. Part 3 is a User's Guide which provides instructions and documentation for HWI software contained on the enclosed diskette. Part 4 is a Reference Manual intended to familiarize the use with the basic principles behind the calculations performed by the HI program. Parts 1 and 2 are the result of a year-long effort on the part of a group of university professors who first met during the summer of 1988 for a College Faculty Workshop.. The workshop was funded by the National Science Foundation. The main objective of the workshop was the development of a problem workbook in the hazardous waste incineration field. During the june 1988 meeting, each faculty member was required to generate six applications-oriented problems. The 1988-1989 academic school year afforded most of the faculty an opportunity to classroom test their own problems, at a minimum, plus many of the other problems. A three-day follow-up session held during June 1989 was utilized to revise, update, and edit the workbook and finalize production and distribution plans. This book is recommended as a desk copy.

Human Exposure Assessment for Airborne Pollutants. National Academy of Sciences, Washington, DC; 1991. 321 pp. (ISBN 0-309-04284-4) hardcover.

Exposure assessment has been integrated into attempts by governmental agencies and other organizations to examine the contact of an individual or population with contaminants released in environmental media. Numerous techniques have evolved concurrently to qualitatively and quantitatively establish éxposure profiles. In industrial hygiene practice, assessments of worker exposure during a work shift have been conducted for many years in attempts to comply with guidelines or standards. The techniques industrial hygienists have used are now being refined and introduced with other new advanced techniques to study the community environment, where contaminant concentrations are usually much lower than those observed in the workplace. The present report focusses on human exposure to contaminants that can be inhaled and potentially cause an adverse health or nuisance effect. It does not cover air contaminants transferred to other media or other routes of entry into the body. The report emphasizes that inhalation must be placed in the context of total exposure assessment, which requires consideration of all pertinent environmental media and all routes of entry into the body. This report is recommended as a desk copy and as a library reference.

In Situ Evaluation of Biological Hazards of Environmental Pollutants. Shahbeg S. Sandhu et al., eds. Plenum Publishing Corporation, New York, NY; 1990. 277 pp. (ISBN 0-306-43617-5) $65.00 hardcover.

This volume contains the proceedings of a symposium held in Chapel Hill, North Carolina. The purpose of the symposium was to address the application of in situ bioassay and chemical analyses for assessing hazards to the ecological health in marine, freshwater, and terrestrial environments, to discuss the application of in situ monitoring to human health in the workplace and living space, and to review the regulatory aspects related to hazardous waste programs. The ultimate goal of this symposium was to encourage the active integration of biomedical research and ecological effects research, an integration which would allow for a more rapid advancement in new techniques, and the development of a broader data base on both biomedical and ecotoxicological effects of environmental pollution.

Issues in Nutrition. Agnes Heinz, ed. American Council on Science and Health, New York, NY; 1991. 156 pp., softcover.

Nutrition today is a very popular topic. Magazines and news shows increasingly feature offerings on nutrition. Diet and nutrition books crowd the shelves of bookstores, promising quick weight loss, a better immune system, cholesterol reduction, and general rejuvenation. Some of the information on food and nutrition reaching the public is scientifically reliable; much of it, however, is not. Food is not only a source of nutrients for energy and tissue replacement; it provides one of the pleasures of life and plays an important role in every culture. Thus, food and its use is also a political and philosophical battleground. Strongly held opinions about food have always existed. What is surprising, however, is that decisions on food and health issues are still often based on personal value judgments, not grounded in scientific fact. This book provides a selection of timely and relevant nutrition articles, reports, and commentaries of interest to both lay people and health professionals. This collection should be of interest to researchers, students, members of the media, and those interested in science and nutrition policy issues in the 1990s. This book is highly recommended as a desk copy and as a library reference.

New Risks—Issues and Management. Louis A. Cox, Jr. and Paolo F. Ricci, eds. Plenum Press, New York, NY; 1990. 716 pp. (ISBN 0-306-43537-3) $135.00 hardcover.

This volume constitutes the proceedings of the annual meeting and conference of the Society for Risk Analysis and is the seventh volume of a series on advances in risk analysis. In selecting and organizing topics for this conference, the organizers sought to identify and include new ideas and application areas that would be of lasting interest to both risk analysts and to users of risk analysis results, and to include innovative methods and applications in established areas of risk analysis. A theme of the meeting was the importance of new technologies and the new and uncertain risks that they create. Thus, several comparatively new applications for quantitative risk assessment are addressed here—risks from biotechnology, genetic engineering, and microorganisms; from innovative technologies, projects, and practices in the telecommunications, transportation and energy industries; and from natural and man-made threats to computer systems. Methodological themes and issues in cancer risk analysis that are now much debated also appear here. These include the use of biologically motivated stochastic models of carcinogenesis as opposed to more traditional statistical models. Other areas of concern were the roles of societal risk management institutions and policy instruments as indispensable parts of practical risk management—especially tort law, regulation, insurance, and negotiated compensation, and conflict resolution. There was also increased awareness of the importance of both effective risk communication and decision-making partnerships and agreements between industry and the public, between industry and government decision makers, and between management and labor for occupational risks. This book is recommended as a library reference.

Opportunities in the Hydrologic Sciences. National Academy Press, Washington, DC; 1991. 348 pp. (ISBN 0-309-03633-X) $34.95 hardcover.

Hydrology is central to our understanding of the global environment and its many problems. Yet the study of water has not developed as a science in the same way as other fields have. This book explains how hydrologic sciences can be used to solve some of those problems. Various chapters explore the forces that drive the global water system, highlighting promising research topics in hydrology's major subfields. The book offers recommendations for improving education in the hydrologic sciences and includes a chapter on the basics of the science that is interesting for the scientist and understandable to the lay reader. Included are a series of brief biographical sketches of leaders in the field and important applied problems, such as waste disposal and global change. This book is recommended as a desk copy and as a library reference.

Ozone Diplomacy. Richard Elliot Benedick. Harvard University Press, Cambridge, Ma; 1991. 300 pp. (ISBN 0-674-65000-X) $27.95 hardcover.

The author, the leader of a U.S. delegation to an international meeting dealing with ozone depletion, describes his views on the impact of chlorofluorocarbons (CFCs) on the depletion of stratopheric ozone layer. The book describes the details of negotiations that finally led to the signing of Montreal Protocols effectively banning the use of many CFCs.

Soil Analysis. Second Edition. Keith A. Smith, ed. Marcel Dekker, Inc. New York, NY; 1991. 659 pp. (ISBN 0-8247-8355-7) $150.00 hardcover.

The theme of this revised and enlarged second edition is the same as that of the first edition, that is, to fill the gap between books covering traditional methods of analysis and specialist monographs on individual instrumental techniques, which are usually not written with soil or plant analysis specifically in mind. The principles of the techniques are combined with discussions of sample preparation and matrix problems, and critical reviews of applications in soil science and related disciplines. This book is aimed at the researcher working in soil science or a related field who is faced with the problem of making a new determination, or of replacing old analytical equipment to make a routine determination more accurately or more efficiently. It is recommended as a desk copy and as a library reference.

The Threatened Gene. Cary Fowler and Pat Mooney. The Lutterworth Press, Cambridge, UK; 1990. 278 pp. (ISBN 0-7188-2830-5) £9.95 softcover.

This book is about a worldwide problem: the loss of genetic diversity in food crops. Since the days of the hunter-gatherers, Man has used for food plants of a vast genetic diversity. However, uniformity in agriculture has been growing as an ever-increasing rate, most particularly in the use of plant breeds. As fewer varieties are employed, so the neglected ones may disappear from the global gene pool. The southern hemisphere now holds most of the world's germplasm—the genetic basis of seeds— while the developed world is consolidating its control of genetic resources. Unexpected disasters to a particular crop variety may hit less developed countries harder than the economic superpowers, which still see the problem in shorter terms. This comprehensive, uncompromising study is written in lay terms from an international perspective. Despite the grimness of the message, the tale is told with fluency and even humour, and offers a solution. This book is written in lay terms and contains a strong advocacy message.

Beeinflussung der Grundwasserqualität durch luftgetragene organische Schadstoffe. Ruprecht Schleyer et al. Institut für Wasser-, Boden- und Lufthygiene des Bundesgesundheitsamtes. Berlin, Germany; 1991. 96 pp., softcover.

Draft Mission Plan Amendment. U.S. Department of Energy, Washington, D.C.; 1991. 208 pp., softcover.

Global Economics and the Environment. Roger D. Stone and Eve Hamilton. Council on Foreign Relations, New York, NY; 1991. 61 pp., $8.95 softcover.

Indoor Pollution. Steve Coffel and Karyn Feiden. Ballentine Books, New York, NY; 1990. 278 pp., $9.95 U.S.\$13.95 Canada softcover.

Informationsquellen auf dem Fachgebiet Reinhaltung der Luft—Fortschreibung—. E. Lahmann. Institut für Wasser-, Boden- und Lufthygiene des Bundesgesundheitsamtes. Berlin, Germany; 1990. softcover.

Jobs in a Sustainable Economy. Michael Renner. Worldwatch Paper 104. Worldwatch Institute, Washington, D.C.; 1991. 58 pp., softcover.

Management of Radioactive Waste. Stewart Kemp, ed. Thomas Telford Publications, London, UK; 1991. 176 pp., £30.00 hardcover.

Obstruktive Bronchitis und Luftqualität in Berlin (West). N. Englert et al. Institut für Wasser-, Boden- und Lufthygiene des Bundesgesundheitsamtes. Berlin, Germany; 1989. 175 pp., softcover.

Recycling Household Waste. Association of Municipal Engineers of the Institution of Civil Engineers. Thomas Telford Publications, Westminster, London; 1991. 96 pp., £25.00 softcover.

Shaping Cities: The Environmental and Human Dimensions. Marcia D. Lowe. Worldwatch Paper 105. Worldwatch Institute, Washington, DC; 1991. 69 pp., $5.00 softcover.

Spurenanalytische Untersuchung von natürlichen Mineralwässern auf Gehalt und Oxidationszustand von Mangan, Arsen und Chrom. Olaf Wilke. Institut für Wasser-, Boden- und Lufthygiene des Bundesgesundheitsamtes. Berlin, Germany; 1991. 71 pp., softcover.

Umwelt-Survey Band I Studienbeschreibung und Humanbiologisches Monitoring. C. Krause et al. Institut für Wasser-, Boden- und Lufthygiene des Bundesgesundheitsamtes. Berlin, Germany; 1989. 286 pp., softcover.

Environment International, Vol., 18, p. I-XI, 1992
0160-4120/92 $5.00 + .00 Printed in the U.S.A.

NEW PATENTS

This Section contains abstracts and, where appropriate, illustrations of recently issued United States patents and published patent applications filed from over 30 countries under the Patent Cooperation Treaty. This information was obtained from recent additions to the Pergamon PATSEARCH® online database in accordance with interest profiles developed by the Editors. Further information about Pergamon PATSEARCH® can be obtained from Pergamon Orbit InfoLine Inc., 8000 Westpark Drive, McLean, Virginia 22102, U.S.A.

Copies of complete patents announced in this Section are available from Pergamon Orbit InfoLine Inc. for $8 per copy. Payment with order is required. Orders outside North America add $2 for air postage. Order by patent number for Pergamon Orbit InfoLine only.

4984449

ULTRASONIC LIQUID LEVEL MONITORING SYSTEM

Joseph W Caldwell, Mark W Slobodnik assigned to Caldwell System Corp

A liquid level measuring system having a tubular ultrasonic probe with a length in excess of the depth of liquid to be measured; for vertical insertion into a tank. A transducer inside the tube, at a first distance above the bottom end of probe body, responds transmits a sinusoidal acoustical pulse through the probe to the surface of the liquid. An echo returns from the surface of the liquid to the transducer and provides a sinusoidal echo signal. A receiver responds to the echo signal by providing a start signal corresponding to the transmitter signal crossing a predetermined amplitude in a predetermined direction and by providing a stop signal corresponding to a first selected echo signal crossing a second predetermined reference level in a predetermined direction. The speed of sound in the liquid is measured by measuring the echo time to a calibration rod in the tube at a known distance from the transducer. A timer measures the time between the start and stop signals and provides the time to a sequential controller. The depth of the liquid and the leak rate of the tank are calculated for display.

4984462

DETACHABLE LIQUID LEVEL MONITORING APPARATUS AND METHOD

Robert Hass, Brian G Hodder, Christopher P Yakymyshyn assigned to Meditor Corporation

Liquid level monitoring apparatus for monitoring the level of a liquid in a container having a wall with an exterior surface and an interior surface and formed of a material which is substantially transparent to optical energy and which has an index of refraction different from that of the liquid. The apparatus comprises an optical sensor holder and adhesive means adapted to secure the sensor holder to the exterior surface of the container at a predetermined level. A sensor head is provided. An attachment mechanism is carried by the sensor head and the sensor holder for detachably mounting the sensor head on the sensor holder. A self-contained power supply is provided which is coupled to the sensor head.

4984524

TECHNIQUE FOR CONTROLLING THE COMBUSTION OF FUEL HAVING FLUCTUATING THERMAL VALUES

Kurt-Henr Mindermann, Franz Wintrich, D 4030 Ratingen, Federal Republic Of Germany

The combustion of fuel having a highly fluctuating thermal value is controlled to permit optimization of air supply and reduction of waste gas impurities. The fuel passes through a combustion chamber having a degassing and evaporation zone, a primary combustion zone, and a secondary combustion zone. Measurements are taken in the evaporation and degassification zone to determine the thermal value of the fuel. This is done by detecting the intensity of H_2O and/or CO_2 spectra emanating from the fuel. The measurement results are utilized to optimize the combustion parameters. Such measurements are also made in the following zones in order to provide further control of the combustion process.

4985682

LEAK MONITOR FOR SECONDARY CONTAINMENT OF LIQUID STORED IN UNDERGROUND STORAGE TANKS

Daniel Boryta assigned to Leak Sensors Inc

A system for monitoring the continuity and potential rate of leakage of an underground tank hole liner formed of a sheet of electrically insulating polymeric material in which a standard current measurement is made of a circuit comprising a standard electrode in the form of a container of electrically insulating material having a small hole in a side thereof and containing an electrically conductive fluid connected to an injection electrode through a current source, the electrodes being immersed in a conductive fluid in the bottom of the tank hole to provide a calibrated liner leakage value, and such measurement is compared with the current provided by a circuit comprising the injection electrode connected to a ground electrode through the current source. If the latter current measurement is less than the standard, the area of the liner tested is considered to meet specifications as regards leakage since the total area of leaks, if any, is no greater than the area of the hole in the standard electrode, where as if the current exceeds the standard value, the liner is deemed not to meet specifications.

4986141

TAPE DRIVE WITH SELF-EXPANDING COILS FOR SLUDGE COLLECTOR

Charles Meurer assigned to Baker Hughes Incorporated

Apparatus for taking up and paying out first and second ends of an endless loop of tape that has an intermediate section. A first reel connected to the first end carries a first coil of the tape. The first coil extends from the first reel and is normally self-expanding and unwinding so as to unwind itself from the first reel. A second reel is connected to the second end for carrying a second coil of the tape. The second coil extends from the second reel and is normally self-expanding so as to unwind itself from the second reel. A drum supports both of the first and second reels for rotation in the same direction. Pulleys guide the intermediate section of the tape from the first reel to the second reel for moving a sludge collector. When the drum is rotated in a first rotary direction, the first coil tends to self-unwind from the first reel and the second coil is wound up on the second reel to move the intermediate section of the tape and the sludge collector. Upon rotation of the drum in a second rotary direction, the second coil tends to self-unwind from the second reel to apply tension to the tape and the first coil is wound up on the first reel to move the intermediate section of the tape and the sludge collector.

4986268

METHOD AND APPARATUS FOR CONTROLLING AN ARTIFICIAL RESPIRATOR

Fleur Tehrani

An apparatus for automatically controlling an artificial respirator includes sensors for receiving the exhaust gas from a patient and providing data signals corresponding to the concentration of the carbon dioxide and oxygen in the gas. The data signals are provided to a microcomputer which, together with data representing at least the patient's lung elastance factor, air viscosity factor in the lungs and barometric pressure, and when the patient is in exercise, metabolic rate ratio, determines the total ventilation and frequency for the patient's next breath and provides data output signals corresponding thereto. The data output signals from the microcomputer are provided, in analog form, to a signal generator and timing control circuit. This circuit provides output pulses which control the respirator and control valves between the respirator and the sensors.

4986905

DISTRIBUTION CONTROL SYSTEM FOR RECYCLING TREATED SEWAGE WATER FOR IRRIGATION

Rocky R White

The present invention is a self-contained residential and commercial treatment system which is capable of purifying waste water and then distributing the purified water by means of a sprinkler system or a drip feed irrigation system or of recycling the purified water in some manner.

4986910

APPARATUS FOR DEHYDRATING SLUDGE

Kiyoshi Uyama, Yasuhiko Kihara, Kawasaki, Japan assigned to Nippon Kokan Kabushiki Kaisha

This present invention relates to a method of dehydrating a wet sludge. The wet sludge which is subjected to a preliminary dehydration by gravity dehydration or the like, is pelletized by a pelletizer, and obtained pellets of the sludge are subjected to compression dehydration with a pair of endless filter fabrics.

4986915

TAPE DRIVE WITH SELF-EXPANDING COILS FOR SLUDGE COLLECTOR

Charles Meurer assigned to Baker Hughes Incorporated

Apparatus for taking up and paying out first and second ends of an endless loop of tape that has an intermediate section. A first reel connected to the first end carries a first coil of the tape. The fist coil extends from the first reel and is normally self-expanding and unwinding so as to unwind itself from the first reel. A second reel is connected to the second end for carrying a second coil of the tape. The second coil extends from the second reel and is normally self-expanding so as to unwind itself from the second reel. A drum supports both of the first and second reels for rotation in the same direction. Pulleys guide the intermediate section of the tape from the first reel to the second reel for moving a sludge collector. When the drum is rotated in a first rotary direction, the first coil tends to self-unwind from the first reel and the second coil is wound up on the second reel to move the intermediate section of the tape and the sludge collector. Upon rotation of the drum in a second rotary direction, the second coil tends to self-unwind from the second reel to apply tension to the tape and the first coil is wound up on the first reel to move the intermediate section of the tape and the sludge collector.

4987584

MATERIALS INSPECTION SYSTEM USING X-RAY IMAGING

Gerhard Doenges, Heidenrod Kemel, Federal Republic Of Germany assigned to Heiman GmbH

A material inspection system, such as a baggage insepction system, uses x-ray imaging to identify organic materials such as drugs and explosives. The articles being inspected are transirradiated with x-rays having different radiation energies. From detected radiation, attenuated by the article under inspection, a materials information signal and a luminance signal are formed. The color of the monitor image is controlled by the materials information signal, and the image brightness, color saturation and white content of the image are controlled by the luminance signal. A color portrayal occurs only when the materials information signal has a sufficiently high signal-to-noise ratio.

4987770

COMBUSTIONING CONDITION MONITORING SYSTEM FOR INTERNAL COMBUSTION ENGINE

Yasutoshi Nanyoshi, Toshio Matsumura, Hyogo, Japan assigned to Nissan Motor Company Limited

An engine combustioning condition monitoring system monitors crankshaft angular position for detecting an engine cylinder in combustion cycle. The system derives variation of velocity of a crankshaft revolution on the basis of the monitored crankshaft angular positions and derives a combustioning coefficient for each engine cylinder. A value representative of the variation of the crankshaft revolution velocity is modified by the combustioning coefficient for deriving internal pressure in each engine cylinder. Discrimination of the engine combustioning conditon is made on the basis of the engine cylinder internal pressure.

4988442

PROCESS FOR DEWATERING OF BIOLOGICAL SLUDGE

Ronald E Highsmith, Frederick J Good, Francis S Lupton, Kenneth P Kehrer, Glenn Petrie assigned to Polypure Inc

The present invention provides an improved biological sludge dewatering process. The process comprises the steps of: (a) heating biological sludge to a temperature of about 90 degrees to about 150 degrees C. which corresponds to a pressure of about 0 to about 55 psig and retaining the biological sludge at that temperature for less than about 15 minutes; (b) centrifuging the heated biological sludge to isolate the solids of the heated biological sludge from the liquid of the heated biological sludge; (c) chemically conditioning the isolated solids; and (d) dewatering the conditioned solids to produce a high solids biological sludge. The present process is used for dewatering any biological sludge to produce a high solids cake. The resulting high solids cake may be used as landfill, incinerated, or used as fertilizer by spreading on land and plowing said fertilizer into the soil.

4988446

METHOD FOR SPECTROSCOPIC ANALYSIS OF HYDROCARBONS

Joel I Haberman, Robert Overfield, Winston Robbins assigned to Exxon Research and Engineering Company

A sample of a hydrocarbon oil containing asphaltenes is chromatographically analyzed by forming a mixture of the oil with a weak solvent. The mixture is passed in contact with a column of a stationary phase of fine solid particles of fully functionalized material, followed by a weak solvent. The solvent, after recovery from the column, is analyzed for aromatics by UV-absorption of UV radiation in the range 200 to 400 nm. The absorbance of the UV light by the irradiated eluents across the UV wavelength range is monitored and the integral of absorbance is derived as a function of photon energy across the wavelength range. The magnitude of the derived integral in at least one time interval corresponding with aromatics in the eluent from the stationary phase is measured as an indication of the level of aromatics in the oil sample. The weak solvent may be followed by a strong solvent which, in turn, may be followed by a strong solvent which is modified by the addition of a hydrogen bonding solvent.

4988487

PROCESS FOR RECOVERING METAL VALUES SUCH AS SCANDIUM, IRON AND MANGANESE FROM AN INDUSTRIAL WASTE SLUDGE

Wen-Cha Lai, William Rourke, Samue Natansohn assigned to GTE Laboratories Incorporated

A process for eliminating an industrial waste sludge by converting its metal values into useful products involves the selective leaching of Mn, divalent Fe, and other valuable metals, such as Sc, Co, Cr, Ni, Th, rare earths, etc. with a mixture of dilute sulfuric acid and a reductant at ambient temperature. Scandium is recovered by passing the leachate through an ion exchange column which is packed with a weakly cationic resin. The retention of other metals on the resin column is negligible. The scandium is eluted from the resin column and converted to a solid product. The raffinate from the ion exchange column is titrated with an alkali solution to convert the metals, except divalent Mn and Fe, to a solid metal hydroxide. After the separation the filtrate is treated with an alkali and an oxidant to recover iron as a solid product of iron oxide which is separated from the solution. The remaining solution contains only Mn values which are recovered by treating the solution with an alkali and an oxidant to yield a solid manganese product. Separation of the solid leaves a liquid that can be discharged directly. The residue from the initial acid leaching contains the remaining metal values. HCl is used to selectively dissolve the Fe values. The insoluble residue is digested in an alkali to extract the total tungsten values. The residue from the alkali digestion contains substantial amounts of Ta, Nb and Ti and is a viable source for these metals.

4988510

INSECT CONTROL SYSTEM

Richard Brenner, Richard S Patterson, Roger R Pierce, Marvin H Hult assigned to The United States of America as represented by the Secretary of Agriculture

A packaged bait system for the control of insects, especially cockroaches and other orthopterous insects, comprising an insecticidal food bait composition housed in a bait block holder that allows for easy placement in locations where the probability of encounter by the target insect is high and that makes the bait readily accessible to the target insect. The toxic bait comprises corn distiller's grain, a humectant, an insecticide and a gel former to yield a deformable hydrophilic gel matrix subsequent to hydration.

4988866

MEASURING DEVICE FOR CHECKING RADIATION FIELDS FROM TREATMENT MACHINES FOR RADIOTHERAPY

Kjell B Westerlund, S 756 53 Upsala, Sweden

A measuring device for checking of radiation fields from treatment machines for radiotherapy, comprising a measuring block (11) containing radiation detectors (1-10) arranged under a cover plate (13) provided with field marking lines (14) and energy filter (16), said detectors being connected to a readout unit for signal processing and presentation of measurement values, the arrangement of the radiation detectors in the block and the signal processing in the readout unit being such that the dose monitor calibration, the homogeneity of the radiation field, the geometrical correspondence of the radiation field and the light field, and the radiation energy can be checked simultaneously in one single irradiation of the measuring block and subsequent reading of the measurement results.

4988876

PERSONNEL RADIATION DOSIMETRY DEVICE AND TESTING UNIT

Kevin Doughty, Caernafon Gwynedd, United Kingdom assigned to Radon Testing Corporation of America

A system for measuring the cumulative amount of radiation received by a person includes a radiation monitoring electret. This electret is supported on a first conductive plate and preferably is positioned within a protective cavity such that it is not discharged by non-radiation sources. Measurement of the charge decrease on the electret over time is achieved by a null method. In particular, a second plate in the monitoring device located over the electret, or the electret itself, is vibrated and an A.C. amplitude modulation detector produces an output signal created by the alternating electric field due to the vibration. A D.C. voltage of opposite charge is then applied to the first conducting plate on which the electret is supported. This field is increased until it cancels the A.C. field above the electret. When this null occurs, the applied D.C. voltage is equal to the charge on the electret. Using this null technique the electret charge can be accurately measured without contacting the electret.

4988988

CENTRAL MONITORING AND ALARMING SYSTEM

Tetsuo Kimura, Tokyo, Japan assigned to Nittan Company Ltd

A central monitoring and alarming system for monitoring and alarming an abnormal condition, for example fire and gas leakage, includes a central monitoring station having a memory device and a signal processor, plural terminals returning information detected by sensors included therein and a supporting terminal unit for specifying a proper address assigned to the terminal units respectively so that an operator can reliably know an address without looking at an address setter disposed in a terminal unit.

4989344

PARTICULATE REMOVAL FOR A SLUDGE TREATMENT PROCESS

John D Glorioso assigned to Enviro-Gro Technologies

A system is described for producing small uniform pellets of predetermined size which are substantially free of fines from mechanically dewatered sewage sludge and a means for controlling odor from the production of said pellets. The system includes a process and apparatus for mixing the dewatered sludge with previously dried recycled particles of said sludge. Drying the mixture in a thermal drier, separating a substantial portion of the dried solids from the drier off-gas. Clarifying said separated solids to separate the pellets of predetermined size, oversized pellets, and undersized pellets and particles, mechanically crushing the oversized pellets and admixing the crushed oversized pellets with the undersized pellets and particles and recycling said mixture for mixture with incoming dewatered sludge to the drier. The off-gas from the mechanical separation process is then passed through a two stage, in series, high pressure cyclone system to remove substantially all of the fines therefrom, without using a wet scrubber. The off-gas is then treated to remove odors and exhausted to the atmosphere.

4989363

BULK MATERIAL TREATMENT AND APPARATUS

Manfred Doernemann, Frankfurt, Federal Republic Of Germany assigned to Degesch GmbH

Process and apparatus for protecting or preserving stored commodities, in particular bulk commodities such as agricultural produce, e.g. grain, against deterioration by pest action, comprising the introduction into and maintenance in the commodity in a substantially gas-tight enclosure of a pesticidal atmosphere comprising carbon dioxide. The carbon dioxide is admitted to the bottom of the storage space so slowly that it spreads out as evenly as possible in the bottom region, being mixed as little as possible with the air or like gas originally contained in the storage space and then displacing that air or gas progressively in an upward direction, to be vented to the atmosphere from the top of the space until the space is filled entirely with carbon dioxide in a predetermined concentration range. This range can be monitored and regulated automatically. Excess gas is vented through vent pipes, a slight back pressure being created by non-return flaps or throttles.

4989522

METHOD AND SYSTEM FOR INCINERATION AND DETOXIFICATION OF SEMILIQUID WASTE

George Cline, Dale Edward, Bob Langberg, Kurt Winkler assigned to Sharpe Environmental Services

A method and system for detoxification of waste materials, comprising incineration of the waste materials followed by additional contaminant reduction steps. The waste material is separated into solid and liquid portions that are fed separately into a combustion chamber wherein they are exposed to a plasma arc torch to affect combustion, producing a gaseous emissions stream and an obsidian residue. The gaseous emissions stream passes through an emissions control unit to eliminate acid gases, metals, and particulates, producing a cleansed exhaust gas and an emissions residue. The emissions residue is passed through an electroplating unit to reclaim metals. The obsidian residue is pulverized and then treated by a chemical process, or passed through the electroplating unit, to reduce the concentration of unbound barium contained therein, producing an inert obsidian residue that is free of toxic levels of all contaminants.

4989570

FAIL DETECTING SYSTEM FOR SENSOR MONITORING CONCENTRATION OF A FUEL IN BLENDED MULTI-FUEL FOR INTERNAL COMBUSTION ENGINE AND FAIL-SAFE SYSTEM IN LAMBDA-CONTROL

Masaru Kuribara, Masamichi Imamura, Yoshiki Yuzuriha, Gunma, Japan assigned to Japan Electronic Control Systems Co Ltd

A fail-detection system is designed for detecting failure of a fuel concentration sensor for monitoring concentration of one of a plurality of different types of fuels which are blended to be supplied to an internal combustion engine, which fuel concentration sensor varies output signal level depending upon the monitored fuel concentration in the blended fuels. The system comprises first means for receiving the output signal from the fuel concentration sensor for providing a monitored data associated with monitored fuel concentration, second means for providing a reference data representative of normal range of the value of the monitored data, and third means for comparing the monitored data with the reference data for detecting abnormality of the fuel concentration sensor when the monitored data is out of a predetermined relationship with the reference data.

4990237

PROCESS FOR THE RECOVERY OF OIL FROM WASTE OIL SLUDGES

Steven R Heuer, Victor Reynolds

Commercially valuable oil is recovered from refinery-produced, Resource Conservation and Recovery Act classified, hazardous waste oil sludges by a series of volatilizing and condensing steps (which may vary depending on the oil, water, and solids content of the sludge) resulting in the production of nonhazardous water and solid waste byproducts. A pumpable, low viscosity, high oil- and/or water-content sludge is first centrifuged to separate free oil and water, while the thick waste oil sludge, centrifuge solids, or other sludges low in oil and/or water content are heated to volatilize the contained water and oil. Dry, friable, deoiled solids are recycled with the oily sludge feed to prevent material agglomeration and heat exchanger fouling. Oil and water vapor from the high-temperature volatilization apparatus is recycled as an indirect heat source to the low-temperature volatilization apparatus. The volatilized oil and water are condensed and combined with the oil and water centrate, and the oil and water are essentially separated as by gravity in a settler. The separated oil is again centrifuged to remove any entrained water and solids. The nearly oil free, nonhazardous waste water and nonhazardous, deoiled solids can be disposed of in a conventional manner, and the commercially valuable recovered oil is suitable for further refinery processing.

4990311

DEODORIZING APPARATUS AND METHOD

Yoichi Hirai, Toshikazu Ito, Ohbu, Japan assigned to Tohkai Kogyo Co Ltd

An apparatus and method for deodorizing a gas mixture including air and a malodorous substance having a flow passage for the gas mixture and a fan for inducing air flow in a predetermined direction through the passage. An ultraviolet lamp for generating uv rays below a critical wavelength is in the flow passage for generating ozone from the air in the gas mixture. An ozone-decomposing catalyst layer is in the passage for contacting the gas mixture, and an ozone-decomposing ultraviolet lamp for generating uv rays above critical wavelength is positioned to irradiate the layer directly. The intensity of the radiation of the two layers is controlled to avoid the discharge of ozone from the downstream end of the passage.

4990313

ULTRAVIOLET DEVICE

Richard W Pacosz assigned to American Ultra Air Inc

A switch-controlled, ballasted, low-frequency, ultraviolet device mounted inline in an air-return system of an air-conditioning unit to resupply return air. The air-return system has an upstream filter and downstream cooling coil, drain pan and blower fan. The ultraviolet device is disposed inline between the filter and cooling coil, and in closest proximity to the cooling coil to maximize its effectiveness. Ultraviolet emissions, directed at the cooling coil and drain pan, destroy cooling-coil-and-drain-pan bacterial accumulations, growth of mold spores or slime, dust mites, airborne diseases, pollens and pollutants, and purify such return air.

4991531

SYSTEM FOR IDENTIFYING UNAUTHORIZED BILGE WATER DISCHARGES FROM MARINE VESSELS

Amant Joseph C St

A system for marking unauthorized discharge of bilge waste, including a supply for containing a dye tracer product within the confines of a vessel, an interface line for adding the dye product via a flow line to the overboard discharge line of a marine vessel, valve controller for valving the flow of dye product between the supply tank and the vessel overboard discharge line, an activator for activating the valve controller responsive to the sensing of a preset level of waste products being discharged via the overboard discharge line so that unauthorized discharge of waste material from the vessel's bilge via the overboard discharge line automatically activates the valve controller to mix a dye product contained within the supply tank with the unauthorized fluid discharge.

4991625

MULTIPLE STREAM FLUID MIXING AND DISPENSING APPARATUS

Paul Manganaro

An improved multiple stream, fluid mixing and dispensing apparatus for automatically regulating flow rate and temperature for one or more preset fluid flows for connection to domestic water delivery systems including a plural station, fluid flow rate and temperature control console adapted for cooperating with the standing hydraulic pressure of a dual temperature fluid supply means with a variable effluent flow rate regulator interposed in each of the main supply conduits and associated controller means for presetting the flow rate through each regulator and determining both the degree of mixing and the incidence of fluid flow to be provided from each supply conduit to the exit conduit.

4992268

NOVEL SYSTEM FOR MONITORING AND CONTROLLING THE PAPAYA FRUIT FLY

Peter J Landolt, Robert R Heath, Herndon R Agee assigned to The United States of America as represented by the Secretary of Agriculture

A method and apparatus for monitoring and controlling the papaya fruit fly are described. The novel system is a combination of the male papaya fruit fly sex pheromone, 2-methyl-6-vinyl-pyrazine, and a fruit mimic.

4992658

ELECTRET ION CHAMBER FOR RADON MONITORING

Robert W Ramsey, Payasad Kotrappa assigned to Rad Elec Inc

An electret ion chamber for monitoring radon comprises a housing having an electret holder and a cover. The cover is attached to a plunger which closes over the electret when the cover is in place and is removed from the electret when the cover is opened. The plunger effectively turns on and off the radon monitor with the opening and closing of the cap. In very short term and very long term radon monitors, this turn on and off feature is not needed.

4993323

FLUIDIZED BED COMBUSTION OF ALUMINUM SMELTING WASTE

Ronald S Tabery, Ky Dangtran

An environmentally acceptable and effective method for thermal destruction of Spent Potliner (SPL) by Fluidized Bed Combustion (FBC) has been established. This method has overcome problems associated with ash agglomeration, ash leachate character and emission control, the primary obstacles for applying FBC to the disposal of SPL and like solid fuels. Specifically, recipes of appropriate additives (fuel blends) are proposed. A mixture of lignite, limestone and SPL in an appropriate proportion has proven to notably increase the agglomeration temperature of the ash, allowing this low-melting waste to be destroyed continuously by FBC. Ash leachate character is modified by control of ash chemistry to ensure that fluoride anions and metallic cations are at or below acceptable limits.

4993372

TWO STROKE INTERNAL COMBUSTION ENGINE WITH DECOMPRESSION VALVE

Constanti Mott, Constantin Noe, Don Mills, Ontario M3C 1C7, Canada

A two-stroke internal combustion engine has an inlet port in the cylinder wall covered and exposed by the piston during reciprocation thereof in the cylinder and to which fresh air is supplied under pressure by a supercharger. An exhaust valve is mounted centrally in the cylinder head for controlled operation independently of the position of the piston. Fresh air forced into the cylinder by the supercharger when the inlet port is exposed by the piston during the exhaust stroke enables any residual unburned gases to burn completely and expels the gasses from the cylinder completely enabling operation of the engine at high compression with relatively low pollution.

4993838

DUST MONITOR

Stewart W Tresouthick, Hugh Love assigned to Construction Technology Laboratories Inc

An apparatus and method for reliably generating simulations of actual dust suspension conditions and measuring the associated density of suspended dust. The dust monitor is constructed to permit generation of dust suspensions by achieving various pre-selected motions for the test material, such as a rolling motion or swirling motion relative to the forward direction of travel of the test material. The apparatus and method permit prediction and control of the propensity to form dust suspensions during actual operating situations in the field.

4993942

LIME SLUDGE KILN

John Boyden, James F Schooling assigned to Champion International Corporation

A kiln for reclaiming quick lime for calcium carbonate sludge formed in the production of cooking liquors in a wood pulping process for the production of paper. The kiln provides increased output with lower energy input due to: measurement and control of oxygen content in the kiln; non-air mixing burner; castable refractory liner with tumbler ribs; a heat transferring chain system; and a variable speed exhaust fan and air flow control. The output of the kiln was increased by more than ten percent along with a forty-five percent improvement in energy efficiency at substantial cost reduction due to its efficient use of energy.

4994187

APPARATUS FOR REMOVING SEWAGE SLUDGE FROM THE BOTTOM OR THE SURFACE IN A SETTLING BASIN

Bernd Glaser, Uwe Kloth, Hamburg, Federal Republic Of Germany assigned to Richard Totzke Mashinen- und Apparatebaue GmbH

Sweeper means for circular settling basins wherein at least a pipe is supported by a radially extending support structure adapted to be rotated about a central vertical axis by driving means, wherein further the discharge end of the pipe being connected to a sewage sludge return line which is extended below the settling basin and extended into the basin in the central area thereof and which is adapted to deliver the sewage sludge outwards of the settling basin, the support structure being suspended on a vertical rotary shaft coupled to the driving means, the other end of the pipe moving in conjunction with the support structure being connected to a rotary connection below the level in said settling basin to which also the sludge return line is connected.

4994280

IODOPHOR COMPOSITION FOR AQUACULTURE

Lyle J Kochinsky

A stable concentrated iodophor composition is useful in aqueous solution for control of microorganisms in the therapeutic and prophylactic culture of aquatic animals such as fish, reptiles, and amphibians. It is effective against bacteria, fungi, viruses, algae and the like in very dilute solution while being non-toxic to higher animals. Its biocidal action is due in large measure to the action of iodine that is slowly released into the water. The solution has low-foaming properties to enable its use with water systems having moving water in fountains, filters and bubble aerators. The composition includes phosphoric acid, ethylene glycol monobutyl ether, and two iodophors, a first iodophor formed by mixing iodomethane with a quaternary ammonium surfactant and a second iodophor formed by heating iodine with either an alkyl phenoxyl polyether alcohol or oleic acid sulfonate.

4994378

METHOD FOR REDUCING BLOOD CARBON DIOXIDE BACKGROUND IN BACTERIAL MEDIA BY THE ADDITION OF MICELLES OF SAPONIN AND A PHOSPHOLIPID

Dolores Berger, Paul E Goldenbaum, Gregory Tice assigned to Becton Dickinson and Company

A non-ionic lytic agent, preferably saponin for reducing the background carbon dioxide produced by blood cell metabolism is used in the testing of cultures for the presence of microorganisms. The hemolytic agent saponin is combined with a phospholipid, preferably L- alpha-Lecithin (phosphatidylcholine), to form mixed micelles which protect saponin from the effects of heat sterilization and high blood cholesterol levels, thus maintaining the lytic activity of saponin. The phospholipid/saponin mixed micelles are added to non-radiometric culture media vials such as Bactec trademark NR6A, NR7A and NR8A. The media vials are used in the Bactec trademark NR-660 and NR-730 instruments. However, the present invention may also be used in radiometric media such as Bactec trademark culture vials 6, 7 and 8 for reducing background carbon dioxide levels detected in C14 radiometric instruments such as the Bactec trademark-460, or in other instruments designed to detect bacteria in the presence of mammalian cells by monitoring the increase in CO2 produced by the metabolizing bacteria.

4994390

ENZYME BLEND CONTAINING CELLULASE TO CONTROL INDUSTRIAL SLIME

Christopher Wiatr assigned to Nalco Chemical Company

A method of attacking and removing microbial slime in slime covered surfaces and maintaining a slime-free surface as in exposed cooling tower surfaces and in waste water treatment and paper making. This method comprises utilizing an enzyme blend in 2 to 100 parts per million (ppm) of cellulase, alpha-amylase and protease. Such enzyme blends have been found specifically to digest microbial slime and reduce microbial attachment and biofilm. A specific combination of polysaccharide degrading enzymes is a ratio of 2 parts cellulase to 1 alpha-amylase to 1 protease utilized in 2-100 parts per million. Broadly, the alpha-amylase must be at least 1 and the protease may vary from 0.5 to 1 part.

4994391

BACTERIA CULTURING SYSTEM

Craig O Hoffmann

An improved bacterial culturing system which is advantageously used on-site at waste water treatment plants. The system rapidly and efficiently produces various types of bacteria having enhanced activity and controllable characteristics. The bacteria are used to break down undesired or unwanted chemical species contained in the waste water stream. The system includes a unique culturing or primary basin in communication with an acclimation or acclimator basin. Bacteria grown in the culturing basin are partially exposed to the materials they are later intended to break down in the acclimation basin.

4994791

PROGRESSIVELY MONITORABLE FIRE ALARM SYSTEM

Henry F Taylor assigned to Texas A & M University System

A method for producing reflectors in a continuous length of optical fiber is disclosed. The present process includes the steps of preparing the ends of two or more optical fibers, placing one or more of these fibers in a vacuum system and applying a metallic or dielectric coating to the fiber ends, and then fusing the prepared, coated ends of the fibers together until the reflectivity of the region reaches a desired value.

4995242

METHOD OF AND MEANS FOR CONTROLLING THE CONDITION OF AIR IN AN ENCLOSURE

Gad Assaf, Rehovot, Israel assigned to Ormat Turbines Ltd

The air in a greenhouse is dehumidified using a direct-contact heat exchanger utilizing concentrated brine. The diluted brine produced when water vapor in the greenhouse condenses on the concentrated brine is regenerated in a fuel-fired boiler whose products of combustion, carbon dioxide and water vapor, are passed into the greenhouse. The products of combustion provide the desired level of carbon dioxide in the greenhouse; and the excess water vapor in the products of combustion as well as a significant portion of the water vapor produced by plants, growing in the greenhouse are removed by the hygroscopic concentrated brine.

4996155

BACILLUS THURINGIENSIS GENE ENCODING A COLEOPTERAN-ACTIVE TOXIN

August Sick, Thomas E Gilroy assigned to Mycogen Corporation

A novel B.t. toxin gene encoding a protein toxic to coleopteran insects has been cloned from a novel coleopteran-active B. thuringiensis microbe. The DNA encoding the B.t. toxin can be used to transform various prokaryotic and eukaryotic microbes to express the B.t. toxin. These recombinant microbes can be used to control coleopteran insects in various environments.

4996156

PREPARATION OF SPORE-FREE, CONCENTRATED PROTEIN PREPARATIONS FROM BACILLUS THURINGIENSIS SEROVAR, ISRAELENSIS, WHICH IS TOXIC FOR GNATS, A MICROORGANISM FOR THEIR PREPARATION, AND THE ISOLATION OF THE MICROORGANISM

Han Zaehner, Konrad Bernhard, Harald Weisser, 7400 Tuebingen, Federal Republic Of Germany

Asporous mutants of Bacillus thuringiensis serovar. israelensis, a process for their preparation and their use for the isolation of bacterial toxins for controlling diptera.

ENVIRONMENT INTERNATIONAL

Aims and Scope

Environment International, published bimonthly, is a multidisciplinary forum for the publication of original environmental literature. Vital data, causes of pollution, and methods for protection are all featured. Covering the entire field of environmental protection, *Environment International* includes contributions from the following areas

- Concentration of elements and compounds, notably pollutants
- Transport of polllutants in the environmental media
- Control technologies
- Public policy alternatives including legislation
- Release rates of pollutants from various sources
- Health and ecological effects of pollutants
- Description and interpretation of laws, regulations, and standards
- Information which will contribute to the understanding of environmental behavior of pollutants or will promote environmental protection
- National and international recommendations and practices to help bring about lasting improvement in environmental protection

From time to time *Environment International* will publish issues devoted exclusively to special topics, e.g., specific pollutants. These issues will discuss such problems as environmental concentrations, health and ecological effects, environmental kinetics, production and release rates, legislative and regulatory aspects, control technologies, and other pertinent data. Other special issues will be devoted to pollution problems in selected geographical areas. Authors and readers are encouraged to send in suggestions to the Editor-in-Chief recommending topics for these topical issues

Information for Contributors

Since the journal will serve a multidisciplinary audience, authors are urged to write for nonspecialists. In particular, they are discouraged from using expressions which are understandable only to a select audience. Clarity should be the guide when preparing manuscripts. All the contributions will be subjected to peer reviews. Owing to the broad coverage of *Environment International*, no single format can accomodate all contributions. Manuscripts must be submitted in English. Mail manuscripts to the Editor-in-Chief, *Environment International*, P.O.Box 7166, Alexandria, VA 22307, U.S.A. The following categories of contributions will be considered for publication in the journal

Articles—Previously unpublished information including data from routine monitoring operations will be published in this category. Papers dealing with new analytical techniques should contain data indicating their usefulness in environmental measurements. Similarly, basic biological effects data should be related to environmental pollutants.

Discussions—This section is intended as a forum for the readers to express their views on environmental problems on a global or national basis. Letters to the editors, editorials, contributions containing personal opinions and comments on articles published in the journal or elsewhere will be included in this section.

Book Reviews—Solicited and unsolicited reviews on relevant books will be considered for inclusion in this section.

News—This section will contain newsworthy items in the scientific, technological, governmental and political areas relating to the environment. Readers are encouraged to suggest subjects for inclusion in this section.

Preparation of Manuscripts—The journal is produced using a computer-based desktop publishing system. Accordingly, the processing time of manuscripts submitted in a computer-compatible form is greatly reduced.

Manuscripts should be typed double-spaced on one side of bond paper with wide margins. Each paper should include a title page with the title of the paper, name(s) of author(s), affiliation(s) and mailing address. In the case of co-authors, it should be clearly indicated which is to receive correspondence and proofs for correction.

All tables and figures must be camera-ready. Use a new ribbon for typing tables. Photocopies, blue ink or pencil are not acceptable. Use blue ink for lettering figures. The lettering should be large enough to be legible after the diagram has been reduced in size for printing. In the interest of conserving space, it is desirable that figures are drawn so they will reduce to the single column width of 8.5cm (3.35 in). Type figure legends double-spaced on a separate sheet of paper. Write article title and figure number lightly in pencil on the back of each piece of artwork.

Submissions in a computer-compatible form require a disk, one original copy on paper containing the original figures and tables, and a second paper copy. The system requires compatibility with IBM computers and can accept 13.5 cm(5.25 in) and 9 cm (3.5 in) disks. The WordPerfect word processing system prepared with an IBM-compatible (MS-DOS or PC-DOS) computer is the preferred submission. If WordPerfect is unavailable, WordStar, MultiMate Revisable-Form-Text (IBM DCA Format) can be used. If none of these is available, use ASCII (American Standard Code for Information Interchange) or DOS text file. Indicate which program was used. In the absence of a computer, one original and two copies are required.

References—The journal generally follows the referencing style of the *Council of Biological Editors*. In the text, refer to the author(s) and the year. Examples for one author, two authors and more than two authors are: Wolf(1984); Repace and Lowrey(1985); Smith et al.(1979). If there is more than one listing of the same author and year, use a, b, c, etc. Prepare a list in alphabetical order containing all literature cited. In this list of references, include initials and surnames of the authors, title of the paper, name of the journal using the *World List of Scientific Periodicals* abbreviations, volume number and page number(s). Note that et al. is not acceptable in the reference list unless the publication has more than six authors. The following examples should be used as a guide:

Article: Repace, J.L.; Lowrey, A.H. A.quantative estimate of nonsmokers' lung cancer from passive smoking. Environ. Int. 11:3-22; 1985.

Report: NIH (Nationa Institutes of Health). Report of the National Institutes of Health ad hoc working group to develop radioepidemiological tables. NIH 85-2748. Washington, D.C : U.S. Department of Health and Human Services; 1985.

Book: Henderson, P.m Inorganic geochemistry. New York, NY: Pergamon Press; 1982.

Regulation: USEPA (U.S. Environmental Protection Agency). National primary drinking water regulations: fluoride. 40 CFR Parts 141, 142 and 143. Fed. Reg. 50:47142-48933; 1985.

Proceedings: Swedjemark, G.A.; M.jönes, L. Exposure of the Swedish population to radon daughters. Berglund, B.; Lindvall, T.; Sundell, J., eds. Proc. 3rd international conference on indoor air quality and climate. Vol. 2. Stockholm: Swedish Council for Building Research; 1984:37-43.

Reprints can be ordered on a Reprint Order Form which will accompany proofs. Unless instructions to the contrary have b een received, only the first named author will receive this order form with proofs of the article. The author filling in the order form should make sure that all co-authors' needs for reprints are incorporated in the total order. Reprint order forms must be received before printing in order to qualify for lower prepublication rates. The original manuscript and diagrams will be discarded one month after publication unless the publisher is requested to return original material to the author.

It is a condition of publication that manuscripts submitted to this journal have not been published and will not be simultaneously submitted or published elsewhere. All authors must sign the Transfer of Copyright agreement, available from the editors, before the article can be published. (U.S. and U.K. government officers or employees whose submitted work was prepared as part of theeir employment are exempt from the transfer requirement, but must certify their status as government writers.) This transfer agreement enables Pergamon Press to protect the copyrighted material for the authors, but does not relinquish the authors' proprietary rights or rights to use their work as they please in the future. The copyright transfer covers the exclusive rights to reproduce and distribute the article, including reprints, photographic reproductions, microform, or any other reproductions of similar nature and translations.

ENVIRONMENT INTERNATIONAL
VOLUME 18, NUMBER 1 1992

(Contents continued from back cover)

ENVIRONMENT INTERNATIONAL

CONTENTS

Volume 18 Number 1 1992

(Contents continued on inside back cover)

INDEXED IN Current Contents, BIOSIS Database, Eng. Ind. Monthly and Author Ind., Environ. Per. Bibl., CABS, Energy Res. Abstr., Energy Data Base, Excerpta Medica, Geo. Abstr., Sci. Cit. Ind., and Biology and Environmental Sciences

ISSN 0160-4120
(326)