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EDITORIAL

STOCKHOLM STATEMENT ON BUILDING-RELATED ALLERGIC AND OTHER ADVERSE EFFECTS ON HUMAN HEALTH AND COMFORT

The Folksam Insurance Group, in cooperation with the Karolinska Institute, Stockholm and the University of Maryland, convened a meeting in January 1992 in Stockholm, Sweden, to discuss problems associated with the incidence of allergy, hyperreactivity, and other reactions attributed to the building environment. The aims of the meeting were to exchange information and to consider strategies for courses of action. The meeting consisted of informal presentations and discussions of various aspects of the adverse effects on health and comfort attributed to buildings, the potential causes, and approaches to their prevention. The participants reached a consensus on the following topics:

Statement of the problem

Available data from various parts of the world suggest an increasing incidence rate of allergy and other hyperactivity reactions. The data from Sweden are particularly persuasive. There also appears to be a significant increase in reports of a number of symptoms that are commonly classified as Sick Building Syndrom (SBS). The magnitude of the prevalence and incidence of allergy, hyperreactivity and other building-attributed adverse effects on health and comfort is not known but it is considerable. Although the exact causative agents for these adverse health effects are unknown, chemicals and microorganisms acting singly or in combination are likely candidates.

Strategies for prevention and remediation

The ideal approach to the prevention of these adverse health and comfort problems would consist of identification of the causative agents, assessment of sources of these agents, exposure assessment, identification of susceptible populations, determination of the exposure-response function and effects assessment. Because of time and expense requirements for the complete and effective implementation of such an approach, it is necessary to explore those initial remedies that are likely to result in significant improvements of indoor air quality at relatively low costs. Such remedies can be implemented at no risk before a complete characterization of the problem can be made. Therefore, the optimum approach should rely on short-term strategies as well as on more long-range research efforts that are likely to yield additional insights for a more thorough assessment of the problem.

Short-term strategies

(1) There is a need for standardized tests to assess the emission of pollutants from building materials, furniture, appliances and equipment, and other pollutant sources associated with occupant activities.

(2) These tests should be applied to relevant sources and the results compiled and made available to potential users to enable the strategic selection of low-emitting sources.

(3) Whenever appropriate (e.g., in larger buildings), an individual should be identified who is responsible for ensuring high indoor air quality, including proper operation of heating, ventilation, and air conditioning (HVAC) systems and for responding to occupant complaints.

(4) Particular care must be taken to avoid growth of harmful microorganisms (e.g., fleecy surfaces).

(5) Outdoor air ventilation rates and ventilation effectiveness must be maintained in accordance with appropriate standards.

(6) Acceptable indoor air quality and energy conservation need not be incompatible. Wherever there is a conflict between energy conservation and human health and comfort, the latter considerations shall prevail.

(7) Precautions must be taken in the proper selection, use, and storage of cleaning agents and other chemicals introduced into buildings.

(8) The effectiveness of human health and comfort outlined above should be continuously assessed.

Long-term strategies

(1) A surveillance program is needed to assess allergy, hyperreactivity and SBS, and their relationship to building parameters.

(2) Methods need to be developed to identify the causative agents responsible for adverse effects attributable to buildings.

(3) Following on current efforts which qualitatively assess the impact of pollution sources, methods are needed to more quantitatively assess these impacts.

(4) Existing methods for the assessment of exposure to indoor air pollutants need to be improved, especially for multiple agents.

(5) One of the most important parameters for the prediction of excess of allergy, hyperreactivity reactions, and other adverse building related symptoms, including SBS, is the correlation between exposure and effects. Therefore, concerted efforts must be made to develop the methods required for such an assessment.

(6) Once the information outlined above is available, the occurrence of allergy, hyperreactivity, and other adverse building-related reactions, including SBS symptoms, can be predicted with an acceptable level of quantification. This would enable forecasting and cost-benefit assessments for different approaches to prevention.

(7) Standardized tests are needed for human mucosal and sensory irritation other then allergy and other hyperreactivity reactions. In particular, it would be highly desirable to develop models and physical and chemical techniques for testing human mucosal and sensory irritation.

Implementation

It is strongly recommended that an international workshop be convened to exchange information on the incidence of building-related adverse effects on human health and comfort in buildings. Such a symposium would enable a more effective discussion of the benefits associated with implementing the short-term strategy outlined above, as well as ensure international cooperation in the planning and conduct of both preliminary and longer-range activities. The implementation of studies of the effectiveness of preliminary strategies in bringing about a reduction of adverse effects of the building environment as proposed by groups such as the Folksam Insurance are reasonable. Such studies are likely to be successful and yield results which are not only applicable to Sweden, but will have global implications for the protection of human health and the environment.

This statement was prepared by a scientific expert group consisting of the following individuals:

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IS THERE A LARGE RISK OF RADIATION? A CRITICAL REVIEW OF PESSIMISTIC CLAIMS*

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A number of situations where it has been claimed that moderate radiation doses cause leukemia or other cancers are carefully reviewed. We look at cases in the United States and Great Britain. Usually, it can be demonstrated that there is an alternative, more probable, explanation for the effect seen. In several cases, the authors of the papers have fallen into statistical traps. The most frequent is a *posteriori* selection of cohort boundaries in both space and time: a trap illustrated dramatically by Feynman. The next most common trap is to arbitrarily select one out of many ways of looking at the data, against which we were warned by Tippett. Several cohorts are compared with respect to the number of persons at risk, average dose, and the number of cancers expected. Of these, only the cohort of A-bomb survivors in Japan provides evidence of clearly visible excess cancers.

INTRODUCTION

Radiation is still perceived by the public as one of the major health hazards. Although x-rays have been with us since the 1890s, and radioactivity was discovered soon thereafter; and while there was some fear of the usual x-rays, the widespread public fear did not arise until 1945 when the first atomic bomb exploded. Fear is a common response among the public — an irrational fear that can prevent rational action to achieve the desired benefits and reduce hazards, while introducing a minimum of new hazards.

When fear exists, there will, in a free society, be those who exploit the fear for their own ends, who feed it and nourish it. The exaggerated claims and predictions of doom appear in the newspapers (or the Congressional Record), but rarely in scientific journals. This whole issue of fear has been discussed by Weart (1988).

Some people make a sharp distinction between natural and man-made radiation. But in practice, this distinction is arbitrary. The natural background can be reduced or increased by our actions. We can build houses to avoid radon gas or to trap it.

In this paper, we review some of the pessimistic claims about radiation. We attempt to discover what,

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*An expanded version of this paper will be published as Argonne National Laboratory Report.

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if anything, that is useful these claims tell us. Ideally, we would only consider data and claims made in journals which have peer review. However, public policy is often made using reports and papers that have not been so published. One ignores these at the price of being irrelevant. However, in the references, we try to make the distinction clear when it is not obvious. For example, newspapers and the congressional record are not peer reviewed, nor are scientific newspapers such as the *New Scientist*. However, *Nature* and *Science* are peer reviewed.

Any discussion and review of the effects of radiation on health is necessarily incomplete. It has been estimated that there are over 100 000 references on the subject. In making this review, we have just begun to address many of the claims and have only read a fraction of the papers. However, we hope and believe that we show how to address the main issues.

In addition to the reports of scholarly and international organizations (BEIR 1972, 1980, 1990; ICRP 1982; NCRP 1980, 1989; UNSCEAR 1986, 1988, Shimizu et al. 1988), there are a number of other review papers and books by distinguished authors. Some of them address the issues considered here, and we list them for convenience (Yalow 1986; Webster 1980; Bond 1970, 1981; Hamilton 1983; Cohen 1980, 1981, 1986; Pochin 1983; Archer 1980; Goldman 1989; Shleien et al. 1991).

There are also a number of books and papers which are written in a less restrained manner by various persons (e.g., McCracken 1982; Grant 1988). These are useful as sources of information, but are, in general, too partisan to present a proper case.

FROM INDIVIDUAL CASE TO CONTROLLED STUDY

When a physician notices an unusual problem among his patients, he looks for a pattern. The literature is, properly, full of such case reports by observant physicians. It was the observation by Percival Pott that most chimney sweeps died prematurely of cancer of the scrotum that led to the realization that the soot causes cancer. This observation was so clear that no fancy epidemiological procedures were necessary. However, when effects are small, more elaborate procedures are needed.

There is some confusion about the terms used by different authors. Sir Austin Bradford Hill (1965) uses the word association to describe a situation when two phenomena are known to occur at the same time or place. A statistician often refers to a correlation between two observables in the same sense and insists that a correlation may not always be causal; However, this distinction between a causal and a non-causal correlation is not always realized, and correlation is often automatically exaggerated into causal correlation. We here use the word association instead of correlation in order to emphasize this distinction, and to reject any implication of causality, although an association may sometimes be a causal correlation.

Hill (1965) outlined nine criteria that have to be considered when attempting to attribute a cause to an effect. He emphasizes that they need not all be simultaneously necessary. For example, the strength of the association observed by Percival Pott was so great that the association forced attention, even though there was little biology to make the causality plausible and nothing with which to make an analogy. The nine criteria are as follows:

1. The strength of the association. If the strength of the association is large, then common sense usually makes it outweigh other considerations. Nonetheless, cigarette smoking gives a large effect, but the delayed nature of the effect meant that 50 years passed before it was generally accepted that most lung cancers are caused by cigarettes.

2. The consistency of the results. If the same data set is analyzed by different people, they should all find similar results.

3. The specificity of the results. If a specific health condition is associated with the claimed cause, it is usually more believable than a general claim of increased mortality.

4. Temporality. The effect must follow the claimed cause and never precede it. If there is a delay (latency period), it must be plausible and understood.

5. Existence of a biological gradient. The effect should increase as the pollution increases.

6. Biological plausibility. The effect should be plausible biologically. This need not mean that there is a detailed explanation, but that the effect should not violate known biological laws.

7. Coherence. Various studies should be correlated in a coherent picture; one isolated study is hard to believe if it seems to contradict others.

8. Experimentation. In some cases, the epidemiological study can be supported by experiments on animals where doses are given in a controlled way. It is such experiments, for example, that led to the Linear Quadratic model of BEIR (1980).

9. Analogy. Sometimes we can make an analogy between two carcinogenic agents. For example, benzene causes acute myeloid leukemia with a short latent period. Thus, one might reasonably expect a short latent period for radiation-induced leukemia.

These may seem sophisticated criteria, but they are just simple logical requirements. Hill (1965) emphasizes that the attribution of cause to an effect does not need all the items to be present; however it is clear that there must be no disproof. Each of these nine criteria are here considered in conjunction with unusual claims of effects of radiation.

If a phenomenon does not fit with existing scientific understanding, it requires more, rather than less, evidence to prove its reality. If, for example, it was claimed that a dog ran down 5th Avenue in the city of New York at noon, not many people would be surprised. But if it was claimed that a lion ran down 5th Avenue at noon, there would be considerable proof required. The required proof would be less if other information made it more plausible—if it were known, for example, that a lion had escaped from the Bronx Zoo, in New York City. However, if it were claimed that a pterodactyl ran down 5th Avenue at noon, most auditors would be skeptical because pterodactyls are extinct.

Anyone who claims that low doses of radiation give large effects must overcome a weight of prior evidence; this demand might be reduced if it could be shown that the instruments measuring the dose or the calculations thereof were faulty, and the dose might not be low after all. In most of the cases we discuss here, the evidence provided is insufficient to challenge the well-established facts.

Associated with this need for increased proof in unusual situations, is the need to create a plausible model to describe the event. This model, which presumably should be valid at other places and times, should be tested to see whether it indeed makes such valid predictions. For example, if occupational exposure to radiation is claimed to cause an excess of cancer, and a background of environmental and medical exposures gives 10 times the radiation dose, one should easily be able to find an excess of cancers from these environmental and medical exposures. If one cannot, then the model must be incorrect. Any claim of unusual association which does not go on to describe a plausible model is incomplete; it will, however, be seen that few authors make such models.

TECHNICAL TERMS

Statistical significance is used to quantify the outcomes of random events (e.g., a throw of a die), by reporting the mean value plus the standard deviation within a certain probability or confidence limit. For normal distributions, if the mean value is N, then the standard deviation is $\sqrt{N}$. The 95% confidence limit corresponds to the range of values not exceeding $(N + 1.64 \cdot \sqrt{N})$. If the expected number of cancers among a group of residents is N and the number observed exceeds $(N + 1.64 \cdot \sqrt{N})$, then one can claim that a cluster is observed and there is less than a 5% chance that the observed excess is due to a statistical fluctuation above the normal rate.

Infant mortality rate is 1000 multiplied by the ratio of number of deaths of infants <1 y to the number of live births during same year (MacMahon 1970).

The Standard Mortality Ratio (SMR), sometimes called the Total Mortality Ratio (TMR), in a given group is the number of deaths expressed as a percentage of the number of deaths that would have been expected if the age-and-sex-specific rates in the general populations were obtained. The Cancer Mortality Ratio (CMR) is the same, with deaths replaced by cancer deaths. Infant mortality ratio (IMR) is the same as SMR, but restricted to infants.

STATISTICAL TRAPS

Hill (1965) did not state the two most elementary criteria—and the criteria most frequently ignored. There must be a statistically significant effect to consider, and secondly, the statistical analysis must not be biased.

Many errors in pessimistic claims considered in this paper are statistical. The most important of these is biased selection of initial data. Errors associated with such data selection are also some of the hardest to explain to those unacquainted with statistical methods.

The late Richard Feynman had a dramatic way of demonstrating that a biased selection of data can invalidate standard statistical tests. Coming into class, he said, "You know, the most amazing thing happened to me tonight. I was coming here, on the way to the lecture, and I came in through the parking lot. And you won't believe what happened. I saw a car with the license plate ARW 357! Can you imagine? Of all the millions of license plates in the state, what was the chance that I would see that particular one tonight?" (Goodstein 1989). We can easily work it out: 3 is one out of 10 numbers, 5 is one out of 10 numbers, 7 is one of 10 numbers, A is one of 26 letters, R is one out of 26 letters, and W is one out of 26 letters. If we multiply these numbers together, we find a low probability of 1 in 18 000 000. Yet Feynman saw it. This commonplace experience does not seem that improbable. What is the answer to this paradox?

As presented, the answer to this paradox is obvious: Feynman did not ask the question about the particular license plate until he knew the answer.

However, in epidemiological studies, the paradox is often disguised. This trap is far from unique to epidemiology, nor is it unusual. Physicists fall into it with surprising regularity. In honor of our friend, the late Professor Richard Feynman, we call it the Feynman Trap.

The importance of using unbiased data in any epidemiological study can hardly be overemphasized. The ideal procedure in epidemiology would be to select a cohort (group of persons) for study while they are young and follow them into the future. Such a study can only be complete after several decades, and even then is not immune from genetic bias or bias due to pre-existing environmental effects.

In practice, what is called a prospective study does not do this; the epidemiologist defines a cohort of interest that existed in the past and then goes through records to find out what happened to the members of the cohort. The epidemiologist must make every effort to be sure that he/she is not influenced by any prior knowledge of the final result in selection of the cohort. This is hard to do; it is not sufficient that the investigator not have prior knowledge. His superior and his funding agency may have such knowledge and have an influence upon the choice of cohort.

This is so difficult, yet so important, that it is preferable that every prospective epidemiological paper starts with a discussion of this point, especially if the numbers are small and the effect of bias most serious. Unfortunately, this is not done in many epidemiological studies, even by some of the best authors and even in some studies using small numbers upon which major societal decisions depend.

For example, if a small, possibly unusual, cluster of cancer cases is found in a certain location, concerned citizens will properly search for possible causes. They might find an abandoned well or dump site containing some chemical known to be toxic, but with no specific known adverse chronic health effects. It is proper to postulate this chemical as a possible cause. This is sometimes called the hypothesis-generating event. This can be related to the automobile in the Feynman example.

The hypothesis generating event can then trigger an epidemiological study; the epidemiologist must search for other similar wells or dump sites also containing the chemical of concern. The people must be similar to the general population in all respects except their proximity to the well or dump site and possess no other difference in common with the people around the original well. Having found such a cohort, and not before (or he/she might be influenced in his/her choice by the result), he/she can then search the records to find out whether the same type of cancer appears at the new location.

Finally, in establishing statistical significance, the epidemiologist must omit the original group of people, with their cancer cases, that brought the subject to his attention in the first place. We see that this then will satisfy the requirements of reproducibility and specificity outlined by Hill (1965). In many of the discussions below of the claims of large effects of radiation, the requirement of the strength of association is met, but the others are not.

There are numerous, well-established, epidemiological studies that show that large radiation doses to people cause an increase in leukemia rates, and we know roughly how much. Moreover, radiation-induced leukemias appear after a moderately short latent period, so that they are easier to identify than radiation-induced cancers with a long latent period. It seems obvious, therefore, to search for possible increases in leukemia near nuclear power plants, or any other known radiation sources. It seems especially appropriate to use leukemia as a marker for chronic effects of radiation. Thus, it would appear that the hypothesis has already been generated. However, this is only true if there is enough radioactivity from the source to cause a statistically significant increase in the leukemias. In several of the cases below, we are discussing a new hypothesis: "radiation causes leukemias at several hundred times the rate expected from the known and published radiation measurements assuming linear dose-response curve." This could happen either because the actual radiation levels are several hundred times the known and published ones, or because of a new, and most scientists would say unlikely, biological phenomenon.

One of the most common temptations for any epidemiologist or other student of statistics, is to decide upon groups of data, or decide upon statistical tests, after the preliminary results of the study are known. It must always be remembered that if 20 independent biological endpoints (such as cancer in 20 separate organs) are studied, and each tested according to separate statistical tests, then one will appear to be statistically significant with $P < 0.05$ by chance alone.

Again, in practice, it is rarely possible to be absolutely pure in this regard. When a new idea for a test arises after the study has started and the data collected, some correction can be made by increasing the level of statistical significance demanded. In the case above, where 20 tests are examined, and it is not known in advance which test is to be examined, one should demand $P < 0.05/20 = 0.0025$ instead of the usual $P < 0.05$. A failure to do this is sometimes called Tippett's Trap, because the well-known statistician Tippett called attention to this problem (Tippett 1937).

The reader can often tell whether basic statistical errors such as these have been made. If an author of a paper has data which are just significant, and does not discuss these potential problems, it can usually be assumed that he or she was unaware of them and may have fallen into one of the traps.

DOES RADIATION CAUSE INFANT MORTALITY?

Ernest Sternglass published a paper (Sternglass 1963) alleging a link between fallout from nuclear bomb tests and the infant mortality rate. This was based on the experimental evidence by Stewart and Kneale (1970) and by MacMahon (1963) that x-rays given to pregnant women increased the incidence of childhood leukemias. Fitting these data to a linear dose-response relationship he argued that fallout from bomb tests should increase childhood leukemias, and then extended the argument to other infant mortality. This paper made a number of arbitrary assumptions which were criticized by Dunham (1963), Bennett (1963) and MacMahon (1963). In 1969, Sternglass produced a number of other papers and reports (Sternglass 1969a, 1969b, 1969c, 1969d, 1969e, 1969f). In these papers, he made a number of suggestions that fallout from nuclear bomb tests was responsible for a number of infant leukemias. These claims were made on the basis of a plot of infant mortality versus time (Fig.1a).

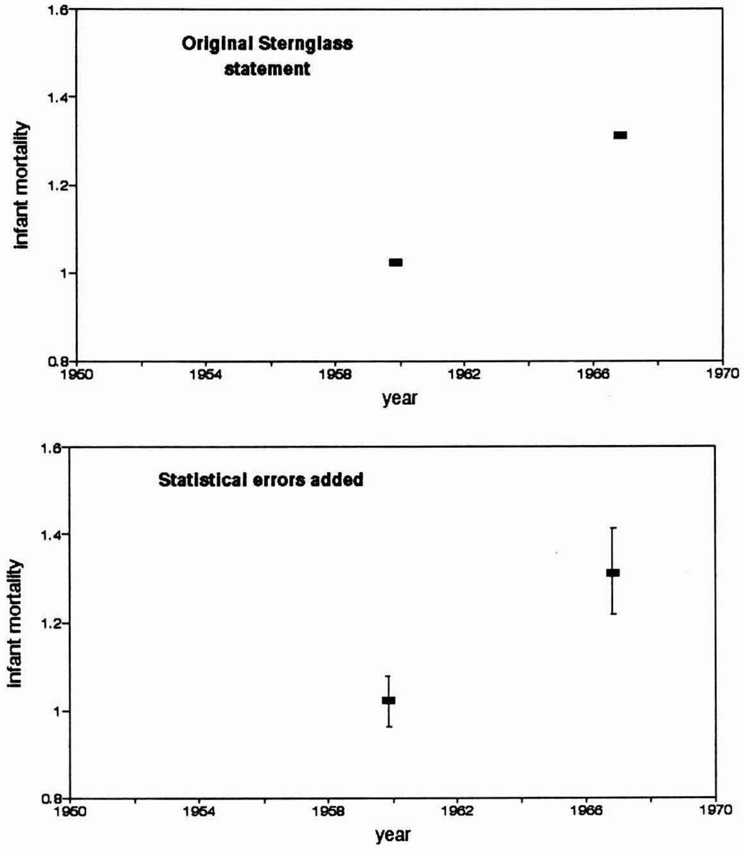

Fig. 1a and b. Infant mortality near Indian Point, New York.

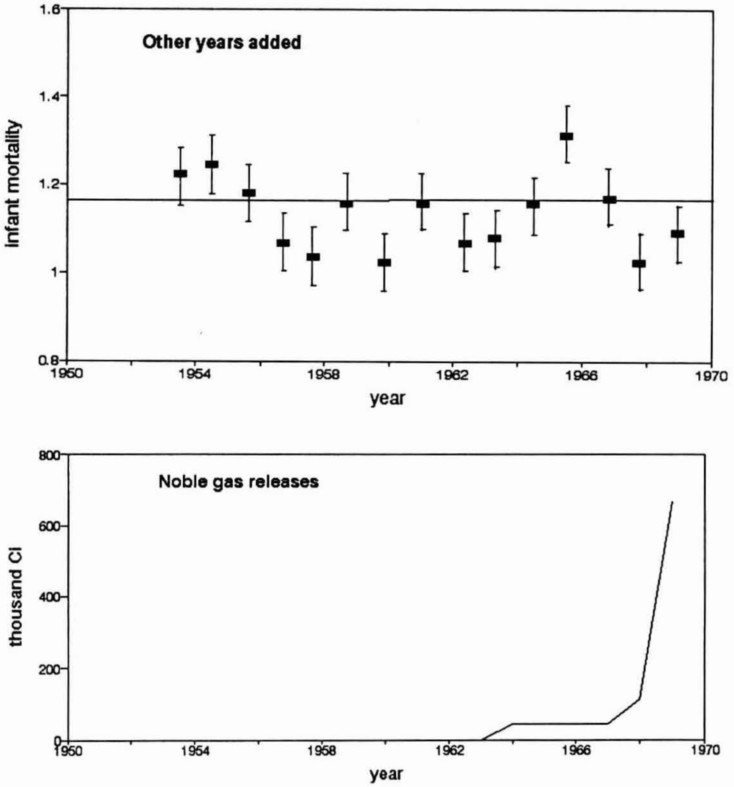

Fig. 1c and d. Infant mortality near Indian Point, New York.

It was tempting at the time for scientists to believe Sternglass' claims without looking carefully at them. By 1963, a majority of scientists had successfully persuaded the major countries of the world to stop testing of nuclear bombs in the atmosphere. Sternglass appeared to provide extra ammunition to justify this. Rotblat (1970, private communication), a leader in urging nuclear test bans, asked that this temptation be rejected; sooner or later, he argued, the acceptance of bad science, even for a good reason, would backfire. He was particularly concerned that it would be used against peaceful uses of nuclear energy.

Sternglass then extended the arguments about fallout from nuclear bomb tests to study infant mortality (and sometimes leukemia) near nuclear power plants. A number of persons have reviewed various of his claims; one of the most specific is that of Hull and Shore (1971). Sternglass has since produced a string of about ten reports a year, none of which has been accepted in the community as having any validity.Sternglass' claims met with a storm of criticism (Graham and Thro 1969; Boffey 1969; Stewart 1969; Wrenn 1969; Sagan 1969; Eisenbud et al. 1969; Heller 1970). This then led to an unprecedented statement read by the current and signed by all living past presidents of the Health Physics Society (Moeller 1971). "We, the President and Past Presidents of the Health Physics Society, do not agree with the claim of Dr. Sternglass that he has shown that radiation exposure from nuclear power operations has resulted in an increase in infant mortality."

An example of one of these is his claim that infant mortality increased near Indian Point I Nuclear Power Plant just after it began operation in 1961. Figure 1 shows how these claims, made for one specific pair of years, show selection bias. The top figure (1a) shows Sternglass' two points. They look less significant when statistical errors are shown (1b). When the whole graph is shown (Hull and Shore 1971), it is clear that the points were arbitrarily selected in time. Figure 1d shows that the increase was not correlated with radioactivity releases as originally claimed, but preceded them. This was a selection bias in time. There also maybe a biased selection of place.

In one of the more recent reports, Sternglass (1986) claims that a release of radioactive material to the environment from the Pilgrim Nuclear Power plant in Plymouth, MA, in June 1982 caused an increase in infant mortality in the counties nearby. As reported to the Nuclear Regulatory Commission (NRC), the release was a solid material and was confined to the power plant property. Nonetheless, it is, of course, plausible to look for effects near the power plant. Sternglass claimed an increase in infant mortality from 1981 to 1982.

In Fig. 2, we show the full data on infant mortality for various years collected by the Massachusetts Department of Public Health (Massachusetts 1987). In Fig. 2a are Sternglass' two points for the town of Plymouth for 1981 and 1982. These indeed suggest an increase. When the statistical errors are added in (Fig. 2b), the claim already looks less impressive. In Fig. 2c, the data for many years are included, showing that the overall trend is opposite to that implied by Sternglass. When the data are collected for the whole county and the whole state, in Figs. 2b and 2c, the fluctuations are reduced because of the larger statistical sample. Finally, we note that the measured radioactivity releases from the power plant were larger during the early years of operation—before a graphite filter was installed and while there was a period of leaking fuel pins. However, at no time would these releases have suggested a large excess of cancers, and indeed no such excess has been found. We call attention to the similarity of the claim of infant mortality around Indian Point, and its refutation, to the claim of infant mortality around Pilgrim. Figure 3 shows the same argument for the recent low birthweight around Pilgrim Power Plant.

Not content with the claim that there was increased infant mortality near Pilgrim in 1982 caused by the 1982 release, Sternglass attributed an increase in infant mortality in southwest New Hampshire, 100 miles (160 km) away, to a combination of Pilgrim and two other nuclear power plants—Vermont Yankee and Yankee Rowe. The smog in Boston is closer, thus providing a more likely potential culprit to study.

LEUKEMIA CLUSTERS

It is self-evident that people dying of infectious diseases do not die uniformly throughout the world, but in clusters, either in space or in time, where the infection has taken hold. Diseases which are not infectious are not expected to cluster, except in so far as there might be exogenous causes. Cancer is generally believed to be a non-infectious disease.

Only 3% of cancers are leukemias; but about 15% of cancers that are induced by radiation in the first 30 y after exposure seem to be leukemias (BEIR 1990). This is because of the relatively short latent period for leukemia. This suggests looking for leukemias—particularly acute myeloid leukemias—as an indicator or marker of radiation exposure. Moreover, leukemia has a short latent period, a causal association with an event becomes easier to prove than for other cancers. But there are several other causes of leukemia; such as benzene and possibly other solvents. Leukemias are believed to cluster in such a way that statistical deviations from expected rates exceed the standard deviation (Glass et al. 1968).

There are four major types of leukemia that are hematologically distinct: acute lymphatic (ALL), chronic lymphatic (CLL), acute myeloid(AML) and its variants, and chronic myeloid (CML). Of these, CLL is not known to be caused by radiation. Indeed the progression of the disease is slow, as evidenced by a doubling time of white blood cells of two to three years after diagnosis. Extrapolating back to a single cell division suggests that CLL is caused early in life, and perhaps has a genetic origin. Therefore, in studies of leukemia caused by an external agent such as radiation, it is usual to exclude CLL (BEIR 1990; Cartwright and Bernard 1987).

However, there have been many searches for clusters, particularly of leukemia, from a suggestion that leukemia, and in particular childhood leukemia, might have a viral origin (Smith 1982). Darby and Doll (1987) also addressed this idea. For a long time, leukemias have been known to cluster without an obvious cause, an effect that suggests that the origin might be an infectious disease. For example, the first child in a family is much more likely to get childhood leukemia than later ones. A particularly interesting phenomenon was noted by Smith, et al. (1985). One way of curing leukemia is to destroy blood cells and bone marrow by heavy radiation exposure. Then, new blood can be provided by a blood transfusion, preferably from a twin. Smith et al. (1985) noted the occurrence of leukemia in a patient with new bone marrow well after the treatment by whole body irradiation.

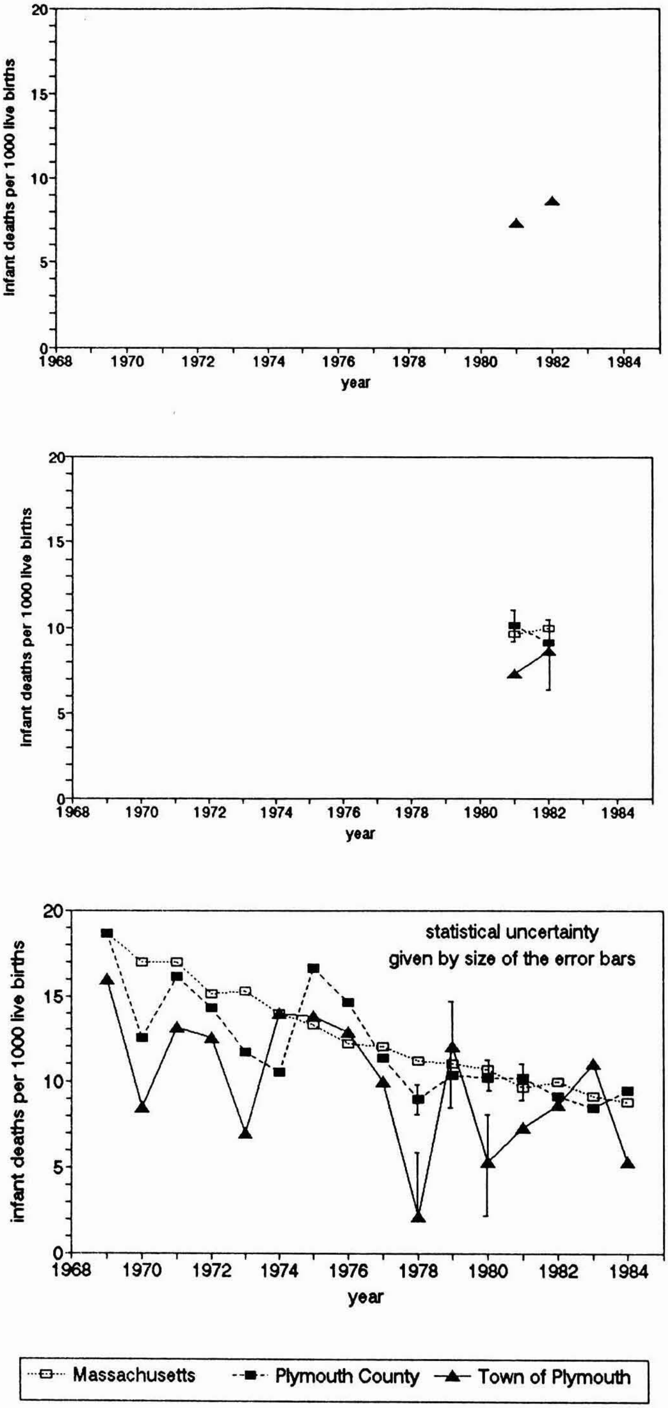

Fig. 2. Infant mortality rate in Plymouth, Plymouth County, and Massachusetts (1968-1984).

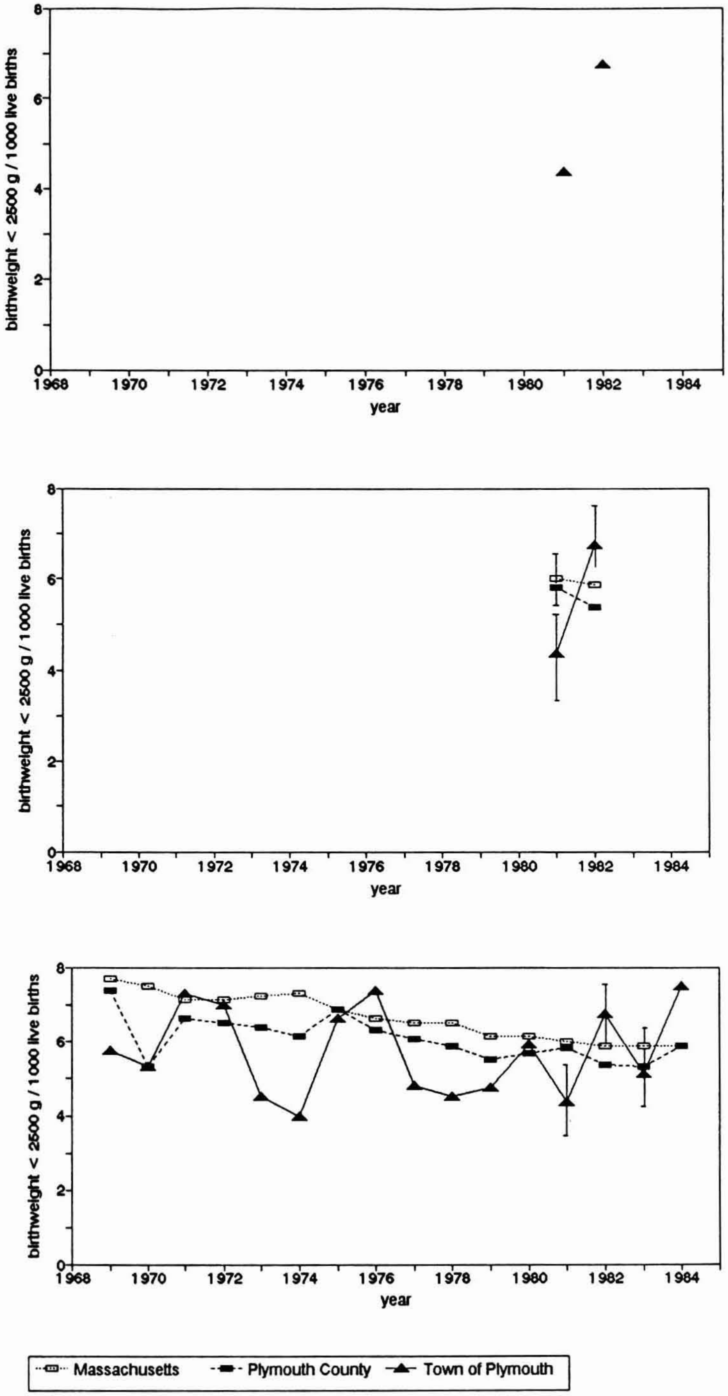

Fig. 3. Percent of low birthweight in Plymouth, Plymouth County, and Massachusetts (1969-1984).

This is consistent with a viral origin for the leukemia. Some earlier suggestions that clustering occurred are usually attributed to biased post hoc selection of boundaries for the grouping of leukemias (Glass et al. 1968).

Few clusters of cancer or leukemia survive as real (i.e., not due to statistical fluctuation) clusters when the data was subjected to careful screening and analysis. Jablon et al. (1990) of the National Cancer Institute (NCI) of the U.S. have carried out a comprehensive analysis of leukemia and cancer incidence at the county level around all nuclear plants in the U.S. and found no significant effect. They noted a deficit of leukemias in Plymouth county which contains the Pilgrim Nuclear Power Plant.

Finally, we reiterate that real (nonstatistical fluctuations) leukemia or cancer clusters can occur randomly without an apparent cause. Such random clusters, it appears, do not discriminate between nuclear or non-nuclear facilities. In a blind attempt to study leukemia clusters, leukemia around 14 military sites in England was studied. Clusters were found around two of them. When the identity of the two military sites was released to the study group, it turned out that the sites were medieval castles. (Cehn and Sagan 1988). It is unclear whether the study group was influenced by the statement that they were military sites.

LEUKEMIAS NEAR PLYMOUTH, MASSACHUSETTS

Cobb (1987) noted that the number of leukemias in certain counties in southeastern Massachusetts was larger than expected. He asked whether they could have been caused by the Pilgrim Nuclear Power Plant. Cobb postulated a certain pattern of coastal circulation of the air within 2-4 miles (3-4 km) of the coastline (Clapp et al. 1987). In his testimony in front of the Joint Committee of Energy of the Commonwealth of Massachusetts, he stated that, "It is easy to imagine how an injection of pollutants to the middle of such a pattern might be contained and carried along the coast." However, detailed measurement shows that winds do not follow the postulated pattern (Stone and Webster 1988). A more detailed listing of leukemias in Plymouth county has been carried out by Rothman et al. (1988) (Tables 1 and 2). In these tables, the expected number is based upon state-wide statistics.

Table 1 shows a small excess of leukemia (excluding CLL which, as noted, is not caused by radiation) for the years 1982-84 in the five coastal towns closest to Plymouth. This is barely statistically significant, and the significance vanishes when more years are included. This is shown more clearly in Table 2 from Rothman et al. Moreover, we know of no postulated reason, other than the impossible one, that they are due to the wind-borne radioactivity. However, an

Table 1. Observed and expected incidence of Leukemias other than chronic lymphocytic leukemia in three groups of Massachusetts towns, 1982-1986[a]. Data from Rothman et al. (1988).

	Five Coastal Towns[b]				Five Towns Closest to Plymouth[c]				Plymouth County[d]			
Years	Obs	Exp.	SMR	95% CI	Obs.	Exp.	SMR	95% CI	Obs.	Exp.	SMR	95% CI
1982-84	27	17.0	1.59	1.05-2.31	13	12.2	1.06	0.59-1.78	63	73.8	0.85	0.66-1.09
1985-86	6	11.8	0.51	0.21-1.06	6	8.6	0.70	0.28-1.45	36	47.5	0.76	0.53-1.05
1982-86	33	28.8	1.14	0.79-1.61	19	20.8	0.91	0.57-1.40	99	121.3	0.82	0.66-0.99

[a] Abbreviations: Obs., observed cases; Exp., expected cases; SMR, standardized mortality ratio (Obs./Exp.); CI, confidence interval (by exact method).

[b] Duxbury, Kingston, Marshfield, Plymouth and Scituate.

[c] Carver, Duxbury, Kingston, Plympton and Plymouth.

[d] 27 towns, including all those in the other two groups.

Table 2. Observed and expected mortality from leukemias other than chronic lymphocytic leukemia in three groups of Massachusetts towns, 1969-1986[a]. Data from Rothman et al. (1988).

Five Coastal Towns[b]				Five Towns Closest to Plymouth[c]				Plymouth County[d]				Plymouth County less 5 Towns		
Obs.	Exp.	SMR	95% CI	Obs.	Exp.	SMR	95%CI	Obs.	Exp.	SMR	95% CI	Obs.	Exp.	SMR
Years 1969-72														
17	17.3	0.98	0.59-1.54	10	10.9	0.91	0.47-1.64	86	87.1	0.99	0.79-1.22	76	76.2	1.00
Years 1973-76														
14	19.3	0.72	0.41-1.19	7	12.9	0.54	0.24-1.07	80	90.7	0.88	0.70-1.10	73	77.8	0.94
Years 1977-80														
18	21.2	0.85	0.52-1.32	13	14.6	0.89	0.50-1.48	79	94.2	0.84	0.66-1.05	66	79.6	0.83
Years 1981-86														
34	35.5	0.96	0.66-1.34	26	25.0	1.04	0.68-1.52	128	152.0	0.84	0.70-1.00	102	127	0.80
Years 1977-86														
												168	206.6	0.81

[a] Abbreviations: Obs., observed cases; Exp., expected cases; SMR, standardized mortality ratio (Obs./Exp.); CI, confidence interval (by exact method).

[b] Duxbury, Kingston, Marshfield, Plymouth and Scituate.

[c] Carver, Duxbury, Kingston, Plympton and Plymouth.

[d] 27 towns, including all those in the other two groups.

interesting fact emerges upon which Rothman et al. did not comment. If we add a fourth group of three columns to Table 2 for Plymouth County less the five towns close to Plymouth, a marked deficit appears after 1977. For the period 1977-86, 168 leukemias were observed, with 207 expected. The deficit of 39 is over twice the standard deviation of $\sqrt{207} = 14$, and therefore significant (Wilson 1991). In a nationwide study of leukemias near nuclear power plants, carried out at a country level, Jablon et al. (1990) also noticed the deficit of leukemias in Plymouth County.

Morris and Knori (1990) performed a case-control study of leukemias near Plymouth, using a complex score of closeness to Pilgrim as a surrogate for exposure level. Table 3 shows the data for cases diagnosed between 1978 and 1986. Since these are the same cases already discussed, a similar difference between close to Plymouth and far from Plymouth is expected. A statistically significant difference is indeed found. Since the previous data and reports already suggested an effect of the same magnitude as found in this study, it is hard to understand the statement on page (vi) of the summary of Morris and Knori, "These (earlier) findings are somewhat inconsistent with those of this investigation."

Morris and Knori further subdivided the data into the periods 1978 to 1981, 1982 and 1983, and 1984 to 1986, and find an effect only in the first two. This is surprising, because our simple calculation in Table 2 shows an effect persisting in 1984-86. Moreover, the Pilgrim plant only began operating after 1973. If it is hypothesized that the radiation from the plant immediately after startup caused leukemias, they would be expected to continue to occur from 1978 through 1993; and there is no valid reason for excluding the years 1984 to 1986 in this analysis. To make such an exclusion without a valid reason makes the statistical calculations invalid.

Even if it is accepted that there is an association between leukemias and something in Plymouth, a causal connection can only be accepted if there is a cause. The reported release of radioactivity materials from Pilgrim were never enough to cause measurable radiation levels above the natural background radiation level and could not therefore have caused measurable cancer increase above background cancer levels. This is a robust conclusion and is independent of any particular relationship that is assumed between radiation dose and leukemia incidence. Anyone suggesting that Pilgrim was the cause of any of these leukemias must therefore postulate unreported

Table 3. Results of matched case-control analyses: Estimated relative risks[a] of leukemia by exposure level; both sexes combined; cases 1978-1986.

Exposure Score	Cases	Controls	O.R. (CI)
low (<.030)	18	56	1.00 (0)
medium (.030-.199)	50	106	1.97 (0.99, 3.95)
high (.2+)	37	46	3.89 (1.74, 8.68)
Total	105	208	

chi square trend - 11.38 p-0.001

[a] Odds ratios presented are controlled for age, sex, vital status, year of death, socioeconomic status, smoking status, occupation and industry

(Table 2 of Morris and Knori, 1990)

and unmeasured release of radioactivity far exceeding the reported levels. Indeed, an examination of the BEIR V report (BEIR 1990), suggests that the exposure must be 200 rem to each individual to quadruple the leukemia rate. If such unreported releases occurred (and that is very doubtful), they should be stopped. But they would not be stopped by the DPH recommendation to reduce the regulatory limit from its present value of 25 mrem. They must also postulate another reason for leukemia to be decreased overall (independent of location), so that the releases appear to leave the number of leukemias near Plymouth unchanged, while reducing them further away.

In this example, Dr. Sydney Cobb should be praised for raising the question and postulating an explanation, even though this explanation was subsequently shown to be invalid (see also poole 1988). However, the report by Morris and Knori was publicly released by the Massachusetts Department of Health in a press conference and television appearances by the Deputy Commissioner of Health (not the authors) just after his budget was cut. The budget was quickly restored.

We must also be aware that another large power plant exists nearby, contrary to one of Sternglass' claims that the only industrial facility near Plymouth is the Pilgrim Nuclear Power Plant. This is the Canal Station, which is fossil fuelled (see Fig. 4). The releases from the Canal Station are of a different type of material, but there is as much reason for attributing the increase in leukemias to them as to Pilgrim. A little further away is another large coal-burning power plant at Somerset. This is upwind. It is well known that coal-burning plants emit radioactive material. The Somerset plant spews more long-lived radioactivity over the counties around Plymouth than does the Pilgrim plant (see, for example, Tables 5-6 and 5-7 of Wilson et al. 1981).

DID THE CHERNOBYL ACCIDENT INCREASE U.S. MORTALITY?

Two reports by Gould (1986; 1988) have been widely publicized. In the first of these reports, Gould et al. (1986) endeavor to see whether increases in overall mortality, total cancer mortality, and changes in fetal or infant mortality can be related, firstly to the presence of nuclear power plants in the state, and secondly to the radioactivity releases from these power plants. As an exploratory study, this is appropriate; but the words imply that the study is more than exploration. We shall assume that the arithmetic calculations are correct, and discuss whether or not they make their case. A statement such as "it is clear that emissions in the nuclear counties have an adverse effect on mortality particularly among the very young and very old" implies causality. We believe that neither this statement, nor the title "Nuclear emissions take their toll" is close to being justified.

Gould et al. first compare Infant Mortality Ratio (IMR), Total Mortality Ratio (TMR), and Cancer

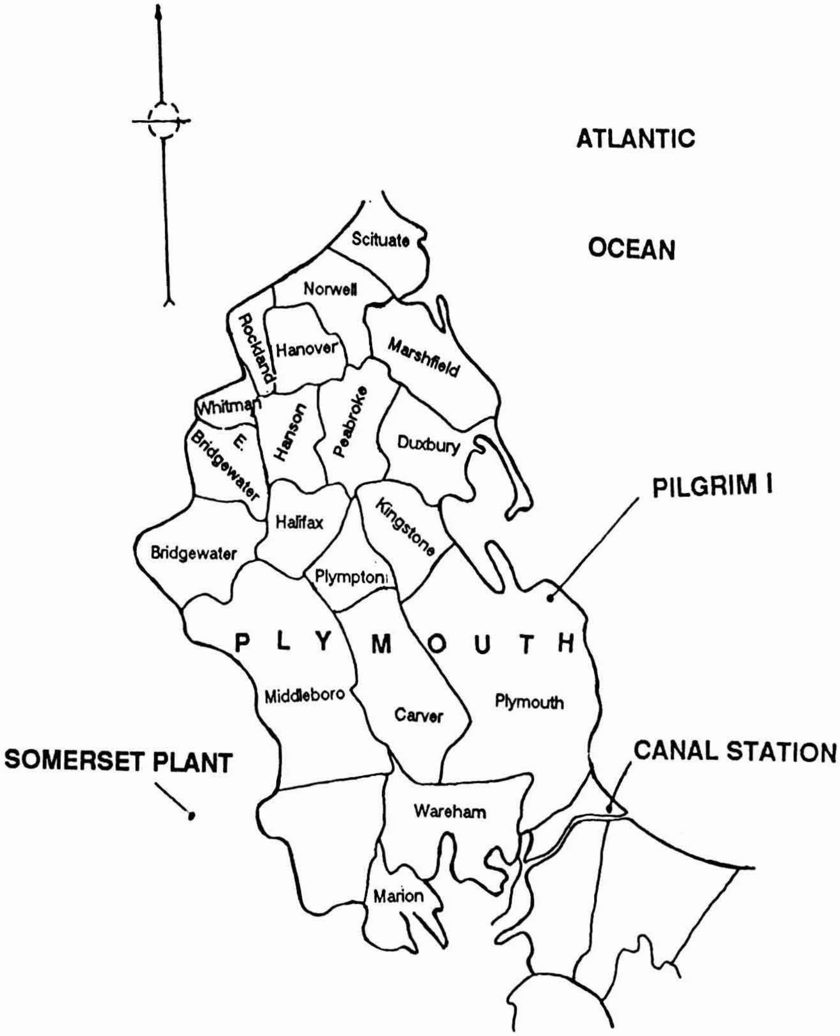

Fig. 4. Map of coastal area around Plymouth.

Mortality Ratio (CMR) for nuclear states and non-nuclear states both for the years 1965-69 and 1975-82. They suggest, reasonably, that effects of nuclear plants would not be present in the earlier period. These are summarized in their Tables 3 and 4. They then note that the infant mortality ratio has fallen less in nuclear states (-3.95% annual rate) than in non-nuclear states (-4.33%) although the infant mortality ratio was still less in 1975-82 in nuclear than non-nuclear states. This is also true of total mortality. Gould et al. claim that cancer mortality increases in the nuclear states more than in the non-nuclear states and is larger in both time periods. They claim, and we have not checked, that these differences are statistically significant.

Gould et al. do note that "there is no clearly defined tendency evident in Table 2 of Gould et al. among each of the so-called nuclear states to have increases in mortality that exceed those of the nation" (Gould et al.1986, p. 5, first column). Another way of saying the same thing would be to say that the infant mortality declines are not distributed about the mean in a statistical manner and this, therefore, calls into question their use of the statistical criteria based solely on the number of persons and cases. One crude way of correcting for this would be to use the observed fluctuations in these parameters among nuclear states and the observed fluctuation in non-nuclear states instead of the square root of the number of cases. Then the statistical significance probably vanishes. Thus, the only valid conclusion from the data that make up their Tables 3 and 4 is that while the data are consistent with the assumption made, they are very far from proving it.

Presumably because they recognize this, Gould et al. go on to look in closer detail at counties within 30 miles (50 km) of a nuclear power plant. Again a slight difference is found. It is just significant (the probability that it is due to chance is less than one in 20), but Gould et al. do not ask how consistent this difference is among the various counties and we must again ask whether there are other causes of fluctuation than the square root of the number of cases. Thus the statement "it is clear that emissions in the nuclear counties have an adverse effect on mortality" is patently false.

Gould has been selective in his choice of items to consider. Just one illustrates a fluctuation in the opposite direction from Gould's argument. BWRs release more radioactive xenon than do PWRs (as noted in Gould's Table 5). Yet the increase in cancer mortality from 1965-69 to 1975-82 (1.140) is less than that for PWRs (1.230) and less than the increase for non-nuclear counties.

In the report, Gould et al. mention the radioactive noble gas releases, but do not discuss them or use them in a correlation. Yet, in any assumed relation of health effects to nuclear power plants, the releases must be more directly related to the health effects than the mere existence of the power plant itself.

Even if consistency and statistical significance were clear, all the other issues in Hill's list would have to be addressed. There may be a real correlation between one of the public health parameters and nuclear power plant location, but it is not necessarily a causal correlation.

If, for example, we compare the number of nuclear power plants in the country with expectation of life in that country, it is obvious that the expectation is higher in the U.S. with its many power plants than in Africa which has none. A priori, this increase of life expectancy near nuclear plants is as likely to be a direct causal relationship as the one Gould et al. propose. Few people believe that the nuclear power plants are a direct cause of the longer life expectation, however, and attribute the causal relationship to nutrition and good health care. These are related to prosperity, just as nuclear power plants are related to prosperity, and prosperity is closer to being the true cause.

As one delves more deeply, Gould's case becomes even weaker. Although not explicitly stated by Gould, it seems that he is endeavoring to attribute the cause of mortality to an assumed radiation dose to human organs. Ideally, therefore, one would correlate cancer incidence with radiation dose. This information is hard to get, but one can imagine using human exposure, and calculate the dose to various human organs from the exposure. Radioactivity releases have been measured, and we know how to calculate exposure from releases. It is then easy to see that the radiation exposure will in all cases be much less than the natural background and less than the fluctuation and changes in natural background. Unless Gould et al. are prepared to claim and substantiate that the radioactivity releases have been grossly understated, or that we do not know how to calculate exposure from release, any case for causality stops at once.

Having shown that the statistical case Gould et al. present is weak and inconsistent, and that it's not plausible based upon the comparison of dose and background dose, we now complete the picture by suggesting a number of other possible causes for the effects which are much more plausible than radiation.

1. For infant mortality, fetal mortality, and total mortality, Tables 4 and 5 of Gould et al. show that the rates in non-nuclear counties and states are now close to those in nuclear counties. This could be due to medical care catching up in rural states.

2. The larger cancer rates in nuclear states can be due to general industrialization.

In the second report, Gould (1988) was even less specific. He noticed that 33.06% of the 1986 deaths occurred in the U.S. during the months of May to August 1986 compared to 31.97% in earlier years. The difference claimed is small (although statistically significant). It might have any of a number of causes. Gould chose to suggest iodine releases from Chernobyl Nuclear Power Plant.

Taking Gould's specific suggestion of the cause first, we note that this suggestion satisfies almost none of Hill's requirements. The only one satisfied is temporality; the suggested cause does precede the effect.

Taking just one other requirement, we note that the iodine doses and doses from other radionuclides around the world from the Chernobyl plant release have been measured. The average first year dose to the U.S. was about 1.3 mrem compared with 60 mrem average in Italy and 40 rem for the 24 000 between

Table 4. Consequences of a linear biological gradient in Gould's predictions.

	1st year dose	Factor to multiply by if effect proportional to dose	% increase
United States	1.3 mrem(Gould)	1.09	9
Italy	60 mrem[1]	5.2	420
Persons 3-15 km from the plant (not including Pripyat)	40 rem[1]	2770	277,000

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* all in 1 week before evacuation.

[1] Calculated here

3 and 15 km from the power plant (excluding Pripyat) (Goldman et al. 1987). The difference of the 1986 mortality in the US (33.06%) and the 1985 mortality (31.97%) is about 3%. If this was due to radioactivity from Chernobyl, and we assume linearity with dose, there would have to be a 415% (5.2 times the natural rate) effect in Italy and 2770 times bigger (2770 times the natural rate) in the area immediately downwind of the Chernobyl power plant. As shown in Table 4, these have not been seen. Thus, the claim fails completely on the question of "existence of a biological gradient." This argument by itself should be enough to discredit the whole discussion. However, it was not enough to stop the Wall Street Journal dignifying Gould's claim by saying, in a column, that it had caused scientific controversy.

A Seattle newspaper was better (News Tribune 1987). It discussed a part of this claim—that cancers in the state of Washington were caused by Chernobyl—and clearly made the above point. Starzyk (1987) noted that mortality only rose 2% in summer 1986, not 9% as was alleged. This was not an unusual increase. Moreover, five traditional medical causes for summer increases have been identified: infectious disease, arteriosclerosis, chronic lung disease, suicide, and diabetes.

However, a more direct refutation of Dr. Gould's claim came from a Los Angeles Times reporter (Steinbrook 1988) who noted that Gould had used incomplete numbers. The 33.06% that Gould had stated as the fraction of U.S. deaths between May and August 1986 was incorrect. A more precise number is 32.2%, which is "identical to the data for the summer of 1984, and consistent with normal seasonal mortality patterns. The 1985 rate was 31.6%."

Another study (Brancker 1988) found no effect in Canada, although the effect on Canada should have been similar to that on the U.S. if Gould et al. were correct. In Canada, deaths from infectious diseases remained steady, while death rates among 25-34 y olds and among infants fell.

THE PORTSMOUTH SHIPYARD PROBLEM

In 1977, a Boston physician became concerned that there was an unusual number of cases of leukemia among workers from the Portsmouth Naval Base and suspected that radiation might be the cause. With the help of reporters from the Boston Globe, he searched through over 100 000 death certificates. He concluded that there were 22 leukemia deaths, whereas 5 should be expected using ordinary death rates. In a later scientific report (Najarian and Colton 1978), he changed this to 20 cases of leukemia and other neoplasms of lymphatic and hematopoietic tissue with 10 expected. Dividing these into cases among nuclear workers and non-nuclear workers on the basis of whether the worker wore a radiation badge, the difference in cases between the two groups is 10 with 2.9 expected from the numbers in the groups (Table 5).

Later it appeared that of the ten nuclear cases, two had no radiation exposure. The effect was getting smaller as the data collection improved. Finally, Greenberg et al. (1985) showed that there was considerable under-reporting and misreporting of cases.

Najarian's observation was published in the medical literature (Najarian and Colton 1978), as is appropriate, even for case reports where statistical relevance has yet to be determined. But, he also publicized his findings in the press (Boston Globe 1978) in a way to arouse anxiety rather than information, and in Congress in a way that aroused disapproval, even of liberal representatives. Congress requested a study by the National Institute for

Table 5. Observed and expected cancer deaths among nuclear and non-nuclear workers by type of cancer.

	Nuclear			Non-Nuclear		
Malignancy	O	E	O/E	O	E	O/E
Leukemia	6	1.1	5.62	2	2.8	0.71
Other neoplasms of lymphatic and haematopoietic tissues	4	1.8	2.26	6	4.3	1.41
All other malignant neoplasms	46	28.6	1.61	80	72.6	1.10
Total	56	31.5	1.78	88	79.7	1.10

(from Table II of Najarian and Colton, 1978)

O = Observed cases E = Expected cases

Occupational Safety and Health (NIOSH). A detailed study was made (Rinsky et al. 1981) which found no statistically significant increase of leukemia among the shipyard workers. No effect was found in a subsequent case-control study either (Stern et al. 1986).

A number of possible sources of bias were discussed in a later paper by Greenberg et al. (1985). These include:

1. The healthy worker effect. Workers are more healthy than the average member of the population, so that comparing the deaths with those expected can understate the effect.
2. Selection bias—which could occur in the selection of cases.
3. Measurement bias—which could result from a misclassification of the occupational exposure of those who died.

A more recent follow-up (Rinsky et al. 1988) found a slight increase of lung cancer among the workers that was not statistically apparent in the first study. Many questions still arise. Can the increase be attributed to the Portsmouth shipyard? If it can, what about the shipyard could have caused the effect? Ninety percent of lung cancers are attributable to cigarette smoking, and cigarette smoking history is not detailed on death certificates, so that corrections for variation are hard to make. Rinsky et al. concluded "This... suggests that radiation workers were more heavily exposed to asbestos and/or welding fumes than were other workers and that these exposures confounded the observed association between radiation and lung cancer."

Radiation per se is not known to be a major cause of lung cancer (although inhaled radon gas is), so that the original suggestion that radiation releases caused the cancers is not biologically plausible. Asbestos exposure does cause lung cancer, especially synergistically with cigarette smoking, and asbestos is common around ships and shipyards, so that asbestos may be a likely cause of the increase. This raises a question; why did Najarian immediately claim radiation as a cause of lung cancer when there were other, more plausible, causes?

Najarian has not accepted the criticisms implied in the NIOSH reports, nor those explicitly made by Hamilton (1983). His last comment there suggests a reason for the concern which led to the article. "One wonders also how these risk estimates (if confirmed with other studies on similarly exposed people) might alter the thinking of those who are planning survival from nuclear war with similar product exposures."

After the Boston Globe article, there was testimony in Congress and the NIOSH investigation which cost over $1 000 000. When the results of this became known, Senator Kennedy, not known for his support of either military or civilian uses of radiation, publicly condemned Dr. Najarian for unduly alarming shipyard workers and their families (Wermiell 1979). Other scientists were also critical (Hamilton 1983).

Cohen (1983) has discussed the way in which this case was discussed in the press. He noted that in 1977-8 there were 14 articles in the New York Times (several on the front page), mostly reiterating that there were a large number of excess cancers among the shipyard workers. In 1981, after the first NIOSH study was published, the New York Times published just one article.

LEUKEMIA AMONG THE HANFORD WORKERS

In three papers, Mancuso, Stewart, and Kneale (1977) and Kneale, Mancuso, and Stewart (1981; 1984) claimed that there was an increase in leukemia and other cancers among those workers exposed to radiation (see also Stewart and Kneale 1991). They compared the estimated (occupational) radiation dose which had been accumulated for patients who died of cancer, with the radiation dose of those who died of other causes. The null hypothesis that these doses are the same was tested. They found that the mean radiation dose for those dying of cancer was 1.38 rad and that for those dying of other causes was 0.99 rad. The implication was that the increase of 0.39 rad over about 10 years was the cause of cancer. This held for eight categories of malignant cancers, namely: multiple myeloma, pancreas cancer, brain tumors, kidney tumors, lung tumors, tumors of the large intestine, myeloid leukemia, and lymphomas. This increase was said to be statistically significant. (The probability is less than 0.05 that it could occur by chance.) From these data they derived very small doubling doses for these cancers.

Their work was reviewed by Gilbert and Marks (1979, 1980) Hutchinson et al. (1979), Hamilton (1980), BEIR (1980), Kleitman (1978), Mole (1977), Sanders (1978), and Speirs (1979), and more recently by Gilbert et al. (1989) who also studied mortality over an extended period 1945 to 1981. For example, Hutchinson et al. (1979) found a statistical bias in the estimation of doubling dose; and made several important corrections to the data for various associated variables; calendar year of exposure, interval between beginning employment and exposure, interval between exposure and death, and age at exposure to age at death. When this was done, there were two significant effects left; for myeloma and pancreas cancer, but not for other cancers thought to be radiogenic.

Kneale et al. (1984) grouped cancers into two groups; group A which are claimed to be cancers in tissues where previous studies had found that radiation produces cancers (radiosensitive tissues), and group B in tissues where radiation is not known to cause cancer (non-radiosensitive tissues). The observed number of cancers was smaller than expected at high doses for group B and more than expected at high doses for group A. Does this mean that radiation is sometimes good for you? This unlikely conclusion is obviated by noting that there are several biases which can be collected together and are called the healthy worker effect. It is well known that employed people are healthier and have a lower mortality rate than unemployed people. Employers tend to employ healthy workers and someone with a job eats better than someone without a job.

It was plausibly suggested (but without proof) that those who had high radiation doses were often professionals with higher income and probably better health. Then, it is the difference in the trend with dose between the A cancers and the B cancers that is important. Kneale et al. related the reductions in group B with increased radiation, to a similar, more significant reduction in total death rate.

There may be another possible reason for finding spuriously significant results. The radiation exposure was measured by dosemeters and film badges, which were worn only at work, and therefore exclude most of the natural background exposures. If we omit radon exposure, and ignore any discussion of the lung cancer that radon might produce, the average radiation exposure at sea level is about 100 mrem, plus 95 mrem x-ray exposure (Table 7 below). In a typical ten-year period, this is 2 rem; comparable to the typical occupational radiation exposure and greater than the 0.39 rem difference between cancer victims and others. Kneale et al. believe they made proper correction for this using the socioeconomic indices. In principle, the comparison of exposed with nonexposed workers corrects for this, if the background and medical exposures are the same in each group.

One obvious correlation exists. Lawyers and bureaucrats have often insisted on extra medical checks for radiation workers. One of us (RW) for example, was asked to take an extra chest x-ray for a summer job involving radiation. His film badge (deliberately worn during the x-ray) showed the highest reading for anyone in that laboratory. It is not possible to correct accurately for effects such as these now. But an estimate can be made that in the early days of Hanford, photofluorographic exposures of about 600 mrem per year were given (presumably to those working in radiation areas). This exceeds 15-fold the increase in radiation doses. In such circumstances, it would seem mandatory to discuss whether these background environmental and medical exposures are indeed correlated with the workers' exposure and can bias the data.

We plot their data in Figs. 5 and 6. Figures 5 a and b show the ratio O/E (observed cancers/expected cancers). The statistical uncertainty is also plotted. The computer-fitted line was calculated without considering these error bars, and assuming that all points are equally weighted—which is approximately true. Although this line goes through more than 2/3 of the error bars (which is all that is required of an adequate

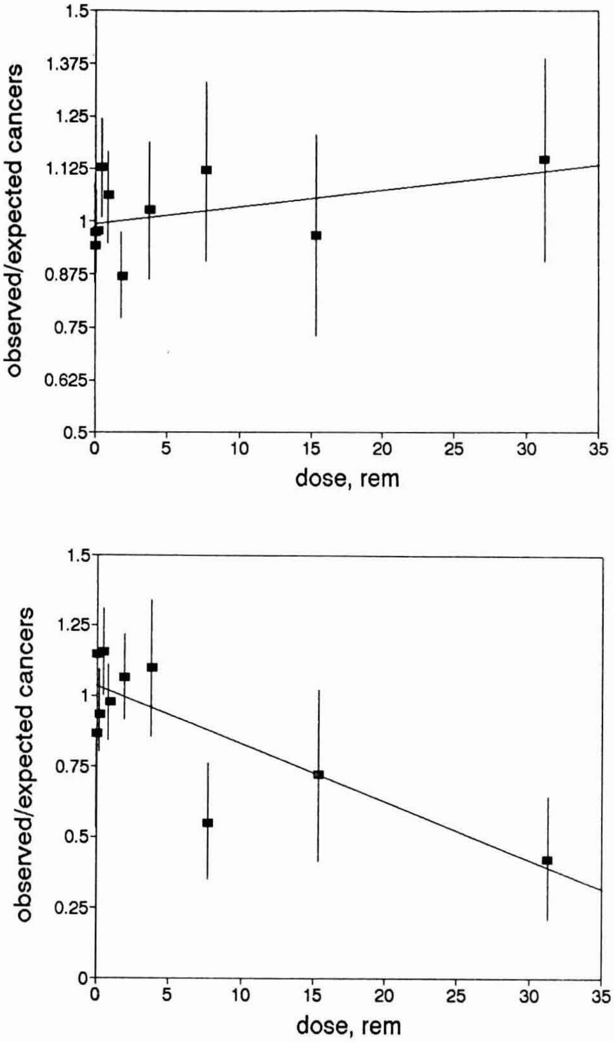

Fig. 5a and b. Cancers among Hanford workers: a) Ratio of the observed cancers of radiosensitive tissue to expected vs. dose; b) Ratio of the observed cancers of non-radiosensitive tissue to expected vs. dose.

fit), we can see clearly the suggestion of Kneale et al. that the data points rise faster at low doses (Fig. 5a).

Figs. 6a and b plot the data corrected for latency and other factors. Again 6a shows a possible rapid increase at low doses. But on 6b, we replot the same data against total dose, and not merely the occupational dose. The origin is shifted to 10 rem, being 5 rem extra medical x-rays and 5 rem lifetime environmental background. Since the expected numbers come from people with similar environmental backgrounds, the fitted curve should go through (or at least close to) O/E = 1 at 5 rem. Also on the plot is a point with O/E = 1.39 ± 0.04 from a fit to the data for all malignant neoplasms in atomic bomb survivors (Shimuzu et al. 1988 Table 2A). The fitted line is not a bad fit to the data, but Kneale et al.'s rapid increase starting at 10 rem (shown in a dotted line) now seems less plausible because a simple plot would

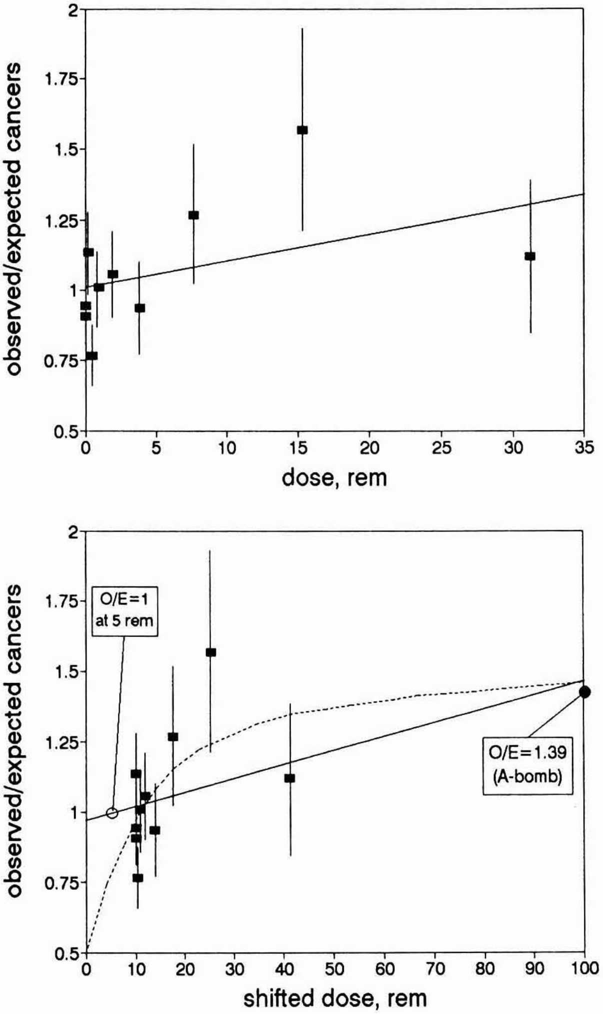

Fig. 6a and b. Ratio of observed cancers of radiosensitive tissue to expected after correction: a) versus additional data; b) with dose scale shifted.

imply that half of all cancers are caused by radiation. However, we should consider this dotted line as a postulate for further study. Are other data consistent with this line? We return to this when we consider variation of cancer rate with natural background in Fig. 13.

There is one more feature of the Mancuso, Stewart, and Kneale analysis that deserves mention. The differences in Figs. 5a and b between cancers of radiosensitive tissue and non-radiosensitive tissue used an old, inaccurate, ICRP classification. If the effect is really due to radiation, this difference should increase when a more modern classification is used. Oral statements have been made at conferences that the effect vanishes. This should be documented.

The residual effect of pancreas cancer is shown in Fig. 7 where the Mancuso analysis (open circles) is compared to data among Japanese atomic bomb survivors. It is hard to relate it to radiation because pancreas cancers are only weakly caused by radiation (Shimuzu et al. 1988 Table 2a). As shown in Fig. 7a,

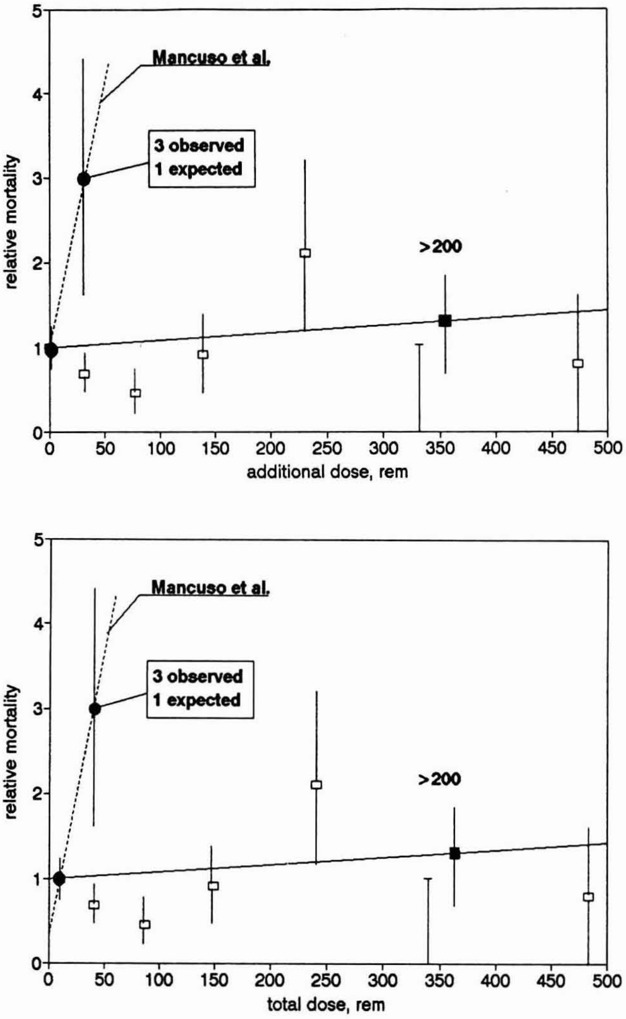

Fig. 7a and b. Mortality from cancer of the pancreas among Japanese A-bomb survivors (open squares), among Hanford workers (filled circles), and according to Mancuso analysis. Points labeled 200 represents the average of all data above 200 rem from Cohen (1983).

the effect might be real but when the dose scale is shifted to give the total dose as in Fig. 7b, the dotted curve becomes even less plausible.

DOES PLUTONIUM FROM ROCKY FLATS CAUSE EXCESS CANCER?

The Rocky Flats facility, 15 miles (25 km) NW of Denver, is used to machine plutonium for manufacture of U.S. nuclear weapons. As plutonium metals are machined, fragments can catch fire and vaporize. Extreme care must be, and is, therefore, taken. However, two fires broke out in 1957 and 1969, and although they were contained, plutonium was found to have contaminated the soil in regions SE of the facility towards, and including, Denver from an oil cleanup in 1968. Fig. 8 shows the distribution of this contamination.

Johnson (1981) and Chinn (1981) examined cancer rates in these areas for the years 1969-1971, and found that total cancer rates in the areas closest to

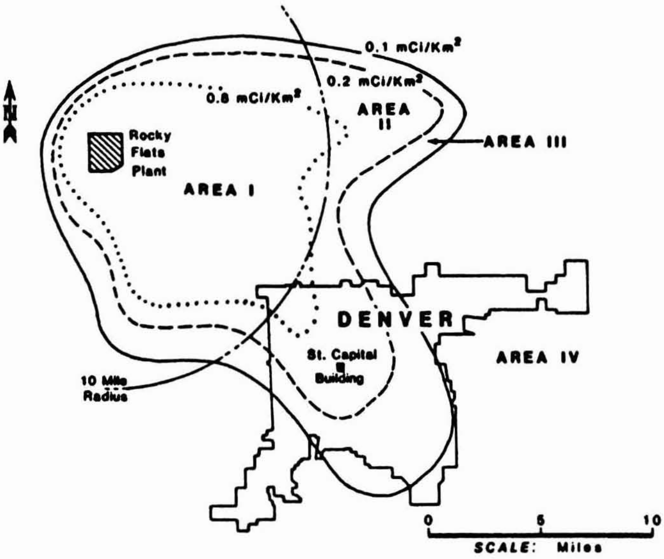
CANCER INCIDENCE IN RELATION TO ROCKY FLATS

Fig. 8. Map of area around Denver and the Rocky Flats plant showing plutonium-in-soil isoconcentration areas.

the plant (area 1) were 24% higher for males and 10% higher for females than in areas of the Denver area further away. He attributed the increase to plutonium.

Plutonium is an alpha emitter, and the cancers should, therefore, arise close to where the plutonium is absorbed—the lung, if it is inhaled, and the liver and bone, if it is absorbed. One should expect more plutonium in the bodies of those with cancer than in others. Also, we should expect the trends to be found at other time periods.

Crump et al. (1987) examined all of these questions. Firstly, they confirmed the statistically significant trend found by Johnson for total cancer, digestive cancer, respiratory cancer, and cancers normally considered radiosensitive (for whole body radiation). However, they found less of a trend for the years 1979-1981. This is the opposite to what one would expect. The years1979-81 are after the latency period for all cancers, whereas 1969-71 is in the latency period for some of them, if the initiating event was plutonium. No excess of bone cancer was found, contrary to the presumption.

Finally, Cobb et al. (1982) found no increase of plutonium in an autopsy of some (but not all) of the cancer victims. None of these fit the hypothesis that plutonium from Rocky Flats was the cause of the cancer increase. However, another, much more plausible cause for the cancer excess can be found. Crump et al. (1987) noted that there is an increased rate of many cancers in urban areas (Goldsmith 1980). This is called the urban factor. Crump et al. corrected the data for the urban factor by looking at the distance from the Colorado State Capitol in Denver. Many persons in Group I are closer to the state capitol than persons in Group IV.

Johnson (1987), in response, called into question each one of Crump et al.'s arguments. He pointed out that the autopsy results were only from a selection of the cancer victims and perhaps a biased selection. Crump found fewer cancers during 1979-81 in area I than area II, but Johnson noted that this was probably due to a large influx of new population into area I who had not been exposed.

But Johnson failed to describe an effective and complete model for the cause of the cancers and its relationship to other knowledge as Crump et al. have done. Therefore, Crump et al.'s explanation must be preferred.

IS THERE A PRECURSOR TO LEUKEMIA?

It is common to believe that the cause-effect relationship in disease etiology is unique; the effect will always be an outcome of the cause. When people are given a large dose of a strong poison like strychnine, they will always die. If they are given a small dose, they will always live. In between, some will live and some will die, and the difference is assigned to a variation of individual sensitivities.

One might expect to find the same behavior with cancer-causing agents, but in general, it does not seem to be the case. Of heavy cigarette smokers, one out of five will develop cancer due to their habit; but four will be unaffected, and we do not know which. Does that mean that one of the five is especially susceptible, and the others are not? So far, we have not uncovered reasons for especial susceptibility, and for practical purposes, we can assume that the outcome is completely random.

This may appear callous in that it seems to ignore the need of the susceptible individuals. But an illustration shows that it is, in fact, in accord with a common-sense approach to risks that society often has. If we knew in advance that a Canadian car, license 423 KBT, will kill a pedestrian in Boston, we would stop the car at the Canadian border—and avert the accident. But we have no way of knowing in advance, which car (if any) will cause an accident. We, therefore, describe the possibility as a risk, and society accepts the risk, because prevention is not possible without draconian measures such as stopping all cars.

Physical scientists, accustomed to fundamental uncertainties of quantum mechanics, have little trouble in accepting this argument. Medical scientists more often have problems and continue to search for precursors to these seemingly random events—such as the occurrence of cancer.

There are some precursors to cancer that can be taken into account. There is a synergistic relationship between cigarette smoking and asbestos; the probability of getting lung cancer (at high doses) is related to the product of number of cigarettes smoked and the asbestos exposure. Therefore, it is possible that anyone exposed to asbestos can reduce the chance of developing lung cancer if he stops smoking. Retinoblastoma, a rare cancer of the eye, runs in families and presumably is genetically caused.

Whether some objective ailments are precursors to cancer has been discussed both for asbestos and benzene. This, however, is usually considered to give suggestions about the shape of the dose-response relationship. Thus the U.K. chief inspector of factories Dr. Merriman (1938) asked "Does silica, or asbestosis or the fibrosis of the lung they produce tend to inhibit cancer of the lung or to produce it? If the latter, do either of these substances act as specific carcinogenic agents like tar, or is it that the disease they produce only prepares the soil for the occurrence of cancer? With asbestosis, among 103 fatal cases in which asbestosis or asbestosis with tuberculosis were present, cancer of the lung was associated in 12 cases (11.6%)." If asbestosis is necessary for lung cancer incidence, the dose-response relationship might show a threshold. This question is still largely unanswered today.

In studying leukemias produced by benzene, Goldstein (1977) commented upon the fact that pancytopenia often precede leukemia, although some cases of leukemia have occurred without a preceding diagnosis of pancytopenia. But because of the limited medical information in the individual cases, undiagnosed pancytopenia could always have preceded it (see also Lamm et al. 1989).

In a series of papers, Bross and Natarajan (1977), Bross et al. (1979), and Bross and Natarajan (1980) make a pioneering attempt to identify persons especially susceptible to leukemia. They choose as a data base, the Tri-State Survey, carried out in certain specified areas of New York, Maryland, and Minnesota (Graham et al. 1963; Gibson et al. 1968). They first concentrated on childhood leukemias.

Other authors have found an association between childhood leukemias and x-ray exposure during pregnancy of the mother. (Stewart and Kneale 1970; MacMahon 1963). This association does not, in itself, tell whether x-ray radiation causes these leukemias, or whether another agent, which caused the leukemia made the x-ray more likely. Even now, this is disputed (MacMahon 1989). Such an effect was also found in the Tri-State Study (Gibson et al. 1968).

Assuming that the cause of these leukemias was intrauterine radiation, Bross and coworkers set out to discover whether there were precursors. They found that several ailments were associated with the leukemias; a virus (red measles or chicken pox); bacteria (whooping cough or dysentery); and allergy (asthma or hives). This is shown in Fig. 9.

The existence of an association in this data set, between two apparently unconnected end points such as virus and leukemia, does not prove causation; the correlation may not persist to other data sets. Moreover, even if it does, one cannot infer unequivocally that viruses cause leukemia, or make people more susceptible; it might be that a latent leukemia

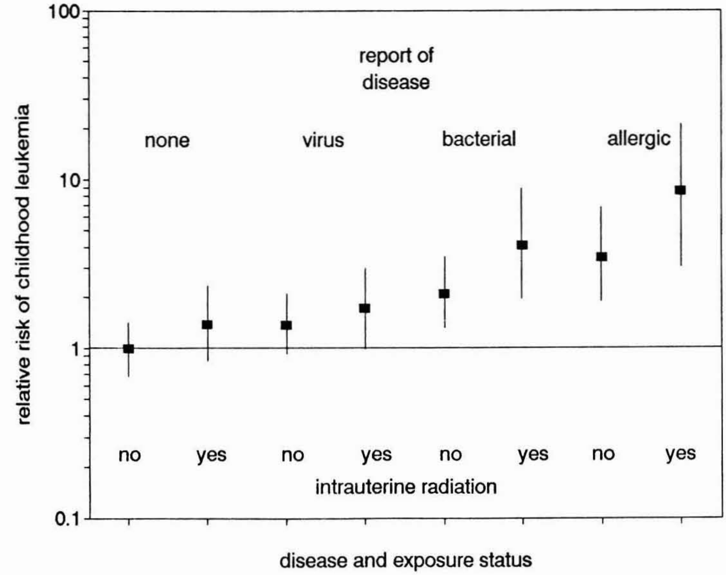

Fig. 9. Approximate confidence intervals on the relative risk of childhood leukemia (age-adjusted risks in relation to children not exposed to intrauterine radiation and without report of specified childhood disease): 1) None: no report of the specified diseases; 2) Virus: report of red measles or chicken pox; 3) Bacterial: report of pneumonia or whooping cough or dysentery; 4) Allergic: report of asthma or hives.

makes one especially susceptible to viruses (Rothman et al. 1988). It is also unclear that this association, even if a causal correlation, has any predictive ability.

The argument is similar to that of Feynman's example. There was an association (and as noted, some call it a correlation) between the particular license plate and the parking lot. Few believe that whenever one has a parking lot, one will see that license plate; or whenever one sees that license plate, it will shortly be in a particular parking lot. In Feynman's example, one can easily repeat the observation on other days and other places to verify that the association is unique to this particular parking lot or the particular time.

Bross and Natarajan must have been aware of these arguments when they stated "a formal objective test of the 'susceptibility' hypothesis requires exclusive information on medical history and exposure to potential hazards on a large series of cases of leukemia and controls representatives of the general populations." Unfortunately, instead of looking at other situations, they put their effort into arguing for a change in radiation safety regulations, which most scientists regard as premature. Apparently, no one else has tried to extend these studies to other cohorts.

Bross et al. (1979) claim that the Tri-State study also shows that diagnostic x-rays affect adult leukemia and heart disease. They write down a model to evaluate a dose-response curve for those persons most affected by radiation. In one figure, they show the number of persons affected as a function of dose. It is not clear how this is derived since details are not provided. It seems likely that this is merely a plot of excess leukemias versus dose, with the ordinate changed by an arbitrary assumption that only a small fraction of persons are affected by radiation.

Even here, however, their claim that these demonstrate a response relationship that is very nonlinear near the origin, in the direction that there are more leukemias at low dose than calculated, cannot be sustained by the data; and they themselves comment that a linear fit cannot be excluded.

Boice and Land (1979) specifically review the work of Bross et al. (1979). They point out that conventional analyses find that radiation, and presumably x-rays, can cause adult leukemia; a causal connection with heart disease has not been established. Such an association could be due to leukemia and heart disease patients receiving more intense clinical examination.

Bross and Natarajan (1980) and Bross (1983) reanalyzed the work of Schull, Otake, and Neel (1980) on genetic effects of the atomic bomb explosions in Japan. Schull, et al. had concluded that "in no instance is there a statistically significant effect of parental exposure." Bross and Natarajan claimed the data shows that there is. Bross' claim was looked at in its turn by Hamilton (1983) and Hamilton et al. (1983). Hamilton shows that Bross used a post hoc grouping of data—a variant of the Feynman Trap. In particular, he included a zero dose group in among a group exposed to 0-9 rads.

We also note that all these authors discuss excess cancers due to x-ray doses. As noted in the preceding sections, the x-ray dose is superimposed upon a natural background, and the full biological dose response curve must include the effect of natural background. A kink in the curve just above the dose that corresponds to the natural background does not, in this context, seem very plausible.

CANCERS NEAR THREE MILE ISLAND

After the accident on 28 March 1979 at the second unit of the power plant at Three Mile Island near Harrisburg, Pennsylvania, there was considerable public concern about a possible increase of cancer because of radioactivity releases. This concern was not allayed by the official report, agreed to by six federal agencies, that radioactivity releases were primarily noble gases, and that the radiation doses were very small (NUREG 1979). The biological plausibility of an effect due to radiation is small.

However, an accident of this nature causes unusual stress and stress, has often been claimed to be a cause of cancer. This is, for example, found in animal bioassays where such trivial matters as size of cages, or possibly lighting, seems to affect the background cancer incidence (Crouch and Wilson 1987). The Kemeny Commission (Kemeny et al. 1979) suggested that if any extra cancers appeared near Three Mile Island, stress would be the most likely cause. There is, therefore, a plausible reason for a search for cancers near Three Mile Island.

Most of the studies were anecdotal (Wasserman 1987). We comment here on one which was more detailed. Two persons, Aamodt and Aamodt (1985) claimed an excess of leukemias around Three Mile Island. They claim 20 cancers from 1979-1984 and 19 between 1980 and 1984 in a population of 443 (433 listed, but this was an addition error) for a ratio of cancer mortality to expected of 6.57 (corrected from their 7.13) with an uncertainty of ±1.5. This claimed effect is large enough that it led to a more detailed study by Public Health for the Commonwealth of Pennsylvania (Tokuhata and Dignon 1985). This study showed that Aamodt and Aamodt fell into the Feynman Trap: they surveyed an area of Newbery Township, but arbitrarily selected 4 out of 14 streets. They failed to show, and could not show, that these streets were selected before there was knowledge of leukemias, or that there was some objective way of selecting them (such as being all the streets within a given distance from the plant). In the ten streets not included, there were no cancers. This gave an artificially large ratio. Tokuhata showed that if a proper selection of an area was made, then there was no excess of leukemia at all. Recent study confirms this conclusion (Tokuhata et al. 1991).

That the Aamodts found there are more cases in these streets than average then becomes a logical tautology and no more surprising than the fact that Feynman's car had the particular license plate it happened to have. It is a lot of work to discover biases such as this; it often involves redoing the study completely, but properly. We also note that radiation cancers manifest themselves with a 5-20 year latency after exposure, so that cancers so soon are doubly implausible. On the other hand, the absence of extra cancers also tells us little because they would not be expected for 25 y.

A review of health effects around TMI has been prepared by Behling and Hildebrand (1986). A new analysis of possible association between the accident rates and cancer was recently published by Hatch et al. (1990; 1991).

DID ATOMIC TESTS INCREASE CANCER IN UTAH?

Between the years 1950-1960, there were many atomic bomb tests in Nevada, and there was some exposure of communities downwind in Utah. Lyon et al. (1979) studied leukemia in children between 0 and 14 years of age, who lived in Utah between 1959 and 1967. They compared the leukemia rate with that expected in the general U.S. population. They particularly looked at those children born between 1951 and 1958 (which they called a high exposure cohort) and who lived in counties where they claimed that the fallout was the greatest. Low exposures were defined as those born between 1944 to 1950 (before the tests), and 1959 to 1975 (after the tests were over).

Their analysis compared the leukemia rates in the exposed and the control group. They chose two control groups; the pre-exposure cohort whose members

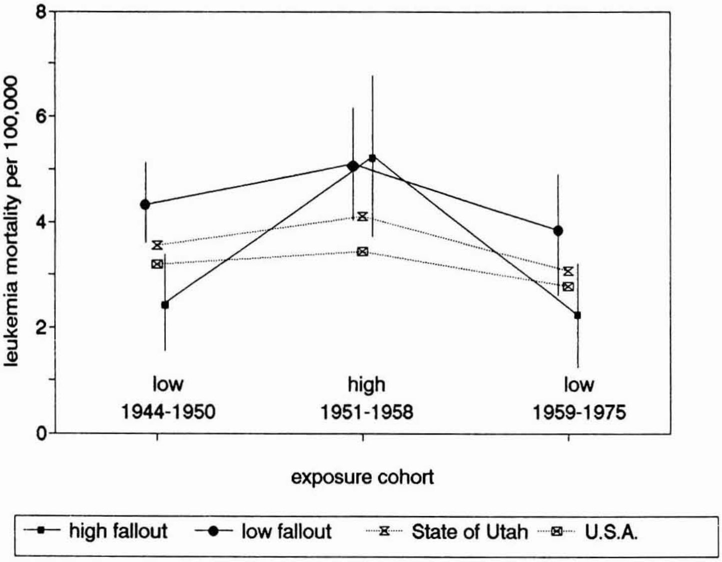

Fig. 10. Adjusted leukemia mortality rates in Utah per 100 000 males and females.

were born between 1944-1950 (and were therefore unaffected by the later tests) and post-exposure cohort born, 1959-1975 (and therefore unaffected by the earlier tests). They chose to compare with these control groups rather than with average U.S. incidence, because "for reasons unknown, leukemia mortality among the low-exposure cohort in the high-fallout counties was about half that of the United States and of the remainder of the state." The data for the three cohorts for the various counties is shown in Fig. 10 drawn from their data (Table 3 and Fig. 1 of Lyon et al.). The data for the high fallout counties show a marked increase (doubling) for the high exposure cohort. We added error bars to their figure (corresponding to the square root of the expected number); these make the uncertainties evident and the data far less convincing. We note that the fluctuations down from 14 cases expected to 7 observed is more likely than a fluctuation upward from 7 expected to 14 observed.

In their Table 4, Lyon et al. produce a single summary statistic as follows. They compare the leukemias in a high exposure cohort with those for the low exposure cohort (defined as above by the time of leukemia), by deriving a standardized (leukemia) mortality ratio. For the high fall-out counties, SMR = 2.44 with 95% confidence limits 1.18 to 5.03. This, then, was their evidence for an effect due to some difference between the two group of counties.

This procedure would, formally, be statistically valid if this combination had been chosen in advance and if we were absolutely sure that there were no other confounding effect or fluctuation. Why not compare the leukemia incidence only to the U.S. incidence? Indeed, Hamilton (1983), Land (1979), and Engstrom (1979, 1980) all concluded that this combining of groups was arbitrary. Even if not arbitrary, it is still susceptible to two meanings. One, the final conclusion of Lyon et al., is that relative excess in the high fallout counties was due to some external cause, such as radiation, another, that the relative deficit in the controls for the high fall out counties was caused by whatever caused the reduction below the U.S. incidence (perhaps low reporting for the early time period). Nothing in the data helps us decide between these two explanations. However, the second is more plausible because it fits better into the general body of scientific understanding (Lyon et al.1979; Hamilton 1983).

Another more telling argument comes from the actual measurements of fallout (^{137}Cs and ^{239}Pu) on the ground in Utah. Figure 11 shows the results of Beck and Krey (1983). Superimposed on this map is the line separating the high and low fallout counties

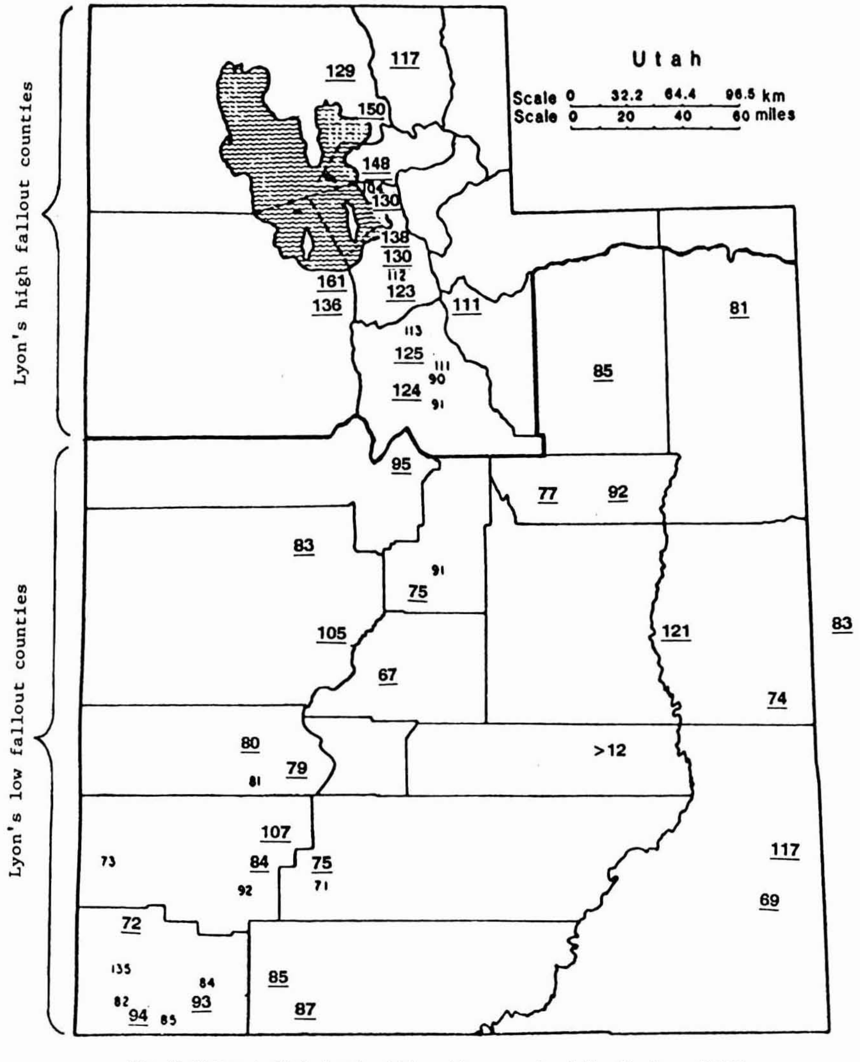

Fig. 11. Fallout in Utah showing high and low counties defined by Lyon (1979).

of Lyon et al. (1979, from their Fig. 3). It appears that this was based on the single "smoky" shot of 31 August 1957). It is clear that some of Lyon's low fallout counties actually had a higher fall-out than many of the high fallout counties. Any assignment of the effect to radiation from fallout becomes harder to sustain.

This, however, is not the end of the story. Johnson (1984) looked at Washington county in SW Utah which is the closest to the test site (and includes the largest town of St. George, Utah). He found 19 leukemias in 1958-1966. This was more than expected and gave a risk ratio of 5.28 (95% confidence 3.18-8.24). Machado et al. (1987) repeated this study and found a smaller effect; 62 leukemias between 1955 and 1980, and a smaller risk ratio of 1.45 (95% confidence 1.18-1.79). Johnson noted in an oral report that Washington county had the lowest leukemia rate in the state.

It appears, therefore, that there is a small cluster of childhood leukemia cases in SW Utah for the period 1951-1960 which was the cause of the original

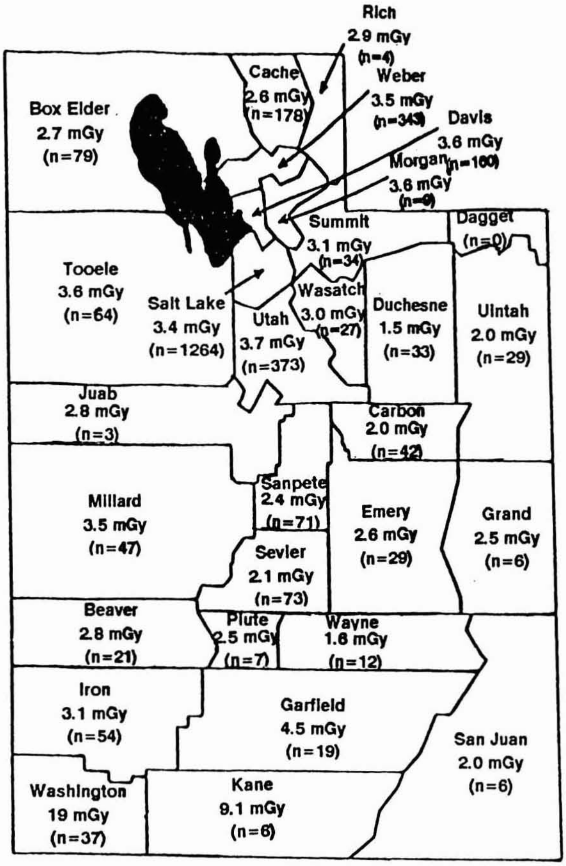

Fig. 12. Fallout map from Stevens et al. (1990).

claim. This conclusion comes out clearly in a most careful case-control study by Stevens et al. (1990). They considered 1177 victims of leukemia, who (a) died between 1952-1981, (b) were born before 1959, (c) were Mormons (members of the Church of Jesus Christ of Latter-day Saints) or spouse or one parent were Mormons, so that church records could be used. These cases were compared with 5330 controls. Total bone marrow dose was computed from residence information and deposition on external surfaces (primarily ^{137}Cs) as measured by Beck and Anspaugh (1990) following the earlier work by Beck and Krey (1983) and Beck (1984). This exposure analysis found a high average bone marrow dose for those in the SW corner of the state (Wartington County containing St. George), where the dose was 1.9 rem between 1952-58.

The bone marrow dose by county is shown in Fig. 12. This seems inconsistent with the map of Fig. 11. The principal result is that for 17 leukemia cases (except CLL) in this high exposure region, there was a risk ratio of 1.72 (95% confidence 0.94-3.12). Five were cases of acute leukemia between 0-10 y, and for them the risk ratio was 7.82 (95% confidence 1.9-32), which is significant ($p = 0.02$). The significance increases ($p = 0.009$) when there is a restriction to acute lymphocytic leukemia. There was no elevated risk ratio for doses up to 5.9mGy (0.59 Rem).

At this altitude and in this general area, background doses are high. The average background bone marrow dose is 70 mrem/y in SW Utah. Over a 20 y period, this gives as much radiation as the addition from the bomb tests. Fluctuation in background should not affect the results so long as they are not correlated with the study group. Stevens et al. (1990) looked for plausible reasons for higher background in Washington County than the rest of Utah, but found none.

A cohort study seems impossible here, but a careful connection to other data is necessary. In particular, if there is a linear dose-response relation, and the risk ratio of 7.8 for acute leukemias 0-19 is to be believed, one should also find a marked increase in leukemias in those western states with a high background compared to eastern states, provided that other factors can be corrected. No such increase has been found, and indeed Washington county has a low background leukemia rate, but this may be due to other compensating factors of urban environment or life style (alcohol, tobacco, and coffee).

Finally, we should learn from this that Lyon incorrectly drew conclusions in his original paper; although, the conclusions were not necessarily incorrect. The more careful look at the data by Stevens et al. pulls out a small group of people that need close examination. Such close examination might include measurement of the concentrations of ^{137}Cs at each residence directly, and also measurement of other background doses both of radiation and chemicals.

One scientist, born and raised in the small town of St. George, noted that he was aware of most family names in that small town, and recognized none of the names of the leukemia victims (Everett 1991, private communication). This suggests a peculiarity that deserves investigation; perhaps they come from some farming group exposed to some other agent.

The conclusion that there is an association of leukemia with fallout therefore rests on the 17 cases in Washington county, and in particular the cluster of five who had acute leukemia at a young age.

LEUKEMIAS NEAR U.K. NUCLEAR FACILITIES

There are epidemiological reports on the incidence of leukemia near nuclear power plants and other nuclear facilities in the United Kingdom. The most detailed report is by Forman et al. (1987). They discuss many different cancers. They conclude that "there has been no general increase in cancer mortality near nuclear installations in England and Wales during the period 1959-80. Leukemia in young people may be an exception, though the reason remains unclear." If the leukemias were due to radiation, why were other radiation-induced cancers not seen?

Forman et al. (1987) show that the Standard Mortality Ratios (SMR) for Local Authority areas near nuclear installations are significantly less than the SMRs for control areas more often than the reverse. Only for acute lymphoid leukemia, which occurs primarily in the age group up to 20 y, does there seem to be an increase. It is hard to explain these cases by either direct radiation exposure, or radionuclide releases. This has been studied in a detailed report by Strather et al. (1988), "These cases could not be explained by radiation alone, unless the release was 300 times that known" (Forman et al. 1987). Another possibility is that the carcinogenic effect at low doses of radiation is much higher than thought. But then, why don't the radionuclides from bomb test fallout, many of which are similar, produce a similarly large effect?

The effect seems to be primarily a reduction in the number of leukemias in the control areas compared with the number expected from national incidence figures. This strongly suggests to be a chance effect. We also note that the increase was not around nuclear power plants, but around experimental sites: Sellafield Fuel Processing Plant, Douneray Fast Breeder Reactor, and the Royal Ordnance Factory.

One other feature of interest comes out of this work. Usually epidemiologists, such as Forman et al. (1987) study cancer mortality. This is because mortality is an objective criterion, and recently has not been subject to reporting bias. Beral (1987) pointed out that there is an increase in cancer incidence near nuclear installations although no increase in mortality. This may be due to a tendency to report cases more frequently near nuclear installations but it may also be due to emigration of diagnosed cancer patients from areas with nuclear installations. The measured effect is small enough (10%) that biases are all important.

The paper of Forman et al. (1987) was misquoted in the U.S. press. The Boston Globe (Tye 1987) had a headline, "More cancers near nuclear plants," and combined this with a discussion of Gould's work to give a confusing picture; nowhere in the text was the main conclusion quoted.

The statistically significant increase of childhood leukemias has aroused a lot of attention. Clusters of childhood leukemia were originally reported near the experimental breeder reactor in Dounreay, North Scotland. Five leukemias in the age group 0-24 were observed, whereas 1.6 ± 1.3 were expected (Heaseman et al. 1986). This is enough to generate a hypothesis that there is something about Dounreay that leads to childhood leukemias. Five leukemias were also found near the British Nuclear Fuel Services Chemical Plant at Sellafield (Taylor and Wilkin 1988; Darby and Doll 1987) (including one who had moved out of the area and found later) with 0.5 expected (when the calculation gives a fractional expectation or a number less than one for the expectation, means that both 0 and 1 are likely). Observation near the second plant seems to confirm the hypothesis that there is something common to Douneray and Sellafield that leads to childhood leukemia. A slight excess in Berkshire, Barrington, and West Hampshire where there are three nuclear establishments, Atomic Energy Research Establishment (AERE), Harwell, Atomic Weapons Research Establishment (AWRE), Aldermaston, and Royal Ordnance Factory (ROF) Burgfield (Roman et al. 1987), made the hypothesis even more likely. However, an examination of Roman et al.'s Table 8 shows that increased leukemias are only significant within 10 km of ROF Burgfield (38 cases ages 0-14 vs. 23.9 expected; 8 vs. 6.4 expected within 10 km of AWRE and 0 vs. 0.4 expected within 10 km of AERE). Inclusive reviews of these and other cancers have been made by Cook-Mozaffari et al. (1987), Forman et al. (1987), and Strather et al. (1988).

Many scientists have searched for a possible cause of these childhood leukemias. Darby and Doll (1987) found higher leukemia incidence near several nuclear power plant sites, even when no nuclear power plant had yet been built. This suggests that there must be another explanation unrelated to nuclear power or radiation itself.

Since Sellafield and Dounray are new communities, the young new population might have brought in viral diseases not common in the region from the outside. But this argument could not apply to Aldermaston which is a settled community. This hypothesis was tested by Kinlen (1988) in another new community in Scotland, Glenrothes, where there were no nuclear facilities. A cluster of childhood leukemias was found—10 in the age group 0-24 (between 1951-67) versus the 3.6 expected. However, this is a bigger cluster than either the one at Dounray or the one at Sellafield. It is also important to realize that this is not enough to prove a viral cause.

Still a third possibility was studied by Gardner et al. (1990a, 1990b) who identified 52 cases of childhood leukemia and 22 cases of non-Hodgkin's lymphoma which had been diagnosed between 1950 and 1985 in the county of West Cumbria, and compared them with 1001 controls. They investigated four possible causes:

1. prenatal x-rays (which are known to cause leukemia);
2. infectious disease (which might have predisposed the victims to a leukemia infection);
3. eating shellfish (which might concentrate radionuclides); and
4. paternal occupation.

The most complete information was available from birth certificates which were available for 46 cases of childhood leukemia and 16 cases of non-Hodgkin's lymphoma. For leukemia alone, Gardner et al. found nine cases whose fathers worked at Sellafield. The risk ratio was 2.62 when area controls were used (95% confidence 1.07 to 7.40) which is just statistically significant. If local controls were used, the risk ratio is reduced to 2.03 (95% confidence 0.69 to 5.93) which is not significant because risk ratio less than 1.0 cannot be excluded. When non-Hodgkin's lymphoma is added, the risk ratio drops to 2.02 even with area controls (95% confidence 0.87 to 4.67) which is insignificant.

One interesting fact, that was not highlighted in press accounts, is that there were nine leukemias and non-Hodgkin's lymphomas among children whose fathers worked in the iron and steel industry. Using local controls, this gives a risk ratio of 3.20 (1.23 to 8.28 at 95% confidence), which is more significant than the relationship to Sellafield. Also elevated, but not significantly so, was the risk ratio for those whose fathers were farmers.

Since the results of the study by Gardner et al. are just statistically significant by only one of the measures, overall, the study cannot be considered significant by Tippett's Rule. Moreover, Gardner et al. do not tell us whether their nine cases overlap with the five cases found in previous studies; presumably, they do and the associations are not independent. Clearly, if a family moved to Sellafield because it is a new town, it is likely that the father worked at the nuclear facilities; the child could nonetheless be subject to specific viral infection as Kinlen (1988) suggests; although Gardner et al. looked for nonspecific infections. If the idea that parental exposure caused the childhood leukemias is correct it is also correct at Dounreay. However, of the five children with leukemia, only one has a parent working at the plant. Clearly this work raises more fascinating questions than it provides answers.

Because of concerns raised by the reports about finding some increase in mortality from leukemia among young persons, especially under ten, living near nuclear facilities in the U.K., a comprehensive survey of cancer rates was conducted by the U.S. National Cancer Institute in the population living near nuclear facilities in the USA (Jablon et al. 1990). The survey evaluated over 900 000 cancer deaths occurring between 1950 through 1984 in 107 counties

Table 6. Ratio of cancer deaths in counties near nuclear plants and cancer deaths in control counties.

	before startup	after startup
Childhood leukemia	1.08	1.03
Leukemia at all ages	1.02	0.98

Jablon *et al.* (1990)

with nuclear installations. This covered all 62 nuclear facilities that went into service prior to 1982, including commercial electricity-generating power plants and major Department of Energy (DOE) facilities. Each study county was matched for comparison to three similar control counties in the same region. Cancer deaths studied in the control counties over the same period amounted to more than 1 800 000 cases.

The study found no evidence to suggest higher occurrence of leukemia or any other form of cancer in the study counties than in the control counties after the start of the nuclear facilities, as can be clearly seen from Table 6. The study did reveal that some of the study counties had slightly higher ratio of certain cancers, and some had lower ratios. This pattern was also observed either before startup of some facilities or after startup of other facilities, and, therefore, no evidence for a cause-effect relationship between nuclear facilities and cancer occurrence in a nearby population could be established. Clearly, because the study was limited by the correlational approach and the large size of counties, it could not prove the absence of any effect; but such effect, if it exists, must be small or it would be detected by such a study.

CANCER FROM NATURAL BACKGROUND RADIATION

Other data can also address this question. In Wilson and Jones (1974), modified here as Table 7, is a list of activities giving various radiation doses. Attached to that list is the number of cancers that would be found if all the U.S. were exposed, on the assumption that the slope of the dose-response is 500 cancers per million person rem (2000 personrem/cancer).

The size and variation of the natural background suggests that there should be changes in cancer incidence associated with changes in the natural background. This has been looked at by Frigerio and Stowe (1980) who compared the vital statistics by state with the natural background. They found that the cancer rate was lower ($132/10^5$) in the states with the highest background (170 mrem/y) compared with that ($147/10^5$) in the states with the lowest background (118 mrem/y) and $155/10^5$ in states with 130 mrem/y. The data are shown in Fig. 13, taken from Goldman (1989). The fitted line is a decrease with increasing radiation dose. The statistical accuracy of such a comparison is excellent. Naively, one would say that radiation at these low doses reduces the cancer probability. But there was no discussion by Frigerio and Stowe of possible alternative explanations—absence of major industry or confounding effects of major lifestyle contributors to cancer such as cigarette smoking. A real decrease is probably not likely. We suggest here that a comparison of lung cancer incidence can tell us whether smoking plays a major role, and a look at bladder cancer might tell us the role of industrial emissions. Cohen (1980) notes that a refusal to accept the data as indicative that radiation is good for you depends upon preconceptions, whether correct or not. He comments "The fact that states with high natural radiation have considerably lower cancer rates than average is generally discussed as indicating only that radiation is very far from being the principal cause of cancer, and this point is logically correct. However this author (Cohen) is highly skeptical over whether that attitude would be accepted if states with high natural radiation happened to have somewhat higher than average cancer rates."

We also note that there is no indication of the steep increase with radiation dose suggested by the dotted curve of Fig. 6b.

Other studies of natural background, with a smaller statistical sample, exist. For example, in an area of Guandong province, Peoples Republic of China, there exists a region with three times the normal level of exposure to radium and thorium products; yet, the lung cancer incidence is actually less in these areas than in nearby areas with normal exposure (Hoffman et al. 1985). In this instance, the increased dose is primarily to the lung and would be expected to cause an increase in lung cancer incidence. Instead, a small decrease was found.

Table 7. Some typical radiation doses.

Source	Dose (mrem/yr)	Radiation cancers/yr if all US pop.(250 million) so exposed (assuming 500 cancers per million person-rem)
Potassium 40 naturally occurring in body	20	2,500
Potassium 40 naturally occurring in neighboring body	2	250
Gamma rays from neighboring soil and rocks (av.)	50	6,250
Gamma rays inside brick or stone buildings	30-500	2200-37,000
Cosmic rays at sea level	30	3,750
Background dose at sea level average	100	12,500
Background dose at sea level in Kerala, India (av.)	500-2,000	37,000-150,000
Cosmic rays at Denver, CO	67	8,300
3-hour jet plane flight	2	250
60 hour/month of jet plane flight	500	62,500
Medical diagnostic x rays in U.K. (av.)	14	1,750
Medical diagnostic x rays in U.S. (av.)		
1964	55	6,875
1970	95	11,875
Weapons tests "fall-out"	3	375
AEC "design criteria" for reactor boundary (upper limits for actual use)	5	625
Within 20-mile boundary of BWR with 1-day hold-up but leaky fuel (gaseous emission) (av.)	0.1	12.5
Within 20-mile boundary of PWR with leaky fuel (av.)	0.002	0.25
Within 20 mile boundary of coal plant (av.)	0.1	12.5

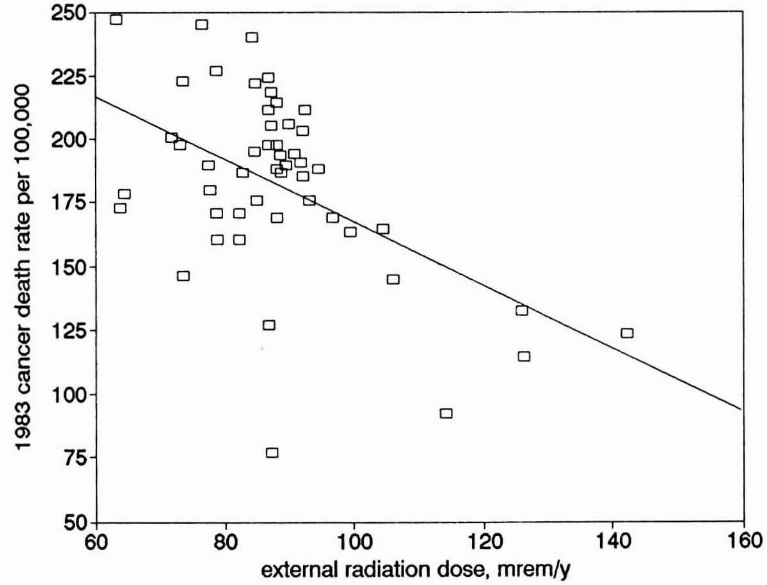

Fig. 13. Cancer mortality vs. natural radiation by state (Goldman 1989).

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THE SPECIATION PATTERN OF LEAD IN STREET DUSTS AND SOILS IN THE VICINITY OF TWO LONDON SCHOOLS

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The chemical association pattern of lead in road dusts taken at locations near two schools in South East London and from soils located within the schools' grounds was investigated using a selective extractant speciation scheme. The results indicate that lead in road dusts is primarily associated with the carbonate and iron and manganese hydrous oxide fractions. In soils, this pattern is altered with lead levels in the carbonate fraction becoming reduced and percentage levels in the iron and manganese hydrous oxide and organic fractions becoming more important. Overall lead levels are variable; some tentative evidence suggests that these overall levels in road dusts may be affected by street-cleaning regimes. The results of the survey are assessed in terms of the potential hazard posed to children in the 0 to 6 y age range.

INTRODUCTION

In recent years, research conducted on the problems associated with lead contamination of the urban environment has focused on the dangers presented by urban dusts. Children, in particular, are considered to be at some risk from ingestion of lead in dust through hand-to-mouth activities (Duggan 1983; Hilburn 1979; Schwar et al. 1988). Several workers have demonstrated significant relationships between lead in dusts and blood and have identified significant transfer pathways (Bornschein et al. 1988; Sayre 1981). The U.S.E.P.A.'s uptake/biokinetic model, too, has been used to demonstrate the importance of dirt ingestion as a major contributor to blood lead levels in children (Hoffnagle 1988).

Even at low concentrations, lead may be responsible for nervous system disorders (Needleman 1979; Odenbro 1983). Recently, Ericson and Mishra (1990) reported on a pilot study which indicates that hyperactivity in school children may correspond with proximity to major highways and soil lead levels. Assessment of lead levels in soils and dusts in the child's immediate environment is thus an ongoing responsibility.

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Many previous studies in this area have measured total concentrations of trace metals in soils and dusts. It has become, however, increasingly common for metals in such matrices to be speciated. Such an exercise involves division of the metal of interest into fractions based upon its various chemical associations as determined by the sequential use of selective extractants (Gibson and Farmer 1986; Hamilton et al. 1984; Harrison et al. 1981; Harrison and Wilson 1983; Tessier et al. 1979). Such detailed work is considered to give greater depth of information concerning the mobility and bioavailability of trace metals in soils and dusts (Harrison et al. 1981; Fergusson and Kim 1991). As such, it ought to provide a more informed indication of the potential hazards associated with the given levels of a particular metal in a given soil (Davies 1981; 1983) or dust (Harrison et al. 1981) sample.

One of the more commonly used schemes is that devised by Tessier et al. (1979). Operationally, the metal content in the sample is divided up into five fractions: (a) soluble and exchangeable, (b) carbonate fraction, (c) associated with iron and manganese hydrous oxides, (d) associated with organic matter, and (e) residual. The order of bioavailability ranges from (a) the most bioavailable fraction to (e) the least available (Harrison et al. 1981; Clevenger 1990).

The purpose of this study was to assess the degree of environmental hazard posed to children attending two schools that are adjacent to a major road junction in South East London known as Fiveways Junction. A 12 h survey (0700 to 1900 h) indicated that some 46 850 vehicles may use the junction (London Borough of Greenwich, private communication). The major road passing through the junction is the A20, an important arterial road running into South East London from the suburbs and Kent.

EXPERIMENTAL

Site description

Fig. 1 is a schematic map showing the proximity of the two schools to the A20 and Five Ways Junction. On a typical working day, traffic will build up at this junction, causing at times long tail backs both on the main road and the side roads. In addition, the side streets experience high levels of on-street parking. At the time of sampling, the street-cleaning regime was as follows (London Borough of Greenwich, private

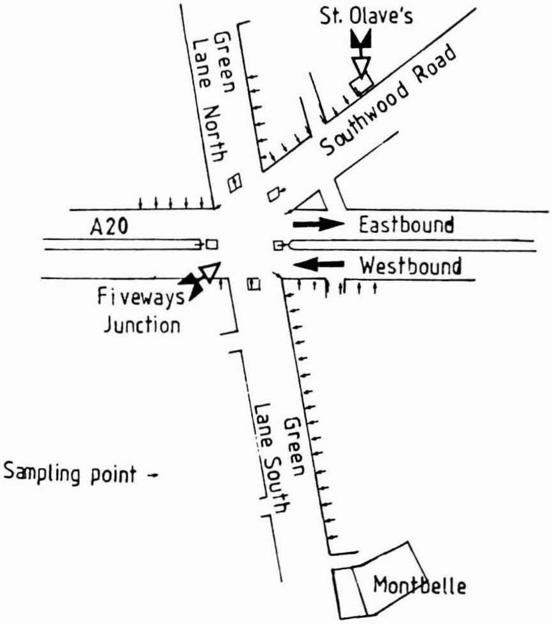


Fig. 1. Schematic map of Fiveways Junction.

communication): A20, once a week by street-cleaning truck; Green Lane, once a week by hand broom; and Southwood Road, twice a week by hand broom.

Sampling

All sampling was conducted in October 1989. Samples of road dusts were collected from the side roads and main road along transects measured from the cross roads at 20 m intervals. The dust samples were taken by careful sweeping of dust contents in gutters. Further samples were taken from the traffic light islands at the cross roads.

Soil samples were taken from the top 5 cm using an aluminum corer. Samples were taken from the playing fields in Montbelle School and flower beds in St. Olave's School. All samples were stored at -8 °C prior to analysis.

Sample treatment

Dust and soil samples were initially air dried. The samples were then passed through a 850 µm sieve to remove all large particles. This was followed by grinding in a mortar and pestle and subsequent passing through a 250 µm sieve. The samples were then dried at 37°C for 7 d. This was followed by the sequential extraction procedure outlined below.

Approximately 5 g of sample was accurately weighed out and treated as outlined in Table 1. At the end of each stage, the extract was separated from the residue by filtration through a Whatman No. 4 filter. The residue was then washed twice and subsequently used for the next stage of the sequential extraction scheme.

The supernatant was analysed for lead using Instrumentation Lab IL 351 flame atomic absorption spectrophotometer at a wavelength of 217 nm using background correction. Blanks were run to assure quality control. Laboratory dust samples were also collected to check for possible contamination of samples during processing. Only one sample gave a detectable lead reading and this was only of 8 µg g^{-1}.

Table 1. The sequential extraction scheme (Adapted from Gentry et al. 1987).

	Extraction Procedure	Fraction
1	1M $MgCl_2$, pH 7 for 1 hour	Exchangeable.
2	1M CH_3COONa pH 5 for 5 hours.	Bound to carbonate.
3	0.04M $NH_2OH.HCl$ pH 2. 25% CH_3COOH 5 hours at 96°C	Bound to iron and manganese hydrous oxides.
4	30% H_2O_2 / 0.02M HNO_3 pH 2. 5 hours at 85°C followed by CH_3COONH_4	Bound to organic matter.
5	HF / $HClO_4$	Residual.

However, due care was taken to protect the samples from laboratory dust contamination.

RESULTS AND DISCUSSION

Overall lead levels

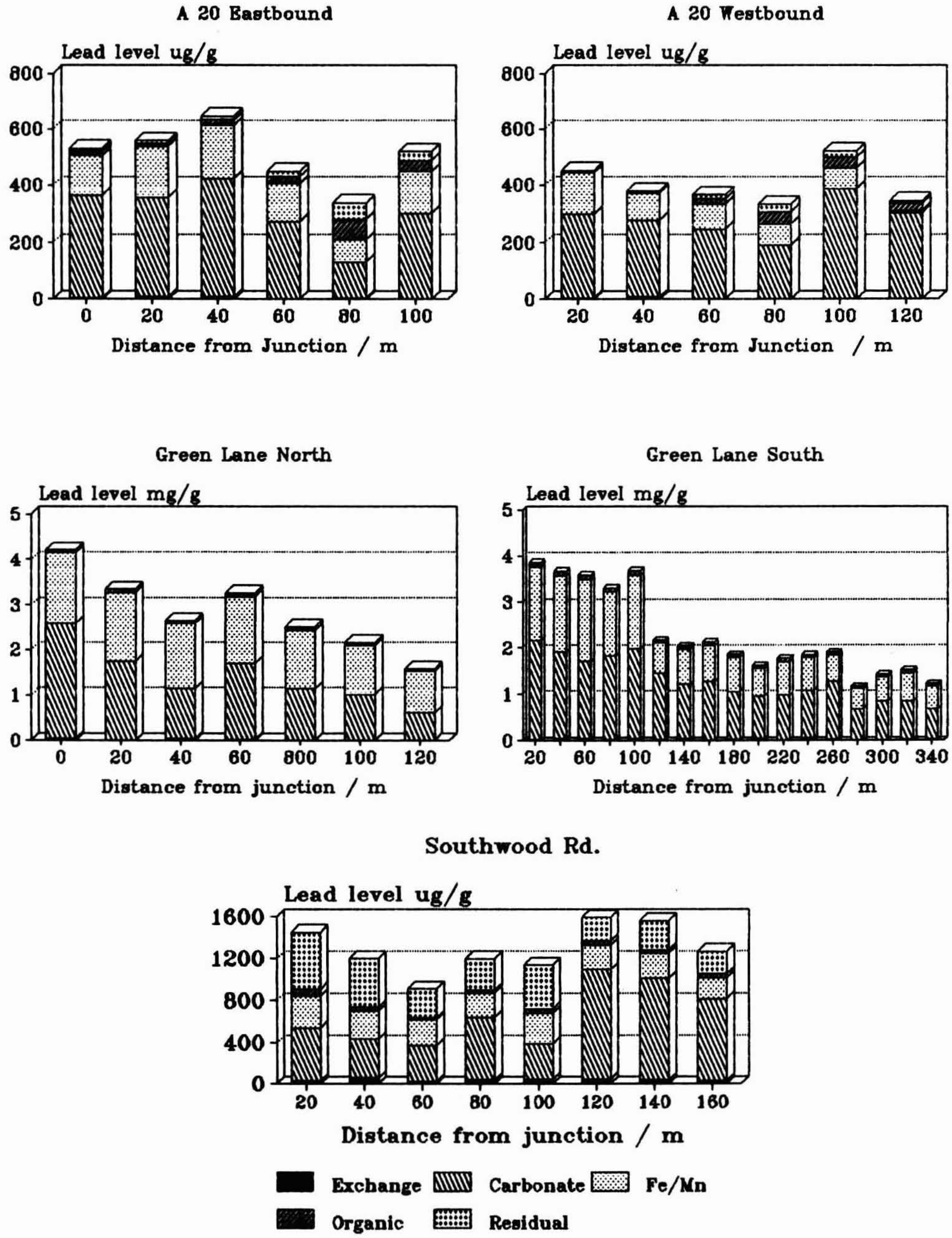
The overall lead levels are easily computed from a simple summation of the data obtained for each dust sample. Table 2 gives mean lead in dust levels for the roads surveyed. The results are somewhat surprising. The main road A20 may have been expected to have the highest results. Green Lane, which has fewer vehicles using it (London Borough of Greenwich, private communication), has lead levels which are some 10 times greater. There is no clearly established reason why the results should display such non-intui-

Table 2. Mean values for chemical associations of lead in soils and dusts. Lead levels are in μg g^{-1} of dry sample.

		Exchange	Carbonate	Fe-Mn	Organic	Residual	Total
A20 Eastbound Dust Samples							
	Mean	4.7	303.7	145.3	29.3	24.0	507.0
	SD	3.4	91.1	36.2	20.5	16.0	95.9
	%	0.9	59.9	28.7	5.8	4.7	100.0
A20 Westbound Dust Samples							
	Mean	2.3	282.0	80.3	20.3	14.3	399.3
	SD	2.9	60.2	40.5	16.5	7.7	66.6
	%	0.6	70.6	20.1	5.1	3.6	100.0
Southwood Road Dust Samples							
	Mean	35.0	625.8	252.5	34.8	341.6	1289.6
	SD	10.7	260.8	31.5	13.7	111.9	216.6
	%	2.7	48.5	19.6	2.7	26.5	100.0
Green Lane North Dust Samples							
	Mean	19.7	1394.3	1334.9	57.3	9.7	2815.9
	SD	14.1	591.7	227.1	11.1	4.2	804.8
	%	0.7	49.5	47.4	2.0	0.3	100.0
Green Lane South Dust Samples							
	Mean	22.5	1267.9	919.4	64.4	9.1	2283.4
	SD	11.9	529.4	493.4	19.7	4.1	1028.6
	%	1.0	55.5	40.3	2.8	0.4	100.0
Fiveways Junction Dust Samples							
	Mean	34.0	311.0	627.5	250.1	240.0	1462.6
	SD	16.0	104.0	286.6	92.3	111.3	524.0
	%	2.3	21.3	42.9	17.1	16.4	100.0
St. Olave's School Soil Samples							
	Mean	14.2	79.8	344.1	51.0	31.2	520.3
	SD	22.2	67.9	294.4	53.0	33.3	402.6
	%	2.7	15.3	66.1	9.8	6.0	100.0
Montbelle School Soil Samples							
	Mean	2.7	1.4	22.0	12.5	1.8	40.3
	SD	3.8	1.1	11.9	19.7	2.0	31.1
	%	6.7	3.4	54.5	31.1	4.4	100.0

tive behaviour. However, it is suspected that the street-cleaning regime may play a role. The gutters on the A20, which has no on-street parking are easily cleaned by street-cleaning vacuum machines. Southwood Road and Green Lane both have on-street parking, which makes gutter cleaning less efficient, a problem com-

Fig. 2. Speciation patterns obtained for road dust samples.



pounded by the use of a handbroom on these streets. This presumably gives rise to the greater build up of lead in dust levels. The fact that Southwood Road is swept twice a week and Green Lane North only once a week may also account for the significant difference (at the 99.0% confidence level) in overall levels between both streets. This is despite the fact that the 12 h traffic survey (London Borough of Greenwich private, communication) reported that some 8 400 vehicles used Green Lane (North) and 10 897 vehicles used Southwood Road.

Previous London-wide surveys (Schwar et al. 1988) of background metal in dust concentrations give mean lead in dust values of 660 µg g^{-1} for Greater London in 1982/83 and 1100 µg g^{-1} for Inner London. A survey in 1985 for Inner London (Schwar et al. 1988) gave a mean lead in dust level of 1050 µg g^{-1}. The side roads in this survey are considerably greater than these values. The spatial distribution of background levels of lead in dust throughout London are also reported (Schwar et al. 1988). The part of London we are interested in is shown as having background levels between 0 and 250 µg g^{-1}. The levels of lead in dust that we report are much higher than the background levels with the exception of those samples obtained from the A20. In the absence of any other major local source of lead emissions, the major roads are clearly responsible for the elevated lead in dust levels.

Sequential extraction

The results obtained from the sequential extraction experiments (Figs. 2 and 3) provide an interesting insight into the variability of lead associations in

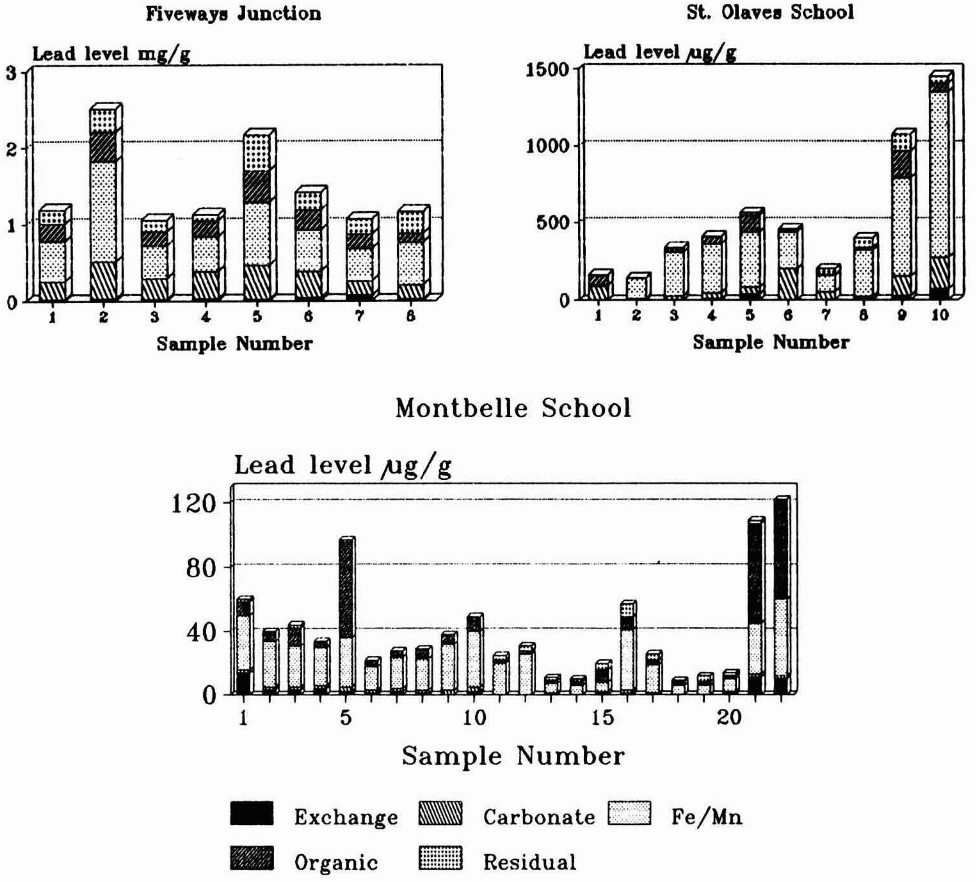


Fig. 3. Speciation patterns obtained for school soil and junction dust samples.

road dusts and soils in a small area. By and large, most of the lead is associated with the carbonate and iron/manganese hydrous oxide fractions. For the A20 and Green Lane, the total loadings in these fractions account for between 88 and 96% of the total lead found in the road dust samples. These results are broadly similar to those results obtained by Harrison and his co-workers (1981; 1983) Interestingly, this pattern of association is not repeated in Southwood Road where some 26.5% of the lead is found in the residual fraction. The reason for this is not obvious.

The samples taken from Fiveways Junction contain relatively sizeable proportions of lead associated with all fractions except the exchangeable fraction. The mean value showing that 17.1% of the lead is associated with the organic fraction may indicate soil input. This is reasonable considering that the central reservations of the A20, from where the Fiveways Junction samples were taken, do contain soils and vegetation.

The speciation patterns obtained for the soil samples are quite different. The carbonate fractions have become less important. This may be as a result of the acidic soil pH conditions. It would be expected that as the pH decreases the percentage of total lead associated with the carbonate fraction should also decrease (Xian and Shokohifard 1989). The mean pH of Montbelle soils is 5.8 (n = 19, sd = 0.28) and the carbonate fraction contains 3.4% of the total soil lead. The soil sampled at St. Olaves School has a pH of 6.7 (n = 10, sd = 0.33) and the carbonate fraction contains 15.3% of the total soil lead. It is clear that the iron/manganese hydrous oxide and organic fractions have become important repositories of lead burden in these soils. This in itself is a cause for some concern. Gibson and Farmer (1986) have already observed that despite reductions of levels of lead in petrol, the association of lead with the iron/manganese hydrous oxide fractions of soils gives rise to a pool of lead which, though relatively immobile, may create long term contamination problems. Lead associated with this fraction may act as a reservoir for replenishing the store of more easily mobilised lead as this latter fraction becomes depleted (Gibson and Farmer 1986).

Hazard assessment

An assessment of the hazard associated with the lead levels measured in the soil and dust samples collected within the vicinity of the two schools may be made in terms of the potential bioavailability of the materials ingested and in terms of potential con-

Table 3. Predicted blood lead contributions based upon total Pb levels. Assumptions: Dirt ingestion, 60 mg; Time outdoors, 2 h.

	Total Pb µg g-1	Ratio of indoor dust to outdoor dust	Contribution to Blood lead µg dL-1		
			0.5:1	1:1	1.5:1
A20 Eastbound Dust Samples	507.0		1.98	3.65	5.32
A20 Westbound Dust Samples	399.3		1.56	2.88	4.19
Southwood Road Dust Samples	1289.6		5.03	9.29	13.54
Green Lane North Dust Samples	2815.9		10.98	20.27	29.57
Green Lane South Dust Samples	2283.4		8.91	16.44	23.98
Fiveways Junction Dust Samples	1462.6		5.70	10.53	15.36

Table 4. Prediction of potential contributions made by school dusts to blood lead burdens. Assumptions: Time at school, 6 h, hence, 15 mg dirt ingestation. Indoor dirt levels = Outdoor dirt levels.

	Total Pb µg g-1	Contribution to blood lead level µg dL-1
Montbelle School Soil Samples	40.3	0.07
Green Lane South Dust Samples	2283.4	4.11
St. Olave's School Soil Samples	520.3	0.94
Southwood Road Dust Samples	1289.6	2.32

tributions to the blood lead burden of young children. For the latter assessment, it is possible to use aspects of the USEPA biokinetic/uptake model (Hoffnagle 1988) to estimate the potential contributions to blood lead levels from dust ingestion. The model is used since its predictions correlate well with actual data obtained for children in the 0 to 6 y age range. The model parameters are derived from data obtained for children aged 2 y, who are considered to be representative of children in this age range (Hoffnagle 1988). The model assumes that children ingest some 60 mg /d of dust and that some 30% of the lead ingested is absorbable. The amount of absorbable lead, expressed in µg, is multiplied by 0.4 to convert to µg of lead per dL of blood. For the hazard assessment, mean total lead levels (obtained by summation of all fractions) for each set of samples are used. It is assumed that children in this age range spend some 2 h outdoors. This is used to compute a time-averaged, lead-in-dust value. Since indoor dust lead levels have not been determined, some reasonable assumptions about their size must be made. Data obtained from Thornton et al. (1990) show that the ratio of the median levels of indoor to outdoor dust lead in London is approximately 1.3:1. In the absence of indoor dust data, Hoffnagle (1988) assumed that indoor and outdoor levels were equal. In Table 3, then, three sets of predictions have been made based upon assumed ratios of indoor to outdoor dust lead levels of 0.5:1, 1:1, and 1.5:1.

The predictions demonstrate that those streets with high dust lead levels and, consequently, potentially high indoor dust lead levels, could make a significant contribution to child blood lead levels. The scale of the contribution would be obviously attenuated by the temporal and spatial variations of the levels and by the scale of the contribution that such contaminated dusts make to the indoor environment.

The possible contributions made by street dusts and soils to the blood lead burdens of children whilst attending either of the schools may also be estimated. For this prediction, the child's day at school is considered to be 6 h long and the child is assumed to ingest 15 mg of dust. Indoor dust lead levels are assumed to be equal to either outdoor dust lead levels or to soil lead levels. For children between the ages of 4 to 6y attending Montbelle School, blood lead contributions could range between 0.07 to 4.11 µg dL^{-1}. For those at St. Olaves (3 to 6 y), the range could be between 0.94 to 2.32 µg dL^{-1}. This data is summarised in Table 4.

The hazard assessment, so far, has been based upon total lead levels. Yet the data obtained in this survey has also enabled the separation of lead into contributing fractions. It is a commonly held view that knowledge of physico-chemical associations is necessary for assessing environmental and health impacts (Tessier et al. 1979; Analytical Methods Committee 1985; Harrison et al. 1981; Clevenger 1990; Gentry et al. 1987; Gibson and Farmer 1986). Despite

Table 5. Prediction of % availability. Lead levels in μg g^{-1} of dry sample.

	Exchange	Carbonate	Overall Total	% Available
A20 Eastbound	4.7	303.7	507.0	60.8
A20 Westbound	2.3	282.0	399.3	71.2
Southwood Road	35.0	625.8	1289.6	51.2
Green Lane North	19.7	1394.3	2815.9	50.2
Green Lane South	22.5	1267.9	2283.4	56.5
Fiveways Junction	34.0	311.0	1462.4	23.6
St. Olaves soil data	14.2	79.8	520.3	18.1
Montbelle soil data	2.7	1.4	40.3	10.0

this, there appears to be little in the literature on the exact relationship between physico-chemical associations and contributions to blood lead burden.

Chaney et al. (1988) have reported that those materials which are readily soluble in weak acid solution were found, in acute rat feeding tests, to be highly bio-available. Though increasing bioavailability could also be achieved by decreasing the particle size, Tessier et al. (1979) have shown that at a pH of 5 all but the biggest carbonate particles are effectively dissolved in 5 h, using extraction procedure 2 in Table 1. The Analytical Methods Committee (1985) reported that the potential bio-availability of metals in foods may be assessed by the use of synthetic gastric juice (of pH 3.5) for 4 h. Given this pH value and time scale, it seems reasonable to suggest that the carbonate and exchangeable fractions will be released into such a solution. At low pH values, it is possible that some of the iron and managanese hydrous oxide fraction is partially attacked (Tessier et al. 1979). The severity of the conditions required to release this fraction, however, suggest that the scale of leaching in gastric solution should be small. It therefore seems likely that those dust samples which contain high amounts of lead in the exchangeable and carbonate fractions pose a greater risk than those samples with lesser amounts.

On the basis of this reasoning, Table 5 gives some indication of the proportions of lead that are possibly available in the acid conditions of the stomach. Soil lead and lead associated with samples obtained from the central traffic islands of the A20 appear to be less easily released under mild acid conditions than does lead associated with street dusts obtained from the gutters. This possibly indicates that lead in the former samples poses less of an environmental hazard. This is now under investigation in our laboratories.

CONCLUSIONS

From the results described, it would appear that lead in street dusts is primarily associated with the carbonate (the possibly more bio-available fraction) and the iron and manganese hydrous oxide fractions. However, this association pattern is variable and is altered when lead in soil speciation patterns are determined. There appear to be some reasons for believing that the street cleaning regimes may affect the overall levels of lead in gutter dusts. However, it is not at all clear if the cleaning regime has any effect upon the speciation pattern. The degree of hazard, in terms of possible blood lead contributions, posed to young children (between the ages of 0 to 6 y) living in and attending schools in the neighbourhood of these dust sample locations is varied, but may possibly amount to a substantial level in certain locations.

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DISTRIBUTION OF INDOOR ^{222}RN CONCENTRATIONS IN TENNESSEE, KENTUCKY, GEORGIA, AND FLORIDA

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Short-term measurements of ^{222}Rn concentrations using diffusion barrier charcoal canisters were made in living areas at the request of volunteer households in Tennessee, Kentucky, Georgia, and Florida from 1986 through 1989. We analyzed the observed radon concentrations in regional sub-areas within these states. After adjusting for oversampling that had occurred in some areas, we estimated state-wide geometric means of radon concentrations in living rooms as 59.7 Bq m^{-3} in Kentucky, 51.9 Bq m^{-3} in Tennessee, and 60.0 Bq m^{-3} in Georgia. Measurements in Florida were scattered over the state and the coverage was inadequate to allow a state-wide estimate. Estimates of the percentage of homes having indoor radon levels equal to or above the action level of 148 Bq m^{-3} are 21.6% in Kentucky, 17.0% in Tennessee, and 6.8% in Georgia, respectively.

INTRODUCTION

In studies of workers in uranium mines, ^{222}Rn and its radioactive daughters have been associated with the induction of excess lung cancer. Although primarily an occupational hazard, radon has been shown to occur in indoor environments sometimes at considerable concentrations. Therefore, it is considered as a factor contributing to the lung cancer risk of the general population. Estimations of the fraction of lung cancer fatalities attributable to radon range from 5 to 20% for the United States.

Despite its obvious importance for the public health field, data on residential exposures experienced by the U.S. population are still limited (Nero et al. 1986; Alter and Oswald 1987), and therefore, the exact population burden is not known. Risk estimates available (Lubin and Boice 1989) are hampered by the uncertainties arising from the paucity of the underlying exposure data. A reliable and complete picture of the exposure dose and its distribution in the United States could be derived from probability-based radon surveys in all the states. However, budget and time limitations, as well as low participation rates, have often conspired against this approach in the past.

Efforts made by the United States Environmental Protection Agency (U.S.E.P.A.) to support state-wide radon surveys have sometimes been directed towards screening for high-risk areas and have, thus, often yielded results that represent maximized radon levels not suitable for estimating state-wide averages or associated health risks for the population. Also, efforts to predict indoor radon levels by using geological information has not been as successful as previously hoped. That is, predictions based on geological considerations aimed at finding high risk homes and areas did not produce reliable results, because indoor radon levels have been shown to be influenced by a variety of other factors. Already available information on radon levels in residential environments can be utilized as an additional source.

This paper presents results of radon measurements in four U.S. States that were made in a non-random fashion at the request of volunteers. One critical consideration when using this data set is that some upward bias is likely to exist, the amount of which is not known. However, a previous comparison of results gained within the "Radon Project" to those obtained by a probability-based study that had been done in New York State revealed results in close agreement (Rahlenbeck et al. 1991). This comparison lends credibility to the assumption that the relevant bias is not pronounced. Moreover, it is felt that the relevant results should be published and used as a preliminary source of information, until data from statistically more valid random surveys are available.

GENERAL SURVEY INFORMATION

The data analyzed constitute short-term radon measurements with charcoal canisters (Cohen and Cohen 1983) made by the "Radon Project", University of Pittsburgh, from 1986 through 1989. All measurements had been done for customers who had purchased a radon detector through the mail from the "Radon Project". Measurements from areas with some radon potential, and where public attention had been directed towards radon as a health issue, are likely to be over-represented in the data set, compared with measurements from regions with low radon potential.

A total of 3833 measurements were made in living rooms of Tennessee, Kentucky, Georgia, and Florida. Additionally, 630 samples derived from basements in Kentucky were analyzed. The data were analyzed by different geographic regions of presumably differing radon potential. Measurements obtained from 3709 living areas and 619 basements (Kentucky) could be identified with respect to the county where they had been made; they were allocated to one of these groups. State mean concentrations were estimated, by adjusting the values for the sub-groups to the population inhabiting these areas. This was done in order to account for oversampling that had occurred in some areas of presumably high radon emanation potential.

General survey information is presented in Table 1. In the four states, samples from 441 counties were available. The coverage of counties with at least one radon measurement ranged between 43% in Kentucky to 75 % in Florida. In general, the distribution of measurements within a state tended to be good in areas with known geological radon potential, and low in remote areas and areas where no indication of elevated radon levels exists.

Table 1. General survey information.

	Number of Counties in:			
No. of Samples	Florida	Georgia	Kentucky	Tennessee
0	17	74	69	29
1-3	12	58	37	28
4-6	10	6	9	12
7-15	6	15	1	11
16-40	12	2	2	7
> 40	10	4	2	8
Counties	67	159	120	95
Coverage (%) *	75	54	43	69

*Coverage: percent of counties with at least one sample

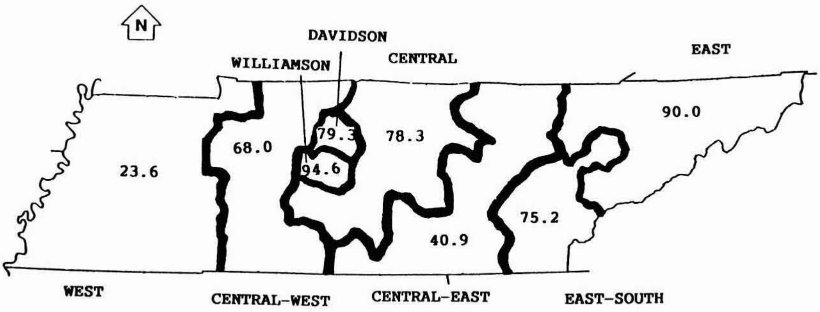

Figure 1. Geometric means of radon concentrations (Bq m^{-3}) in living rooms in Tennessee.

TENNESSEE

Based on geologic and geographic characteristics, the Tennessee counties were grouped into six regions that corresponded, with slight modifications, to the risk grouping used in the radon survey conducted by the Tennessee Department of Health and Environment (1987). In each of the states, the total territory was divided up in regions with comparable radon potential, based on the geologic formations identified. In Tennessee, these regions are identified and described below and shown in Fig. 1. Results obtained from measurements of two counties, Williamson and Davidson, were calculated separately, because these counties had a very large number of samples available. These regions were:

West — comprising the 21 counties west of the Tennessee River;

Central-West — the central counties adjacent to the western counties, comprising Benton, Cheatham, Dickson, Giles, Houston, Hickman, Humphreys, Lawrence, Lewis, Montgomery, Perry, Robertson, and Wayne county;

Central — the 16 northern-central counties, containing phosphate-rich limestones of Ordovician age;

Central-East — the 16 counties in the Cumberland Plateau, including the outcrop area of the Mississippian-Devonian black shale;

East-South — counties Bradley, Knox, Loudon, McMinn, Meigs, Monroe, Polk, Rhea, and Roane, which contain Cambrian and Lower Ordovician Carbonate rocks and Mississippian-Devonian black shales. The relevant rocks and soils are expected to have the potential for generating elevated indoor radon levels.

East — the 18 counties in the east-northern outcrop areas of Precambrian granites, that contain uranium- and thorium-rich rocks with known elevated radon-potentials.

A total of 1605 readings were obtained in Tennessee, of which 1560 (97%) could be allocated into one of these groups. The summary statistics for these groups are presented in Table 2. Measured ^{222}Rn concentrations in the western part were generally low, resulting in a geometric mean of 23.6 Bq m^{-3}. Medium values (GM = 40.9 Bq m^{-3}) were obtained from the central-eastern counties, and higher levels were observed in the central parts of Tennessee, where the geometric mean ranged between 68.0 Bq m^{-3} (Central-West) and 78.3 Bq m^{-3} (Central). The highest concentrations were found in East Tennessee (GM = 90.0 Bq m^{-3}), where Precambrian granites exist that constitute a potential for high radon emanation rates.

The state-wide geometric mean, adjusted for oversampling, was estimated as 51.9 Bq m^{-3} with a geometric standard deviation of 3.4; the distribution of these levels is skewed, with 60% of the measurements below 74, and 83.3% below 148 Bq m^{-3}.

These results agree well with those obtained by the Tennessee Department of Health and Environment (1987), who in cooperation with the U.S.E.P.A. conducted a state-wide radon survey during January through April, 1987. In this survey, 2000 charcoal canisters were distributed to owners of single-family homes, of which 1787 could be analyzed. The state-

Table 2. Radon concentrations (Bq m^{-3}) in living rooms in Tennessee (AM = arithmetic mean, ASD = arithmetic standard deviation, GM = geometric mean standard deviation, GSD = geometric standard deviation, 90th P = 90th percentile).

	Population (thousands)	Samples	AM	ASD	GM	GSD	90%	% > 148 Bq/m^3
State, adj.			98	146	52	3.4	222	16
State, raw	4803	1560	117	147	73	2.8	215	
West	1349	58	42	50	24	3.9	74	2.6
Central-West	334	64	108	126	68	2.9	185	18.0
Central	535	228	116	152	78	2.4	222	18.0
Central-East	577	190	69	79	41	3.3	141	8.2
East-South	602	127	128	190	75	2.6	289	20.9
East	836	138	148	206	90	2.6	337	30.1
Williamson	72	361	135	148	95	2.3	266	17.8
Davidson	497	394	123	134	75	2.7	296	23.6

wide arithmetic mean was calculated to be 99.2 Bq m^{-3}. It was estimated that 84.2% of the single-family dwellings in Tennessee should have radon levels below 148 Bq m^{-3}, 14.5% between 148 and 740 Bq m^{-3}, and 1.3% above 740 Bq m^{-3}. In another previous U.S.E.P.A. screening survey (Dziuban et al. 1988), the arithmetic mean of radon concentrations in 1773 Tennessee homes was 100 Bq m^{-3}, with 16% of the measurements above 148 Bq m^{-3}.

Estimations of percentages of radon levels in the various regional strata obtained within the Radon Project also agree very closely with the values gained by the Tennessee Radon Survey. Their survey indicated that the percentages of homes with radon levels above 148 Bq m^{-3} in the various regional groups, which were nearly identical to the ones formed here, were: 2.4% (west), 17.4% (Central-West including Williamson County), 29.9% (Davidson County), 9.7% (Central-East), 20.8% (East-South), and 25.1% (East), respectively. Though the study base of both surveys is not identical (samples from lowest livable living rooms under closed-house conditions during winter season in the state survey versus samples at any time from living rooms excluding basements in the Radon Project), the estimation of relevant percentages reveals similar results. Because both surveys presumably over-represent higher levels, the state-wide average might, in reality, be lower.

KENTUCKY

The counties were grouped into five different groups based on radon emanation potential; also, Jefferson county was taken as a separate entity, because a large number of measurements had been made in this county. The five regions were:

—the Bluegrass Region in the most northern part (10 counties),
—the Cumberland Plateau in the east (37 counties),
—the Central-East (28 counties),
—Central-West (15 counties), and
—the western region (29 counties).

A total of 344 measurements were derived from living rooms and 619 from basements in these areas. Table 3 exhibits the summary statistics for the six groups in Kentucky. Measured radon concentrations in living rooms of the western parts, the Bluegrass Region and the Cumberland Plateau had generally low levels with geometric means of 30.0 Bq m^{-3}, 39.3 Bq m^{-3}, and 42.1 Bq m^{-3}, respectively. Medium level geometric means were found in

Table 3. Radon concentrations (Bq m^{-3}) in living rooms and basements in Kentucky (AM = arithmetic mean, ASD = arithmetic standard deviation, GM = geometric mean, GSD = geometric standard deviation, 90th P = 90th percentile).

	Population (thousands)	Samples	AM	ASD	GM	GSD	90%ile	%>148 Bq/m^3
Living Rooms								
State, adj.		344	118	243	60	3.4	263	20.4
State, raw	3729	344	242	1654	81	3.5	359	
Western Reg.	730	36	43	28	30	3.3	81	<1.0
Bluegrass	344	21	80	145	39	3.8	111	5.0
Cumberland	861	22	61	53	42	2.7	133	6.8
Jefferson	681	94	129	136	79	3.0	274	52.5
Central-East	754	131	409	2636	110	3.2	396	41.0
Central-West	361	40	320	622	144	3.4	712	17.0
Basements								
State, adj		619	298	672	125	3.3	636	
State, raw		619	342	605	155	3.5	833	
Western Reg.		42	106	95	70	3.1	237	
Bluegrass		31	73	54	54	2.4	141	
Cumberland		33	321	933	120	3.0	296	
Jefferson		304	330	513	161	3.5	736	
Central-East		145	354	521	181	3.2	895	
Central-West		64	674	1034	296	3.6	1547	

Jefferson county (79.0 Bq m^{-3}) and the central-east group (109.9 Bq m^{-3}), and the highest concentrations occurred in the central-west group (144.0 Bq m^{-3}). The geometric means of basement concentrations within these groups are more than twice as high as the ones obtained from living areas (Fig. 2 and 3).

The geometric mean for the state, adjusted for oversampling, is 59.7 Bq m^{-3} with a standard deviation of 3.5, that is, 26% below the unadjusted mean. The estimated arithmetic mean is 118.1 Bq m^{-3} which corresponds well to the U.S.E.P.A. survey that revealed, on the basis of 900 samples, an arithmetic mean for Kentucky of 103.6 Bq m^{-3}. State-wide, 21.6% of Kentucky homes are estimated to have radon levels equal to or above 148 Bq m^{-3} (4 pCi L^{-1}). In the USEPA state survey, 17% had been estimated to exceed this action level. In another U.S.E.P.A. survey, a state arithmetic mean of 100 Bq m^{-3} was calculated, with 17% of the readings above 148 Bq m^{-3} (Dziuban et al. 1988).

GEORGIA

Georgia was divided into four geographical regions:

—the Blue Ridge Mountains in the most northeastern part, consisting of granites and gneisses (17 counties);

—the Piedmont Plateau adjacent to the Blue Ridge Mountains (19 counties);

—the Appalachian Mountains at the northeastern border (35 counties); and

—the coastal region including all remaining parts,

—the geology of which is characterized by silts and clays (88 counties).

The highest radon concentrations were found in the Blue Ridge Mountains (GM = 68.7 Bq m^{-3}), followed by the Piedmont Plateau (GM = 47.5 Bq m^{-3}) and the Appalachian Mountains (GM = 35.5 Bq m^{-3}). The coastal areas showed comparatively low values with a geometric mean of 25.3 Bq m^{-3} (Table 4, Fig. 4). This picture is in agreement with expectations based on the geology of Georgia.

The distribution of the concentrations throughout the state shows the typical high degree of skewness with 53% of the measurements below 37 Bq m^{-3} (1 pCi L^{-1}), and 6.8% equal to or above the action level of 148 Bq m^{-3} (4 pCi L^{-1}). The state-wide geometric mean, adjusted for oversampling, is 34.1 Bq m^{-3}; the

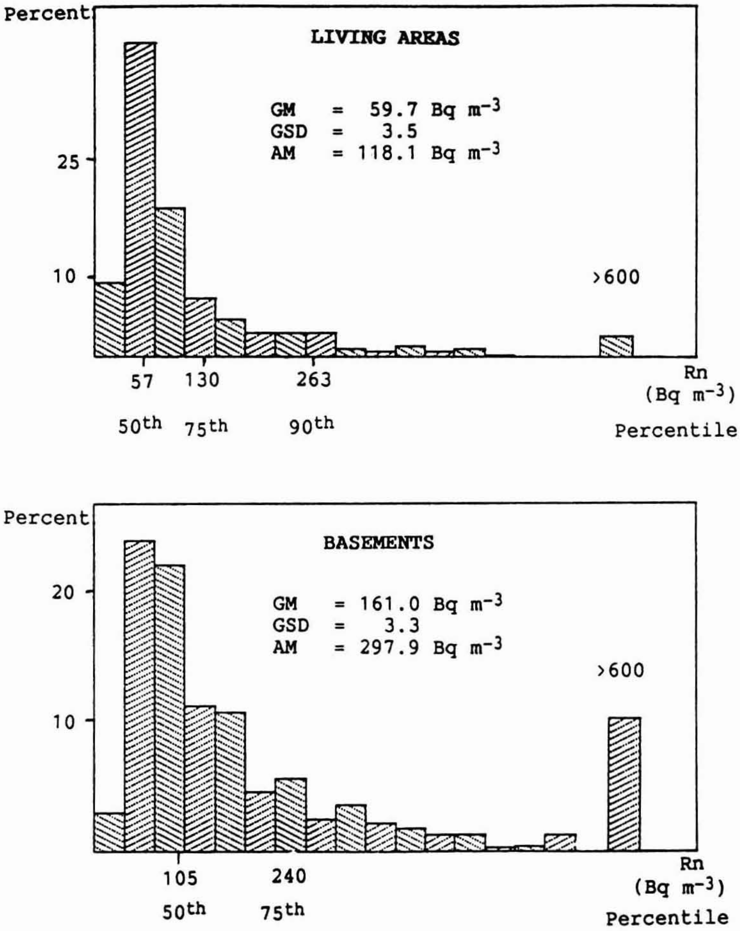

Figure 2. Frequency distribution of radon concentrations (Bq m^{-3}) in Kentucky.

arithmetic mean is 53.4 Bq m^{-3}. The results are slightly below the state survey, in which 1534 homes in Georgia had been surveyed, during 1988 to 1989, with the assistance of the U.S.E.P.A. The arithmetic mean of this survey was 66.6 Bq m^{-3}, and it was estimated that 8% of the homes throughout the state had radon levels above 148 Bq m^{-3}.

FLORIDA

Florida contains in its north and central parts phosphate-rich regions that may release significant amounts of radon during mining processes or when the phosphate rocks are used as deposits for land reclamation. The relevant areas are located in two districts, the northern land-pebble district stretching along the Ocala Uplift, belonging to the Alachua and Hawthorn Formations; and the west-central land-pebble district of the Bone Valley Formation.

In an attempt to characterize the distribution of areas with high radon emanation potential, a radon potential index had been calculated by Nagda (1987), based on data of indoor radon concentrations in 6465 Florida homes that had been collected through a statewide radiation survey, and incorporating data on geologic and soil parameters affecting radon availability. Eighteen counties were accordingly desig-

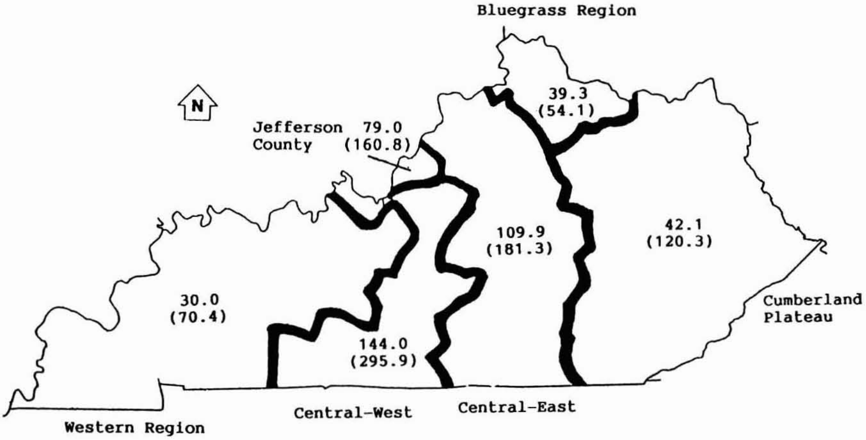

Figure 3. Geometric means of radon concentrations (Bq m^{-3}) in living rooms and basements (in brackets) in Kentucky.

nated as counties with definite evidence of elevated radon potential: Alachua, Charlotte, Citrus, Columbia, Dade, Gilchrist, Hardee, Hillsborough, Lee, Leon, Levy, Manatee, Marion, Pasco, Pinellas, Polk, Sarasota, and Sumter (Nagda 1987); additionally, 14 counties were designated as counties with limited evidence of elevated radon potential. A strong correlation between geologic factors and indoor radon levels was stated (all counties located on phosphate rich ores were found to have elevated radon potentials). Conversely, however, some counties with high radon potentials were situated far away from the relevant districts. For example, Dade county, which is located at Florida's southeastern coast on limestone that does not contain any uraniferous material, was found to have fairly high levels.

Figure 5 maps the distribution of geometric means in all those counties for which at least 11 (4) measurements were available from the Radon Project. High geometric means ranging from 59 to 103 Bq m^{-3} were obtained in the counties Marion, Leon, Alachua, and Citrus, counties that were all designated as having a high radon potential. Medium high geometric means between 37 and 55.5 Bq m^{-3} (1 and 1.5 pCi L^{-1}) were found in Polk, Lee, Dade, and Sarasota county, also counties with definite evidence of elevated radon potential. Out of the counties ($n > 10$) designated as having definite evidence, geometric means below 37 Bq m^{-3} were found in Charlotte (35 Bq m^{-3}), Hillsborough (33 Bq m^{-3}), and Pasco (28 Bq m^{-3}).

Within the counties designated by Nagda (1987) as having limited evidence of elevated radon potential, only in Seminole were results of more than 10

Table 4. Radon concentrations (Bq m^{-3}) in living rooms in Georgia (AM = arithmetic mean, ASD = arithmetic standard deviation, GM = geometric mean, GSD = geometric standard deviation, 90th P = 90th percentile).

Living Rooms								
State, adj.	6104	605	53	62	34	2.8	111	16.0
State, raw		605	56	63	36	2.7	115	
Coastal	2396	139	39	53	25	2.7	70	1.8
Appalachian	2211	277	52	54	36	2.6	100	5.4
Piedmont	1189	166	71	78	48	2.7	126	9.0
Blue Ridge	308	23	91	66	69	2.2	189	19.6

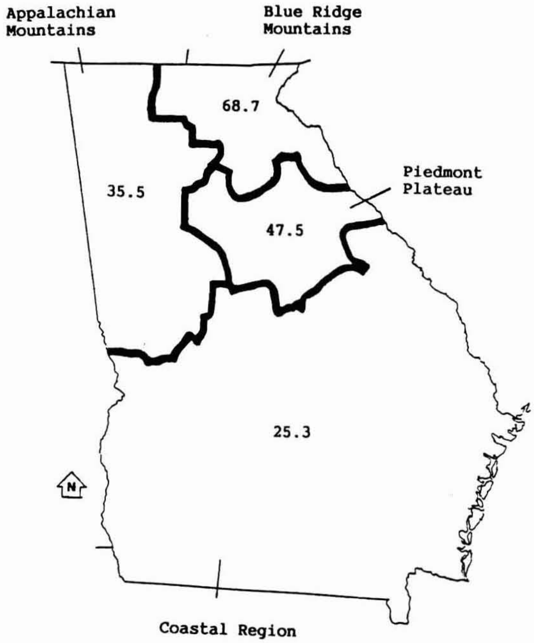

Figure 4. Geometric means of radon concentrations (Bq m^{-3}) in living rooms in Georgia.

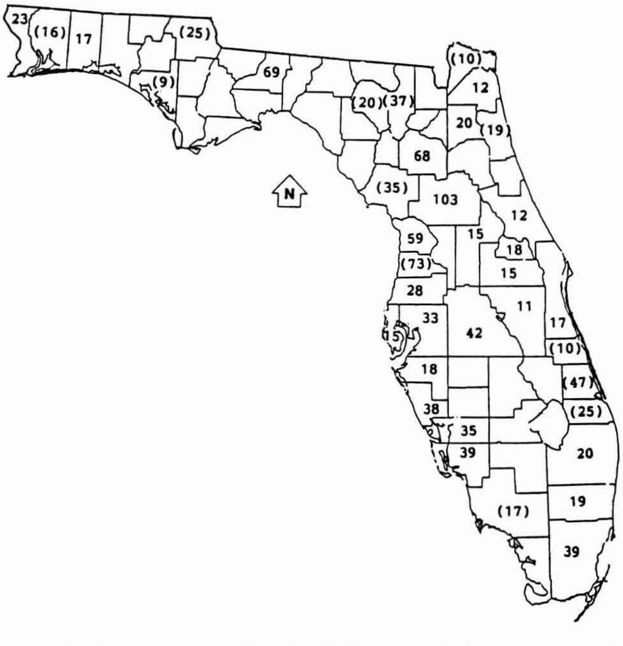

Figure 5. Geometric means of radon concentrations (Bq m^{-3}) in living rooms of Florida counties with at least 11 samples (counties with 4 to 10 samples in brackets).

State	Percent of homes <148	>148 <296	>296	>740
Georgia	93.2	5.8	1.0	<0.3
Kentucky	78.4	13.5	8.1	0.4
Tennessee	83.0	10.1	6.1	0.9

Table 5. Estimated percent of homes having indoor radon levels (Bq m^{-3}) below and above "action" levels.

samples available, resulting in a geometric mean of 18 Bq m^{-3}. Values from other counties range from 11 to 23 Bq m^{-3}, and may therefore be rated as low, which agrees with the expectations based on geologic criteria.

SUMMARY AND CONCLUSIONS

Based on the results of this convenience sample of short-term indoor radon measurements, percentages of homes in various states above and below certain levels of concern can be estimated. The U.S.E.P.A. has recommended two action levels: 4 pCi L^{-1} corresponding to 148 Bq m^{-3}, and 8 pCi L^{-1} (296 Bq m^{-3}) for indoor levels of radon. That is, if a level greater than 148 Bq m^{-3} is found in a building, action should be taken to correct the situation. If the level found is above 296 Bq m^{-3}, the action should be taken immediately. Based on the survey results, estimations of relevant percentages of homes through-out Georgia, Kentucky, and Tennessee are presented in Table 5.

It is well recognized that there might be marked differences between results obtained from surveys of randomly selected participants and those consisting of all volunteers. It is generally believed that the latter type of study might produce results that are as much as twice as high as those gained by a probability-based study. The results presented here generally agree with the state-wide surveys that had been done under the auspices of the U.S.E.P.A. This suggests that if an upward bias exists in our method of estimation, then many of the state-wide surveys experienced a similar bias.

Extrapolation of results from a volunteer-based and/or self-selection-based study to the entire population is methodologically incorrect. However, in view of the paucity of relevant random data available, non-random results can be used as a first estimate of the relevant real distribution. Moreover, it is likely that the real distributions do not exceed the results presented here, and therefore the values presented can be seen as upper bounds of the possible real levels.

The results presented here generally agree well with those obtained by local health departments that followed the U.S.E.P.A. protocol. As both data sets were obtained under conditions that would produce an upward bias, actual exposures of the general population are most likely below the ones found in these investigations. Additional studies to elucidate the real picture are needed in order to better define the extent of the problem.

Screening surveys which use short-term samples have an inherent limitation if they are to be used for assessment of health risks of the general population. This is even more true if risks of individuals are considered, because indoor radon levels vary significantly with time and location of the measurement within a building. Short-term measurements can be markedly influenced by the rapid fluctuations in radon concentrations (Matuszek et al. 1988). In large-scale surveys, this problem becomes less relevant because the effects of time and location will average out provided there are no systematic instructions that produce a bias such as placement at the lowest living level, or the sealing-up of a space. For decisions about an individual residence, a long-term (one-year) sample in the most occupied part of the residence remains the appropriate tool.

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USING LONGITUDINAL DATA TO UNDERSTAND CHILDREN'S ACTIVITY PATTERNS IN AN EXPOSURE CONTEXT: DATA FROM THE KANAWHA COUNTY HEALTH STUDY

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An important component of assessing the levels, the sources, and the health effects of children's exposure to air pollution is understanding how and where members of this sensitive population spend their time. There are, however, few data bases that allow the documentation of the day-to-day nature of children's activities. Of particular concern is whether the one-day snapshots provided by time/activity diaries typically used in exposure studies represent the actual temporal and spatial extent of children's activities. As part of a community health study, longitudinal data on children's time/activity patterns were recently collected. A respiratory health status and gender stratified sample of 90 children kept daily diaries over two-week periods during both the summer and the fall. This paper first presents baseline information of children's activity patterns: the sample distribution of time spent in each of five microenvironments (travel, outdoor, at school, at home, and inside other locations) and the daily temporal pattern of activities. The consistent patterns of children on school days suggest that for most days we can accurately predict children's locations by time of day. The second part of the analysis shows that there is both high child-to-child variation in the average time spent in each microenvironment, even after controlling for gender and respiratory health status, and strong temporal variability in activity patterns within a child over time, even after controlling for school days versus nonschool days.

INTRODUCTION

Understanding how and where people spend their time is an important component of assessing total human exposure to environmental contaminants, thus the risk of health effects (Ott 1982; Duan 1982). Since the early 1980's, personal air pollution monitoring studies have used diaries in which participants are asked to record their activities by time of day for one- or two-day periods (e.g., Akland et al. 1985; Quackenboss et al. 1986; Wallace et al. 1989; Robinson 1988; Spengler et al. 1990). The resulting information, referred to as time/activity data, has mainly been used for modeling the population distribution of exposure. From an epidemiological perspective, time/activity data can also be viewed as providing

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information on potential exposure. Only a few health studies, however, have used activity data (Armstrong 1985; Colome et al. 1986).

Preadolescent children constitute one of the more sensitive population subgroups for air pollution exposure because of their stage of immunological and physiological development, their higher metabolism, and their higher exertion levels (Noyes 1985). Further, studies suggest that children who exhibit respiratory illnesses or allergic/atopic reactions such as asthma are more sensitive to a variety of environmental contaminants (Schenker et al. 1983; Vedal et al. 1984; Ware et al. 1984; Dockery et al. 1989). Information on children's activity patterns should improve the accuracy of exposure measures, thereby increasing the statistical power of epidemiologic investigations.

Children's activities have been the focus of a variety of studies. Unfortunately, however, because the data collected in conjunction with sociological investigations are arrayed by activity type (e.g., play, chores) rather than the spatial and temporal factors that influence exposure, they are not appropriate for exposure assessment (Gray and Brower 1978, Michelson et al. 1979, Medrich et al. 1982). More recently, several air pollution studies included the collection of time/activity data for small samples of children (Adair and Spengler 1989), often focusing on asthmatics (Goldstein et al. 1986; Lichtenstein et al. 1989; Stock and Morandi 1989). The size and demographic structure of these data sets, however, are not suitable for addressing whether children's personal characteristics such as health status and gender lead to differences in activity patterns. Can or should exposure estimates be stratified? Second, because time/activity data are rarely collected for more than one or two days, they are not suitable for characterizing the nature and implications of the day-to-day variability in time use (Hanson and Huff 1986). In particular, are such limited periods of observation adequate for estimating exposure?

Specific questions include:

Is there a consistent temporal structure to all days or certain types of days? Can between-child and between-day differences be ignored?

If there are between-child differences, are all days usually the same for a given child, in which case monitoring any day will provide essentially the same information?

If there are within-child differences, do all children exhibit similar distributions, implying that monitoring a representative sample will provide an accurate picture of each child's distribution?

If children exhibit dissimilar means and variances, how many days of data are necessary to capture the variability in time use for a child?

How is a child's time-use pattern misclassified on the basis of a single day of data? (e.g. Are the same children always in the high end of the distribution?)

This paper uses the time/activity diary data collected during the Kanawha County Health Study (KCHS) to consider these issues. After outlining the study design and protocol, baseline information on the distribution of time spent in outdoor, home, school, travel, and other indoor microenvironments is presented. We conclude with a descriptive analysis designed to provide insight about the extent of between-child and within-child variability in time/activity patterns.

METHOD

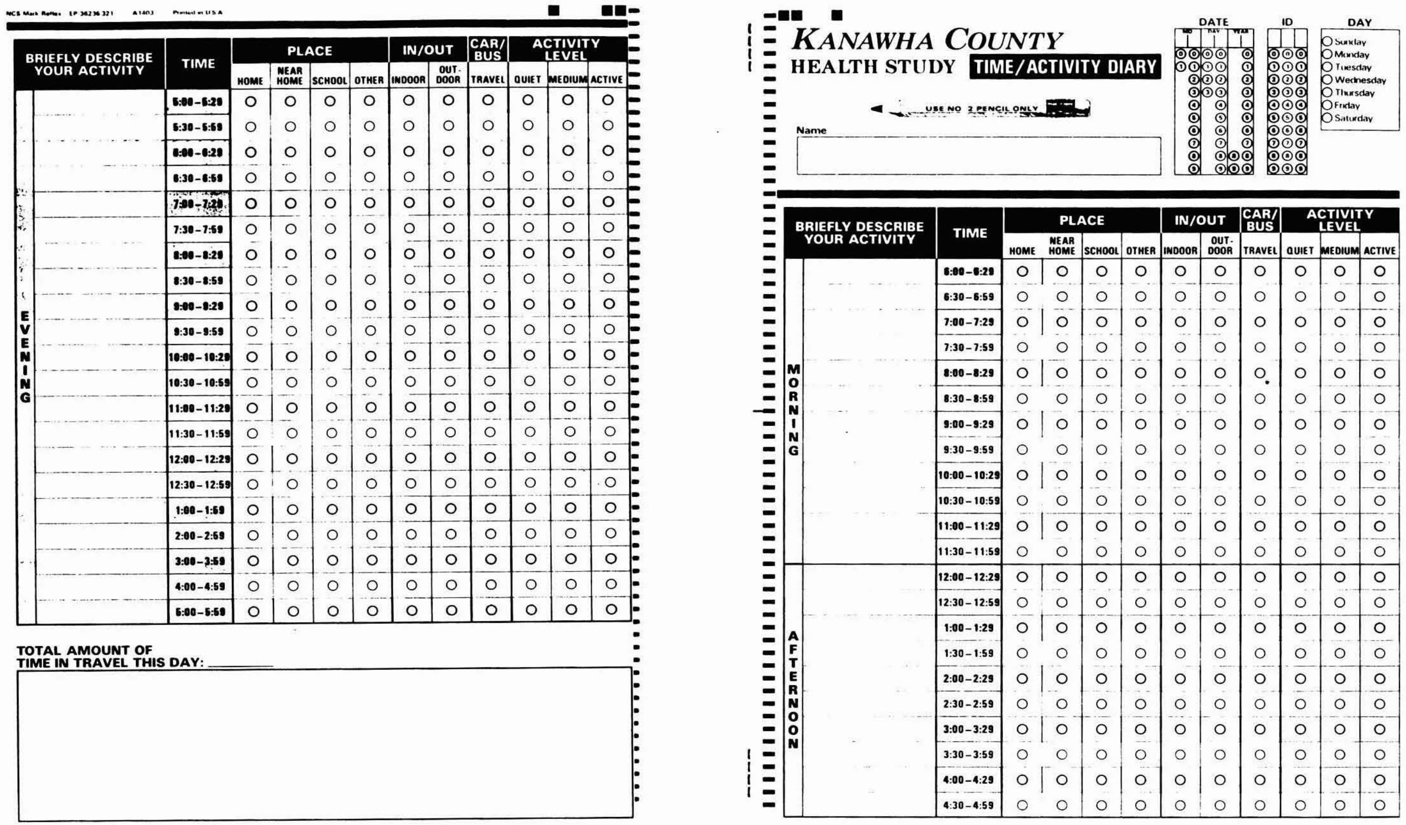
Sample design

The data presented in this paper were collected during an investigation of children's respiratory and sensory responses to air quality that is influenced by chemical industry emissions (Schwab et al. 1990c). The participants of the time/activity component of the KCHS were fourth through sixth graders residing in the Kanawha Valley of West Virginia. The target sample of 100 was stratified on two levels: 50 respiratory "responders" (those who reported either asthma or persistent wheeze during the past 12 months on the chronic respiratory health survey administered in autumn of 1988) and 50 respiratory "nonresponders", each with 25 girls and 25 boys.

A longitudinal design was implemented. The goal was to collect four weeks of daily activity data for each participant. The diary was administered between 9-22 July 1989 (summer/no school) and between 15 September to 1 October 1989 (fall/school in session).

Diary design

The activity diary used in the KCHS was designed to yield information about how often children visited various microenvironments, at what times of the day, and for how long. In order to insure compliance and facilitate coding, the diary (Fig. 1) included the following features:



KANAWHA COUNTY
HEALTH STUDY **TIME/ACTIVITY DIARY**

USE NO 2 PENCIL ONLY

Name

DATE
MO DAY YEAR

ID

DAY
○ Sunday
○ Monday
○ Tuesday
○ Wednesday
○ Thursday
○ Friday
○ Saturday

	BRIEFLY DESCRIBE YOUR ACTIVITY	TIME	PLACE				IN/OUT		CAR/BUS	ACTIVITY LEVEL		
			HOME	NEAR HOME	SCHOOL	OTHER	INDOOR	OUT-DOOR	TRAVEL	QUIET	MEDIUM	ACTIVE
MORNING		6:00-6:29	○	○	○	○	○	○	○	○	○	○
		6:30-6:59	○	○	○	○	○	○	○	○	○	○
		7:00-7:29	○	○	○	○	○	○	○	○	○	○
		7:30-7:59	○	○	○	○	○	○	○	○	○	○
		8:00-8:29	○	○	○	○	○	○	○	○	○	○
		8:30-8:59	○	○	○	○	○	○	○	○	○	○
		9:00-9:29	○	○	○	○	○	○	○	○	○	○
		9:30-9:59	○	○	○	○	○	○	○	○	○	○
		10:00-10:29	○	○	○	○	○	○	○	○	○	○
		10:30-10:59	○	○	○	○	○	○	○	○	○	○
		11:00-11:29	○	○	○	○	○	○	○	○	○	○
		11:30-11:59	○	○	○	○	○	○	○	○	○	○
AFTERNOON		12:00-12:29	○	○	○	○	○	○	○	○	○	○
		12:30-12:59	○	○	○	○	○	○	○	○	○	○
		1:00-1:29	○	○	○	○	○	○	○	○	○	○
		1:30-1:59	○	○	○	○	○	○	○	○	○	○
		2:00-2:29	○	○	○	○	○	○	○	○	○	○
		2:30-2:59	○	○	○	○	○	○	○	○	○	○
		3:00-3:29	○	○	○	○	○	○	○	○	○	○
		3:30-3:59	○	○	○	○	○	○	○	○	○	○
		4:00-4:29	○	○	○	○	○	○	○	○	○	○
		4:30-4:59	○	○	○	○	○	○	○	○	○	○

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	BRIEFLY DESCRIBE YOUR ACTIVITY	TIME	PLACE				IN/OUT		CAR/BUS	ACTIVITY LEVEL		
			HOME	NEAR HOME	SCHOOL	OTHER	INDOOR	OUT-DOOR	TRAVEL	QUIET	MEDIUM	ACTIVE
EVENING		5:00-5:29	○	○	○	○	○	○	○	○	○	○
		5:30-5:59	○	○	○	○	○	○	○	○	○	○
		6:00-6:29	○	○	○	○	○	○	○	○	○	○
		6:30-6:59	○	○	○	○	○	○	○	○	○	○
		7:00-7:29	○	○	○	○	○	○	○	○	○	○
		7:30-7:59	○	○	○	○	○	○	○	○	○	○
		8:00-8:29	○	○	○	○	○	○	○	○	○	○
		8:30-8:59	○	○	○	○	○	○	○	○	○	○
		9:00-9:29	○	○	○	○	○	○	○	○	○	○
		9:30-9:59	○	○	○	○	○	○	○	○	○	○
		10:00-10:29	○	○	○	○	○	○	○	○	○	○
		10:30-10:59	○	○	○	○	○	○	○	○	○	○
		11:00-11:29	○	○	○	○	○	○	○	○	○	○
		11:30-11:59	○	○	○	○	○	○	○	○	○	○
		12:00-12:29	○	○	○	○	○	○	○	○	○	○
		12:30-12:59	○	○	○	○	○	○	○	○	○	○
		1:00-1:59	○	○	○	○	○	○	○	○	○	○
		2:00-2:59	○	○	○	○	○	○	○	○	○	○
		3:00-3:59	○	○	○	○	○	○	○	○	○	○
		4:00-4:59	○	○	○	○	○	○	○	○	○	○
		5:00-5:59	○	○	○	○	○	○	○	○	○	○

TOTAL AMOUNT OF TIME IN TRAVEL THIS DAY: ________

Fig. 1. Time/activity diary used in the Kanawha County Health Study.

—optically readable format,
—one page of the diary for each day (24 h),
—pre-assigned 1/2 h time increments,
—pre-categorized microenvironments, and
—a column for describing the actual activity.

The last feature was included to help the child remember the sequence of events; we did not code the individual activities. The microenvironments were selected in the context of studying exposure to industrial emissions, the distribution of which may vary by time of day, meteorological conditions, and distance from the source. For each one-half hour of the day, the participant indicated, by filling in the appropriate circle, their place (home, near home, school, other), whether they were indoors or outdoors, whether they traveled during that half hour, and the exertion level associated with the activity (quiet, medium, active). To discourage the underreporting of short trips, we separated travel from the indoor/outdoor question. We asked the children to fill in the travel circle if they spent any time in a car, bus, or truck during the given one-half hour increment. Walking and bicycling were considered "outdoors."

Protocol

Children were selected from schools located in the Belle and North/South Charleston areas, with preference for those living on the Valley floor. During the initial home visit, the interviewers instructed each child on how to complete an example diary covering the previous day's activities. The child was given primary responsibility for filling out the diary; the parent was asked to monitor the process. At the end of each data-collection period, the interviewer visited the home again, this time to go over the diaries with the children and their parents in order to clarify inconsistent or confusing responses. Finally, the diaries were edited for consistency and prepared for scanning. The protocol for this study is described in more detail elsewhere (Schwab et al. 1990b).

Variable definition and analysis

Information on children's activity patterns was derived from the child-day (i.e., the daily diary). For the purposes of this paper, we aggregated the diary data to formulate five distinct microenvironments: outside, inside at home, inside at school, inside other than at home or school, and travel. If both travel and another microenvironment were reported during a half-hour increment, the time was equally divided between the two. The microenvironments were not disaggregated by exertion level because of concerns about the reliability of these data (Schwab et al. 1991). In addition, preliminary analysis (t-tests) showed that there were no statistically significant differences in time use between July weekdays versus weekends but that there were significant differences between September weekdays and weekends. Thus, all analyses reported in this paper were stratified by school days versus nonschool days but not by the month of data collection. Finally, although we had hypothesized that time/activity patterns would vary with weather conditions, the analysis was not further stratified because there was little variability in temperature within either of the sampling periods and t-tests showed that aggregate time use did not vary with precipitation.

One purpose of this study was to determine differences (if any) in activity patterns among children categorized by gender and respiratory health status. To this end, we used the child rather than the diary as the unit of analysis. An intra-child average for time spent in each microenvironment was calculated using all diaries provided (i.e., if a child provided data for all days of the study, the average is based on 10 d of data for school days and on 18 d of data for nonschool days).

Variability in activities for a subject across time as well as the variability among subjects are important considerations for the design and conduct of future studies. If activity patterns are homogeneous across subjects with similar characteristics (i.e., preadolescent school children), then patterns could be established with fewer measurements. For the last set of analyses we normalized the data set to an equal number of days of data per participant. For school days, we restricted the data set to those with eight days of data (Mondays and Fridays are considered consecutive days). If the participant had less than eight diaries they were removed, if the participant had more than eight diaries, only eight were used in the analysis. For nonschool days the data set was restricted to those with 14 d of data.

RESULTS

Response

For the first two-week period of data collection (July), 91 children were recruited (24 boy responders, 24 boy non-responders, 19 girl responders, and 24 girl non-responders). For the second period of data collection (September), the sample size dropped to 79. During the July period, 1154 diaries were received; 84% of the participants returned 12 or more com-

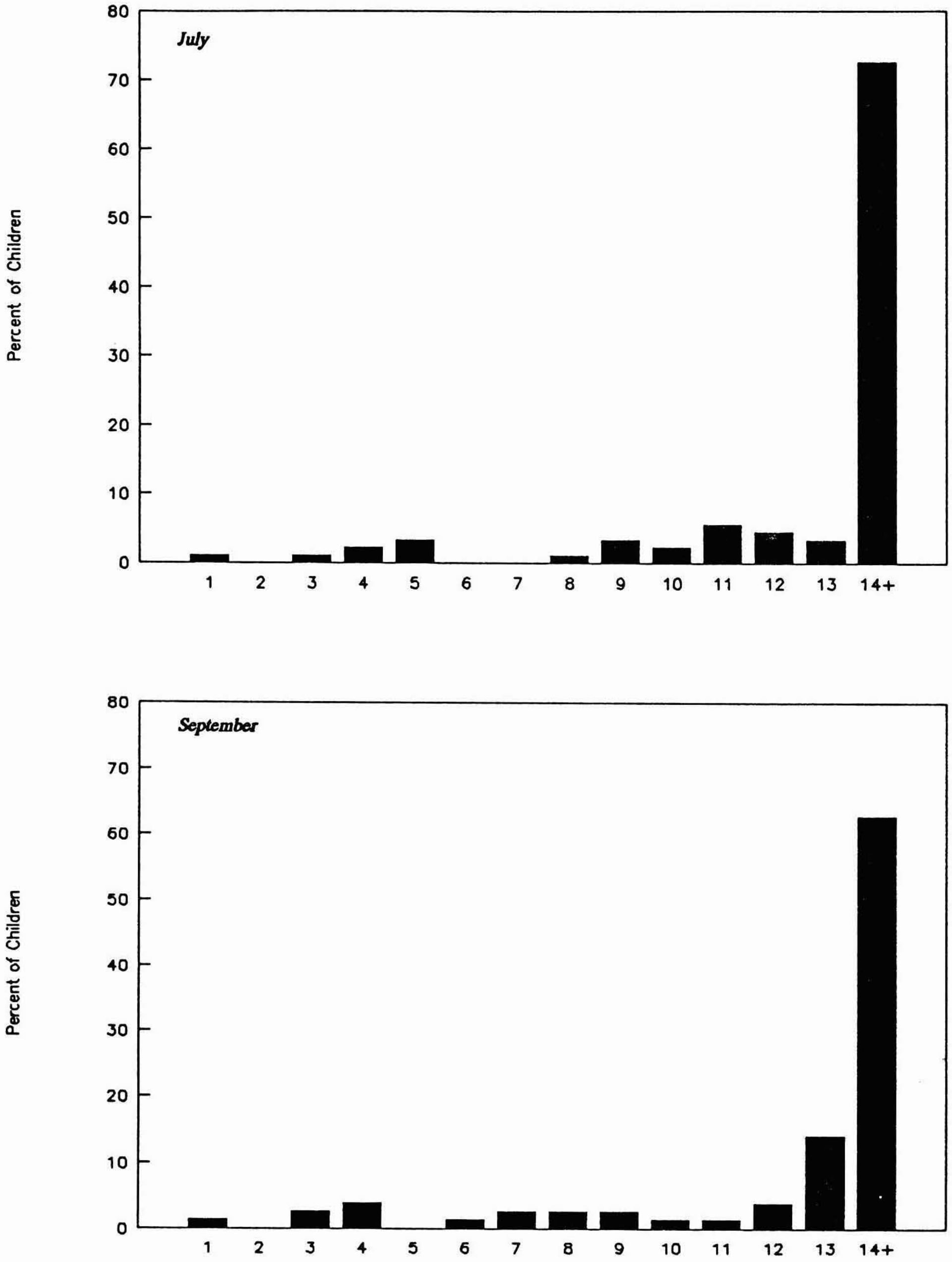

Fig. 2. Diary return rates by data collection period: percentage of sample returning various numbers of diaries.

pleted diaries. The remainder were away on vacation for part of the period or did not complete the study. In September, 962 diaries were received; 12 or more diaries were received from 73% of the children. Figure 2 shows the distribution of the number of diaries received over the course of the study.

As a quality assurance measure, we removed all diaries that were missing four or more hours from the analysis (6% of the diaries in July and 1% of the diaries in September). We also removed children who provided less than four daily diaries. The final sample included data for 78 children on school days, of which 50% were boys and 46% were designated as respiratory "responders" based upon their pre-assigned health status. The restrictions placed on the data set in the last set of analysis (i.e., 8 d of data for school days and 14 d for nonschool days) leave only 62 children on school days and 72 children on nonschool days.

Issues surrounding the validity of self-reported survey data have been raised in the context of health questionnaires (Brunekreef et al. 1990), dietary recalls (Liu et al. 1978), and time/activity diaries (Moschandreas 1990). In this study, a method of assessing compliance levels presented itself in the form of a natural experiment. During the September monitoring period, hurricane Hugo came through the Kanawha Valley. All of the schools in the Kanawha County system released students early on that day. It was disturbing to find that this alteration from the regular school-day routine was only noted on 53% of the diaries available for that day (20 children did not provide a diary). Because we were able to correct most of these inconsistencies (as well as other oversights) during our review of the diaries with the children and their parents, we do not have any reasons to suspect that these data are any less valid than those collected during other time/activity studies. But these results highlight the need for vigilant surveillance and strict quality assurance, as well as improved data collection methods.

In a longitudinal study, there is also the concern that subjects provide less detailed diaries toward the end of the study period. We tested the hypothesis that the number of changes in microenvironments per day, suggestive of more attention to detail, decreases over time. Using only diaries without missing data, the sample distributions of the number of changes in microenvironments reported on a diary did not vary between Day 3 (i.e., the third day a child filled in the diary), Day 7, and Day 12, once school versus nonschool days were separated. The average number of changes in microenvironment per day was higher on

Table 1. Daily average (standard deviation) hours spent in each microenvironment across all diaries.

Microenvironment	School Days (683 Diaries 79 Children)	Nonschool Days (1428 Diaries 98 Children)
Outside	2.30 (1.78)	3.96 (3.27)
Inside		
Home	13.98 (2.64)	15.61 (5.41)
School	5.83 (1.01)	-------
Other	1.24 (2.22)	3.61 (4.57)
Travel	0.65 (0.53)	0.81[a] (1.13)

[a] Without the 14 diaries with more than 5.0 h of travel time, the average is 0.73 and the standard deviation is 0.77.

school days (8.3 with a standard deviation of 2.8 across all diaries) than on nonschool days (6.7 with a standard deviation of 3.5 across all diaries), perhaps reflecting the additional microenvironment changes associated with going to and coming from school and the longer periods available for play and other leisure activities on nonschool days. The results seem to indicate that these subjects were completing diaries with the same level of detail across the first 12 d of participation.

Time-use distributions: total sample

In this section we provide baseline information on the temporal and spatial extent of children's activities. Table 1 gives the descriptive statistics for the time spent in each microenvironment across all child-days (i.e., diaries) of data. On both school days and nonschool days, children spent most of their time (on average, 20 h) indoors. Time spent outside averages 1.6 h more on nonschool days than it does on school days and time inside other than home or school averages 2.3 h greater on nonschool days than on school days. Travel time is only slightly lower on school days (mean = 0.65 h) than on nonschool days (mean = 0.81 h). However, without the 14 cases for which travel time exceeded 5 h, the nonschool travel time average is down to 0.74 h with a standard deviation of 0.80 h.

The standard deviations reported in Table 1 reveal substantial variability in the time spent traveling and outdoors. This may reflect the fact that no time was reported outside on 12% of the school-day diaries and on 13% of the nonschool-day diaries. Travel was not reported on 20% of the school days and 30% of the nonschool days.

To understand population exposures to indoor and outdoor pollutants, especially those pollutants with diurnal variation, it is important to document the temporal patterns of activities. For instance, we might want to know if children's outdoor activities tend to occur during the same period of the day that irritant concentrations are at their peak. Figures 3 and 4 are plots of the percentages of child-days (i.e., diaries) associated with time in each microenvironment, in 30 min increments, between 7 am and 11 pm. The school day plot is indicative of the day's structure; there is a sharp rise in travel and outside time in the early morning, and by 8:00 am 80% of the diaries show inside at school. At noon there is an increase in the percentage of diaries showing outdoor activity, followed by a return to the indoor/school environment until 1:30 pm. The percentage of the diaries showing time outdoors then rises steadily to a peak of 35 at 6 pm. Reports of travel increase modestly (i.e., to 15%) during the hour after school ends, and then remain at a very low level (i.e. less than 10%) for the remainder of the day. By late evening most of the diaries show children inside at home.

The plot for nonschool days shows a different pattern. The percentage of the diaries associated with time indoors at home gradually declines from near 90% (some children slept away from home) in the early morning to a low of 35% at 1 pm. There is an increase in reports of being home between 6 and 7 pm (dinner time). Time outdoors displays a trend in the opposite direction, gradually rising to a peak of 40% of the diaries at noon and then slowly declines after 6 pm. These indoor/outdoor trends are similar to the findings reported for the exertion-level data; much of the time indoors at home was coded as quiet whereas most time outdoors was coded as active (Schwab et al. 1991).

These plots reveal a consistency in time use across child-days that is masked in the measurement of the total amount of time in each microenvironment. We can accurately place most children on school days between midnight and 1:30 pm, but not between 1:30 pm and midnight or on nonschool days. However, these plots do not allow us to gauge the extent to which the observed population patterns are a function of equally high variability across children or differences between children. For instance, is there a subset of children who are always outside from 1:30 pm to 10 pm, or are all children spending only an hour outdoors during this period?

Child-to-child variability

In this section, we characterize the between-participant variability in activity patterns. Table 2 shows the 10th, 50th, and 90th percentiles for the sample distribution of the intra-child averages in time spent in each microenvironment. There is a wide distribution of time use across the children, suggesting that individual children exhibit very different patterns. These differences are primarily manifest in time spent outdoors (10% average less than 1 h/d whereas 10% of the sample average more than 4 h/d) and traveling (10% average less than 5 min whereas only 10% average over 1 h/d). Differences among children are further highlighted by an examination of the distribution of diary days without reports of time in the travel and outdoor microenvironments. After normalizing the number of observations available per child to eight on school days and fourteen on nonschool days (see Methods Section), we found that such nonreports are confined to a small number of children.

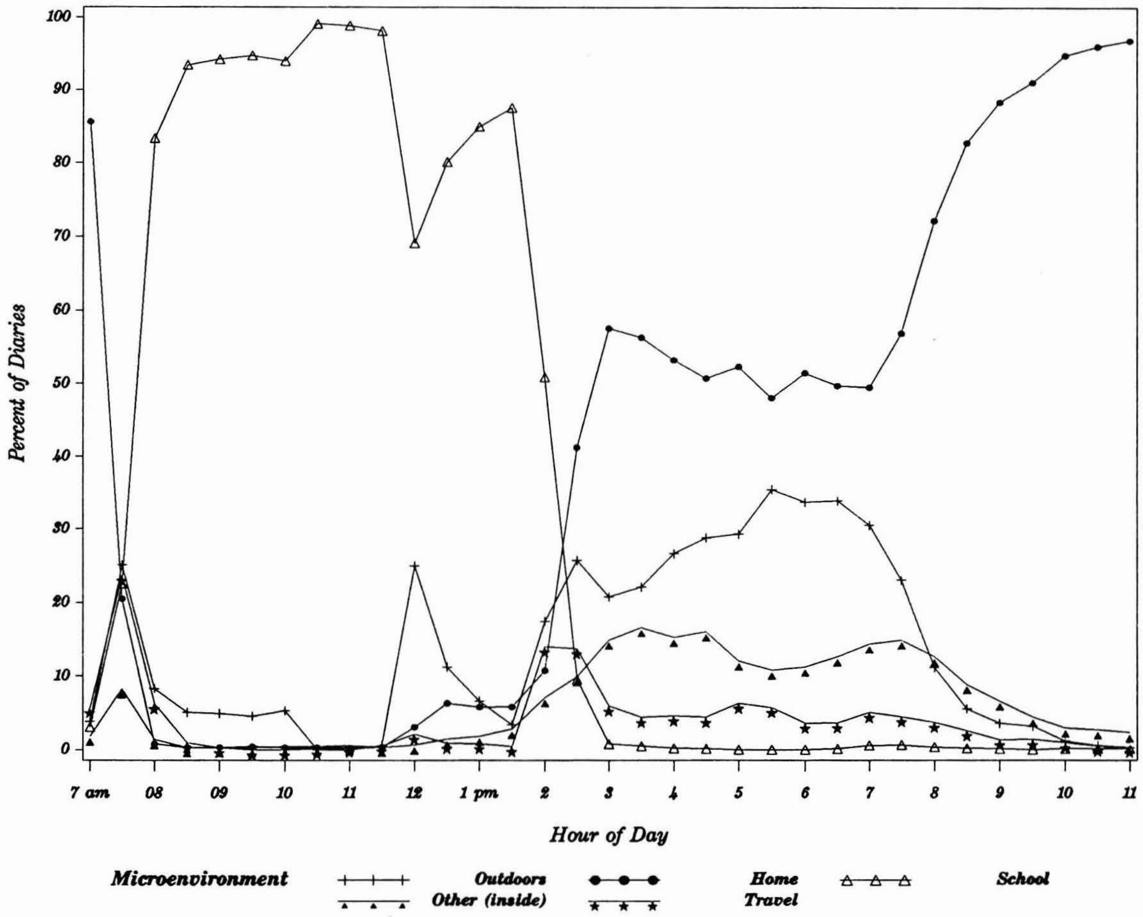

Fig. 3. Distribution of time per microenvironment on school days (i.e., percentage of diaries reporting time in each microenvironment during a given 1/2 h, 7 am to 11 pm).

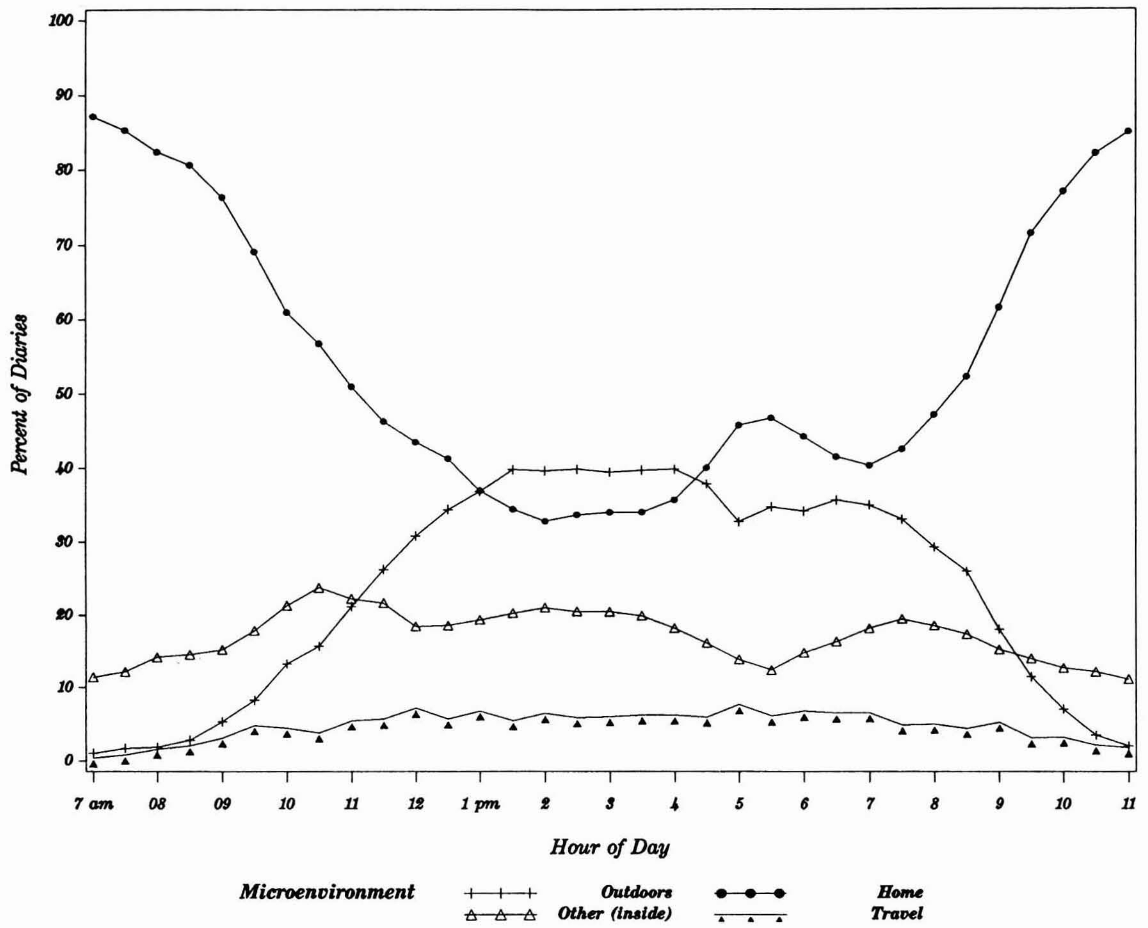

Fig. 4. Distribution of time per microenvironment on nonschool days (i.e., percentage of diaries reporting time in each microenvironment during a given 1/2 h, 7 pm to 11pm).

Table 2. Distribution of intra-child averages for daily hours in each microenvironment.

Microenvironment	Percentile[a]		
	10th	50th	90th
School Days			
Outdoors	0.68	2.25	4.19
Indoors			
Home	11.8	14.07	15.78
School	5.08	5.94	6.65
Other	0.0	0.88	2.8
Travel	0.0	0.63	1.1
Nonschool Days			
Outdoors	1.56	3.74	6.23
Indoors			
Home	11.65	16.0	19.15
Other	1.11	3.01	7.51
Travel	0.30	0.76	1.33

[a] For example, 10% of the children reported an average of 0.68 h or less outdoors on school days, whereas 10% of the children reported an average of over 4 h outdoors on school days.

On school days, only 25% of the children reported one or more days without time outside and 25% reported two or more days without travel. For nonschool days, 50% of the children reported four or more days without travel and 25% reported 6 to 12 days (out of a possible 14 d) without travel; 50% of the children did not report time outdoors on one or more days and 25% did not report time outside on between three and eight days.

Another method of characterizing the extent of between-participant variability is to examine the ratio of the intra-child mean to the sample mean for time in each microenvironment. Table 3 shows the standard deviations and the 90th percentiles for the sample distributions of ratios. The mean is one, thus the coefficients of variation (std. dev./mean * 100) for most microenvironments are between 20% and 80%. The between-child variability is most extensive for time in travel and outdoors, where 10% of the children exhibit average time-use patterns that differ from the sample average by a factor of two.

In order to investigate whether the variability in activity patterns across children is a function of differences in gender and respiratory health status, t-tests were performed on the child-averaged time spent in each microenvironment. The results (Table 4) show that the only statistically significant difference in time use based on respiratory health status is that respiratory "responders" reported an average of one hour more outdoors than did "nonresponders" on nonschool days. The only statistically significant differences between boys and girls are that boys reported one hour more outdoors than did girls during both school days and nonschool days.

Table 3. Sample distribution of the ratio of the intra-child average to the sample average for daily hours per microenvironment.

Microenvironment	Std Dev (90th %)
School Days (N=62)	
Outside	0.58 (1.86)
Inside	
Home	0.10 (1.12)
School	0.10 (1.13)
Other	0.80 (2.29)
Travel	0.57 (1.69)
Nonschool Days (N=72)	
Outside	0.45 (1.56)
Inside	
Home	0.21 (1.21)
Other	0.80 (2.21)
Travel	0.55 (1.66)

Temporal stability

Whereas the preceding discussion focused on the between-child component of variation in time use exhibited by this data set, in the current section the stability of activity patterns over time by focusing on within-child, day-to-day variability is explored. Table 5 shows the descriptive statistics for the distribution of standard deviations associated with the intra-child average time in each microenvironment. On average, a child's mean time at home varies across days by 2 h on school days and 4 h on nonschool days. A child's mean for time outdoors and in travel varies by an average of 1.2 h and 0.3 h on school days, respectively, and double these amounts on nonschool days. Table 5 also shows that the amount of day-to-day variability in time use differs considerably across the sample. Analysis of variance, a common method of examining the extent of the within-participant variation in measurements relative to the between-participant variation (Liu et al. 1978; Brunekreef et al. 1987), could not be used on this data set because of severe deviations from normality in the within-child distributions of time spent in the narrowly defined microenvironments such as travel and outdoors (e.g., the participant did or did not travel for the usual amount of time).

In the context of exposure assessment, it may be less important to predict accurately the absolute amount of time spent in a given microenvironment than to predict whether an individual is in the high or low tail of the exposure distribution. We used crosstabulations to gauge the increase in our ability to predict the sample distribution of "true" averages by adding successively more days of data. In this analysis, a person's true long-term average activity pattern is assumed to be equivalent to that presented by 8 d of school data and 14 d of nonschool data. We calculated the intra-child average time spent in each microenvironment, based on two days of data, three days of data, etc., and then divided each distribution into quartiles, signifying high to low time use.

We assessed the misclassification of time use by crosstabulating quartiles based on the true mean with those based on fewer days of data. Results are

Table 4. Comparison of time use by personal characteristics: t-test results.

Microenvironment	Personal Characteristic	
	Gender	Health Status[a]
School Days	N=78	N=78
Outside	1.99[b] (0.050)[c]	1.12 (0.266)
Inside		
Home	0.75 (0.454)	-0.25 (0.805)
Other	-1.84 (0.069)	-0.5 (0.617)
Travel	-0.79 (0.433)	0.29 (0.775)
Nonschool Days	N=97	N=97
Outside	3.19 (0.002)	2.93 (0.004)
Inside		
Home	-0.08 (0.937)	-1.35 (0.180)
Other	-1.96 (0.053)	-0.46 (0.650)
Travel	-1.14 (0.256)	0.41 (0.681)

[a] asthma or persistent wheeze
[b] t-statistic, assuming unequal variances
[c] probability associated with t-statistic

presented for travel and outdoor microenvironments, where time-use patterns and pollutant exposures are most variable. Less than 5% of the sample was misclassified from high to low or from low to high, regardless of the number of days of data available. Figures 5 and 6 depict the misclassification from both the lowest and highest quartiles to the two medium quartiles for travel and outdoor microenvironments. Figure 5 shows that, for school days, 30% of the children classified as high (i.e., greater than 3.1 h) or low (i.e., less than 1.3 h) for time outside based on eight days of data are classified in the medium quartiles based on one day of data. The misclassification from the high and low quartiles to medium drops to 10% by using four days of data and then to 5% by Day 5. For travel, 30% of the children classified as high (i.e., greater than 1.0 h) or low (i.e., less than 0.3 h) based on eight days are classified as medium based on one day of data. The proportion of misclassification drops to 10% using four days and remains at that level until there are seven days of data.

Table 5. Distribution of intra-child variability for time in each microcroenvironment[a,b]

Microenvironment	School Days (76 Children)	Nonschool Days (98 Children)
Outside	1.21 (0.49)	2.59 (1.01)
Inside		
Home	1.97 (1.23)	4.16 (1.72)
School	0.72 (0.47)	N/A
Other	1.37 (1.38)	3.51 (1.80)
Travel	0.32 (0.21)	0.82 (0.63)

[a] Values in table are the mean and standard deviations for the distribution of intra-child standard deviations of time spent in each microenvironment.

[b] See Table 2 for distribution of intra-child averages.

For nonschool days, Fig. 6 depicts that 45% of the children classified as high (i.e., greater than 5.5 h) or low (i.e., less than 2.9 h) for time outside based on 14 days of data are classified as medium for time outside based on one day of data. The misclassification drops to 15% by using seven days of data and then to 10% by Day 13. For travel, 65% of the children classified as high (i.e., greater than 1.2 h) or low (i.e., less than 0.5 h) based on eight days are classified as medium based on the first day of data. The proportion of misclassification drops to 25% using nine days and remains at that level until there are eleven days of data. The larger proportion of misclassified days during the nonschool period is probably a function of both the larger number of days and the higher variability in activity patterns (i.e., the lack of a structured day).

DISCUSSION

Time/activity data can be used to predict exposure by providing an understanding of the location of the population with respect to pollution sources and concentrations. The data collected during the KCHS provide information from which to characterize the spatial and temporal aspects of children's time/activity patterns. The distributions of time spent in each microenvironment reported here compare well with the children's data for two other cities in the U.S. (Adair and Spengler 1989): total indoor time in Portage, WI and Steubenville, OH averaged 22 h, home time averaged 14 h, travel time averaged 0.7 h, and outside time averaged 1 h in the winter and 4 h in the summer. Our findings show differences between children and adults with respect to time spent in key exposure microenvironments. Specifically, children reported an average of twice as much time outdoors as has been recorded by adults monitored in several previous time/activity studies but only half as much time in travel (Schwab et al. 1990a). The reported time/activity patterns also show strong seasonal and diurnal components, implying that the greatest contribution of the outdoor environment to children's total exposure will be on nonschool days during the afternoon.

The data in this paper show substantial between-child differences in activity patterns. For instance, 10% of the children recorded twice as much time

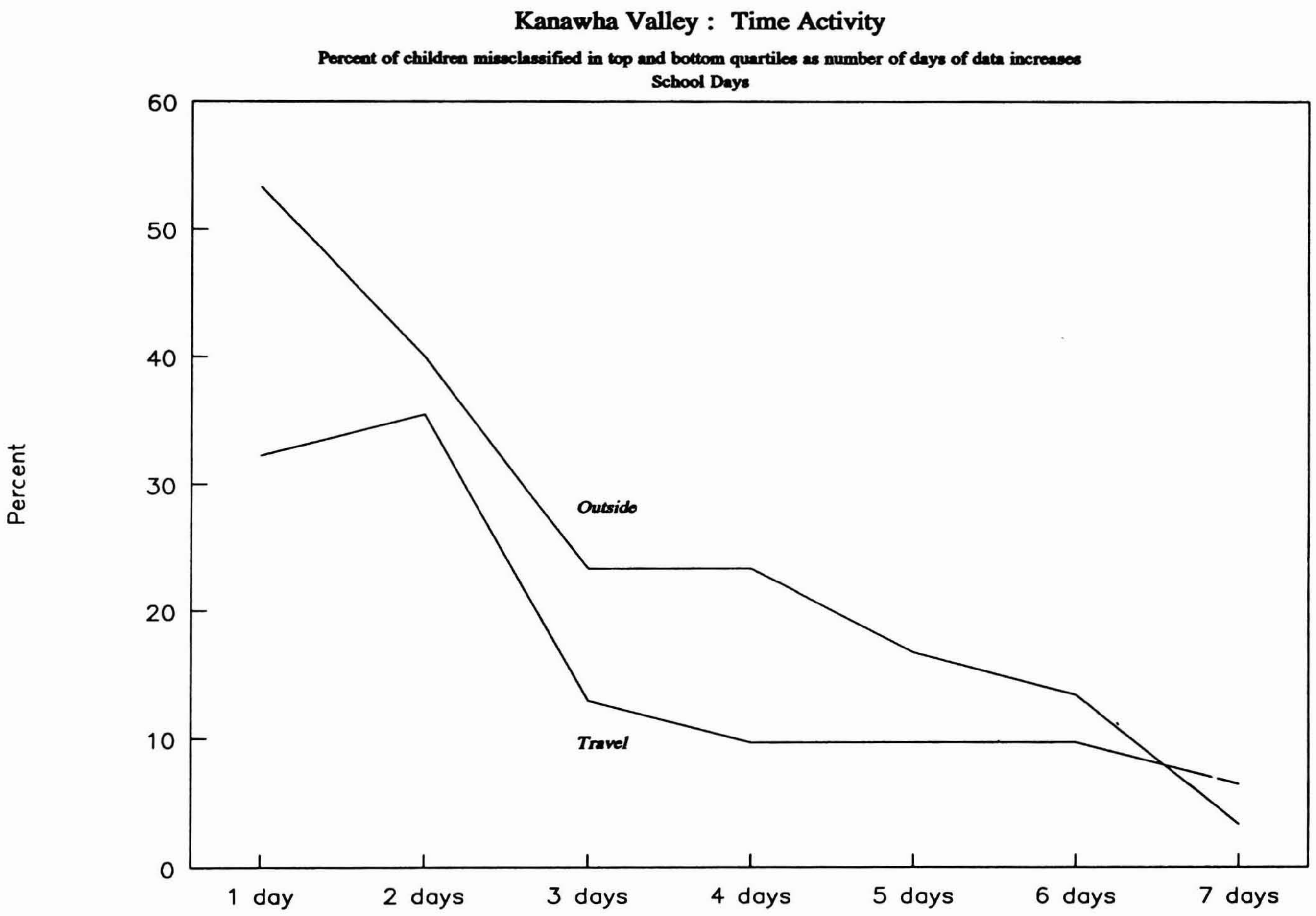

Fig. 5. Percentage of children in the highest and lowest quartiles misclassified to medium as the number of days of data used to calculate the quartile increases (school days).

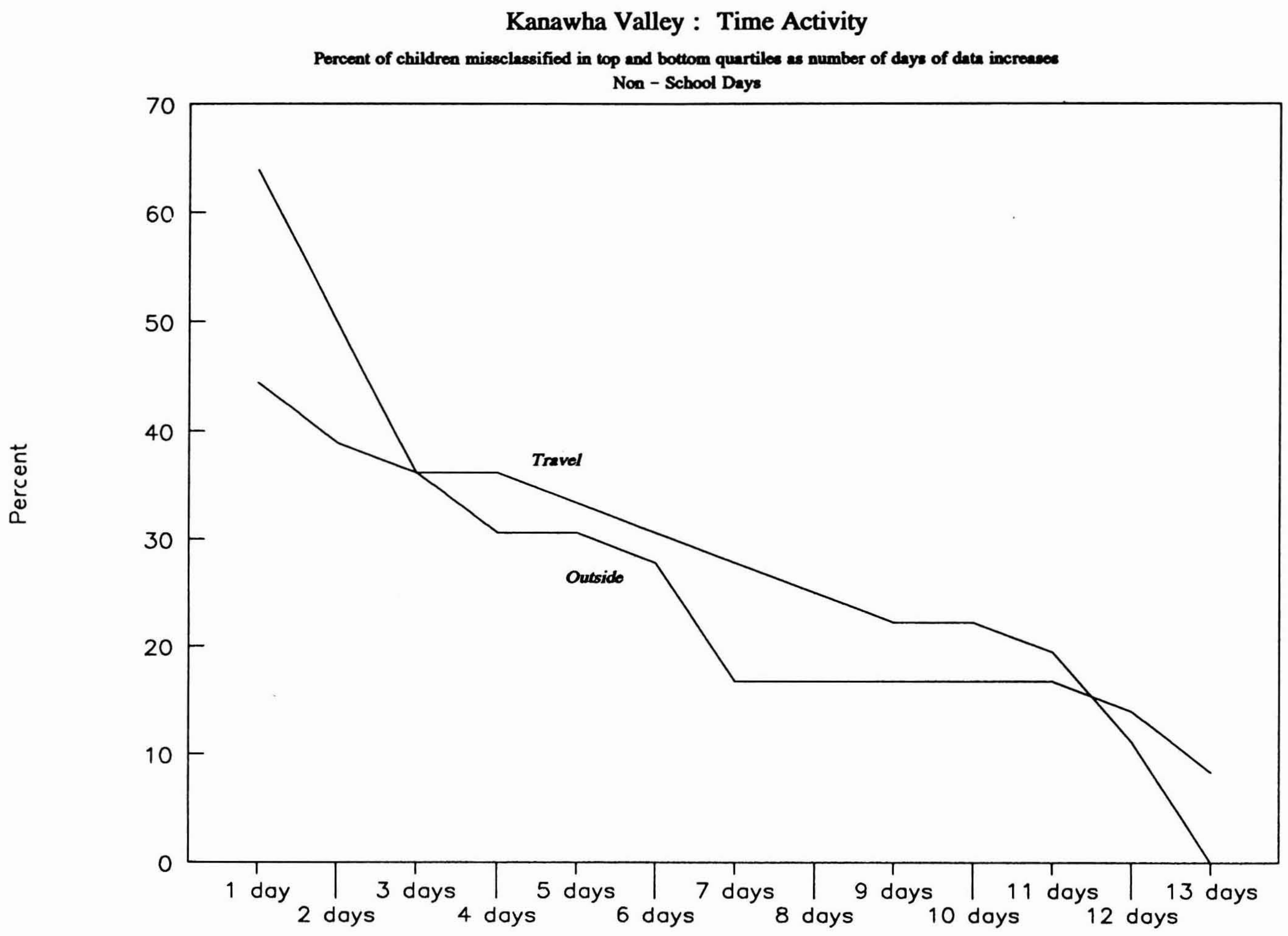

Fig 6. Percentage of children in the highest and lowest quartiles misclassified to medium as the number of days of data used to calculate the quartile increases (nonschool days).

traveling as the sample average; a similar distribution was found for time outdoors. We did not find systematic differences in activity patterns based upon reported respiratory health status. The finding that boys average one hour more outdoors than do girls is similar to the differences in activity patterns by gender reported previously for both children and adults (Adair and Spengler 1989; Schwab 1989; Schwab et al. 1990a). These results highlight the importance of including data for a broad distribution of individuals; a single activity pattern type (i.e., daily routine) will not necessarily be representative of an entire demographic group.

It was also shown that most children exhibit considerable day-to-day variation in time spent traveling and outdoors. This finding is similar to that found in a recent analysis of a two-day data set of adults' time/activity patterns in Los Angeles; the day-to-day difference in the amount of time spent in potentially high exposure microenvironments (e.g., cooking and near major roads/traveling) differed considerably with respect to the average time in these microenvironments (Schwab et al. 1990a). It could be argued that if all children exhibit the same extent (i.e., amount) and type (i.e., changes in microenvironmental time use) of day-to-day variability, collecting one day of data for a moderate sample of children may be sufficient for characterizing the general activity patterns of a group. Our analysis, however, suggests that this may not be possible because whereas some children exhibit very little variability across days, others are more erratic.

The current analysis shows that the degree of within-child variability also differs across microenvironments and seasons. More days of data will be needed for predicting exposure to ambient pollutants than for those whose source is primarily indoors, because there is more variability in time spent in travel and outdoor microenvironments. The strong temporal structure of the day during the school term can be an added tool for predicting time/activity patterns as it means data collection can focus on a more limited period of time. Finally, the analysis shows that if exposure estimates can be formulated on the basis of categorical measures of time use, misclassification of individuals can be reduced to 20% using only a few days of data, even for high variability travel and outdoor microenvironments.

Finally, the results of this analysis must be interpreted within the context of the concerns about reporting behavior. The analysis assumes that children accurately recorded their activities and that activities with a smaller resolution than the diary format are not relevant. For instance, there is the possibility that the reduction in variance with time may be a function of reporting bias; if the children lost interest in keeping the diary, they may have recorded a similar, generalized activity pattern for each day. Thus, the convergence of the mean time use after a few days may also be an indication of the optimal diary data collection period.

CONCLUSION

Exposure assessment is a new field; our understanding of the optimal type of time/activity data and how to apply it is still evolving. The innovative features of the sample, diary, and protocol design in the Kanawha County Health Study yielded the first longitudinal data set on children's activities. In addition, the sample stratification allowed comparisons based upon respiratory health status, gender, and season (school versus nonschool days). Our analysis represents an attempt to describe the nature and extent of between-person and within-person variation in microenvironmental time use that should be expected from time/activity diary data. Conclusions cannot be made about the optimal number of days of diary data, however, because this data set represents a limited population subgroup, at a specific time and place. Rather, the findings of this paper should be viewed in the context of providing insight for refining exposure assessment methods and providing new information on the activity patterns of a sensitive subpopulation.

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A STUDY OF SPATIAL DISTRIBUTION OF AIR POLLUTANTS IN SOME COAL MINING AREAS OF RANIGANJ COALFIELD, INDIA

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Ambient air quality monitoring for suspended particulate matter, sulphur dioxide, and nitrogen oxides was carried out over a period of one year to study diurnal and seasonal variations and spatial distribution of said pollutants. Dustfall rate measurements were carried out for a period of one month out of each season and for all the four seasons of the year. Studies were also carried out at selected work places to determine levels of the above-mentioned pollutants. Studies indicate that mining and associated activities have raised the background levels of particulate pollution in the region. The coal handling plant and poorly maintained roads, resulting in transport of coal dust by means of wind, are identified as the sources of particulate pollution in a coal mining area. Coal burning and transportation activities appear to be major sources of SO_2 and NO_x in coal mining areas.

INTRODUCTION

Coal mining operations inevitably lead to the release of particulate and gaseous pollutants into the atmosphere. Over the past few years, with the introduction of mechanized mining techniques and heavy earth moving equipment, this problem has been further aggravated. In underground mines, blasting and loading operations generate considerable amounts of dust particles and sulphur dioxide which, through ventilation systems, are ultimately released into the atmosphere. In opencast situations, mining operations involving use of heavy machinery for extracting and transporting coal release substantial quantities of both particulate and gaseous pollutants directly into the atmosphere. Continued exposure to high concentrations of these pollutants poses a health hazard not only to the workers in the site, but also to the local residents living in the mining areas.

Mining activities have resulted in serious air pollution problems in some Indian coal mining areas. Studies conducted in the Jharia Coalfields (India) highlighted the pollution caused by mining activities (Ghosh et al. 1982; Bose et al. 1982). Banerjee and Hussain (1989) also carried out a short study on the level of air pollution in some fire areas of Jharia Coalfield. They observed that SPM concentrations were much above the permissible limits of 500 $\mu g/m^3$ of the National Ambient Air Quality Standards for Industrial and Mixed Use Areas; and dustfall rates were quite high as compared to that of the National Environmental Engineering Research Institute (NEERI) standards of 10 Mg/km^2/month. Studies conducted in the Raniganj West and Mugma areas of the Baraker-Ajoy river belt indicated deterioration of air quality due to mining and other industrial activities (Bose et al. 1986). Ghosh (1983) observed that minimum seasonal mean SPM levels around the Jharia Coalfields occur in the monsoon season. Particulate pollution studies on mine atmosphere of two mines, Godhar and Khas Kusunda, of the Jharia Coalfield have shown that the concentration of airborne dust is highest in the winter season and lowest during monsoon season (Sahoo 1981). Most of the studies on air pollution in coal mining areas have been carried out in the Jharia Coalfield, but so far no systematic study has been reported on the Raniganj Coalfield.

Since the adverse effects of pollutants are directly related to the quantities in which they are present in the atmosphere, monitoring their levels in the atmosphere would not only help in understanding the extent of air pollution in the region, but also to decide strategies for its control and abatement. The present investigation was undertaken with the objective of determining the ambient air quality with respect to suspended particulate matter (SPM), SO_2, and NO_x in certain coal mining areas of the Raniganj Coalfield. Studies were carried out for a period of one year to determine diurnal and seasonal variations, spatial distribution, and possible sources of these pollutants. Meteorological parameters such as temperature, relative humidity, wind speed, and direction were monitored simultaneously during the sampling period. Dustfall measurements were carried out at six sites to monitor general dust deposition in the area. Studies on air quality were also conducted at various work places outside the mines to determine the levels of pollutant concentration to which workers are exposed while carrying out their routine duties.

LOCATION OF MONITORING STATIONS

A part of Raniganj Coalfield lying between 23° 37'12" N - 23° 41' 50" N and 87° 8'4" E - 87° 20' E was selected for the study. The area has four underground mines, one opencast project, and a planned underground mine. A map of the study area is given in Fig 1. A network of fourteen air monitoring stations, adequately covering the area of interest, was set up to maintain the security of the sampling equipment and provide easy access to the sampling stations apart from other siting criteria as per the Indian Standards Institutions (ISI) guidelines (ISI 1985). Stations A-1 to A-10 were set up around underground mines while stations A-11 to A-14 were set up around an opencast mine. Of these stations A-2, A-4, A-6, A-8, A-10, and A-14 were set up in residential areas located near mines while station A-5 was located in an area where development of an underground mine was in progress. The rest of the stations were set up around coal production sites. All the stations were set up in suburban areas, and sampling height was between 3 - 12 m. The locations of these stations are shown in Fig. 1. Dustfall rate measurements were carried out at six sampling locations. Dustfall samples were collected 3 m above the ground level. Nine stations were set up for sampling of air pollutants at work places. All of these stations were set up near pits and/or exhaust fans in the case of underground mines. These stations were set up 1.5 m above the ground level to sample the pollutants which may be inhaled by the workers while working in those locations. A central meteorological station was set up at the Haripur residential colony for the measurement of micro-meteorological parameters.

EXPERIMENTAL METHODOLOGY

Ambient air monitoring

Ambient air samples were collected for four seasons: monsoon, winter, spring, and summer during the period August 1988 to June 1989. Different seasons were

Table 1. Seasonal sampling duration.

Season	Period of the year
Monsoon	20 August 1988 to 30 September 1988
Winter	25 November 1988 to 6 January 1989
Spring	1 March 1989 to 31 April 1989
Summer	1 June 1989 to 31 June 1989

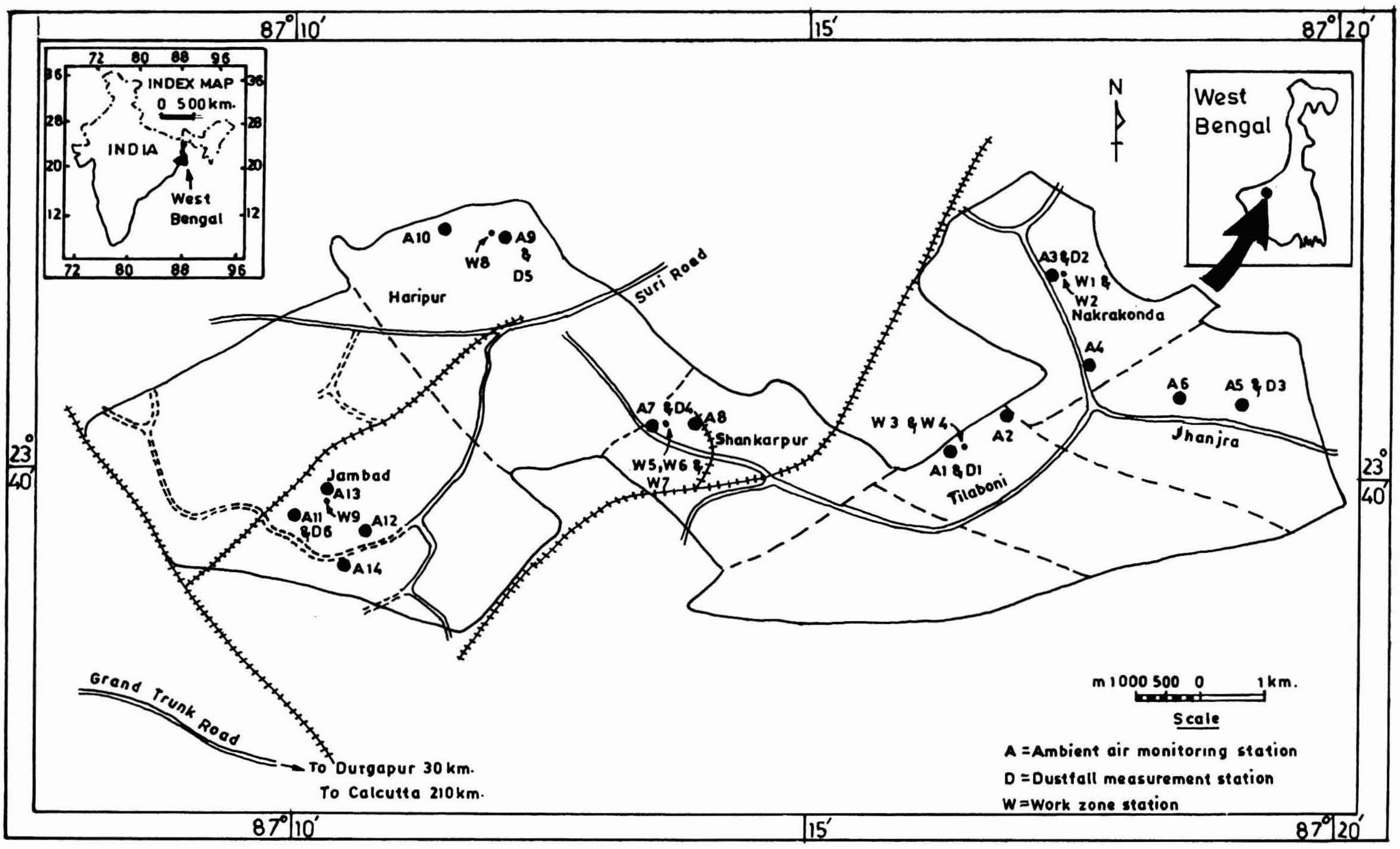

Fig. 1. Map of Raniganj Coalfield showing study area and air sampling stations.

divided among different months of the year as detailed in Table 1. Samples were collected for four weeks of each season and twice in each week. Two samples were collected for each sampling day, one during the day (6 am to 6 pm) and one during the night (6 pm to 6 am). Thus, four samples were collected for each week, and a total of 64 samples were collected for each of the sampling stations. The methods, as given in the ISI Standards for sampling of SPM and gaseous pollutants (SO_2 and NO_x) (ISI 1973; ISI 1975), were followed. High Volume Air Samplers (HVAS) were used for drawing air samples. Details on sample collection and analysis are summarized below:

Suspended particulate matter. High volume samplers were operated at an average flow rate of 1.0-1.5 m^3/min for collection of SPM. Pre-weighed glass fiber filters (GF/A of Whatman) were used and the SPM was computed according to the ISI-recommended method (ISI 1973).

Sulphur dioxide. The SO_2 in the ambient air was absorbed in 30 mL of sodium tetra-chloromercurate at an average flow rate of 0.2-0.5 L/min and was further analyzed according to the ISI recommended-method (ISI 1969).

Nitrogen oxides. The standard method given by ISI (ISI 1975) was followed for the sampling and analysis of NO_x. So, NO_x was absorbed in 30 mL of sodium hydroxide at an average flow rate of 0.2-0.5 L/min.

Dustfall measurement

Dustfall samples were collected for the period of one month, for each of the four seasons. Deposit gauges of British Standards were used for dustfall collection which consisted of a collecting bottle of 10 L capacity, collecting funnel (36.5 cm diameter), bird screening net, and a metal stand.

Work zone air quality analysis

Similar techniques were followed for sampling and analysis of work zone air samples as already described for ambient air monitoring. However, HVAS were operated for 8 h in actual daytime working conditions.

Meteorological data

A Stevenson's screen with thermometers for the measurement of maximum and minimum temperature, wet bulb and dry bulb temperature was kept at the central meteorological station. Wind data were recorded with the Lynx wind speed and direction system.

RESULTS AND DISCUSSION

The SPM, SO_2 and NO_x levels observed in each season are illustrated in Fig. 2. Diurnal variation of these pollutants is presented in Fig. 3.

Suspended particulate matter

Diurnal variation of suspended particulate matter. SPM levels were generally found to be higher during the day although the difference in concentration levels between day and night periods was not large. Levels at both day and night periods were found to be comparable at stations A-1, A-2, A-4, A-5, A-6, and A-8. Day duration levels were higher by less than 50 µg/m^3 at all other locations (A-3, A-7, A-9, A-10, and A-12) which were set up around underground mines. Higher day levels at these locations could be due to more vehicular activity, which normally takes place during the day. Day time levels were higher by more than 50 µg/m^3 at those locations which were set up around an opencast quarry. Higher day time levels at these locations appear to be linked to production activities.

Spatial distribution of suspended particulate matter. The spatial pattern of SPM levels for different seasons are presented in Fig 4. Isopleth diagrams for SPM indicate that minimum SPM levels in monsoon and summer seasons were 100 µg/m^3 and 150 µg/m^3, respectively, while they were 200 µg/m^3 in winter and spring. These levels were observed near station A-5 and closely represent background levels of the region under investigation. Contribution to SPM levels above the background levels was found to be largest during the summer season when the surface of the soil is continually dry and when there is much more windblown dust. The highest levels occurred in those areas where mining and other related activities take place. A general tendency for the levels to decline gradually towards the outer, non-mining areas, clearly points towards mining operations as the primary source of SPM in the region.

Sulphur dioxide

Diurnal variation of sulphur dioxide. Annual mean SO_2 levels remained similar during day and night periods throughout the year except for station A-7 where annual mean day levels were observed to be higher by 5.5 µg/m^3. Open coal burning for soft coal preparation and for domestic heating is a major source of SO_2 in that area, taking place both day and night. Higher day levels at station A-7 suggest that, in addition to coal burning, there could be another source of SO_2 near the station which is more active during

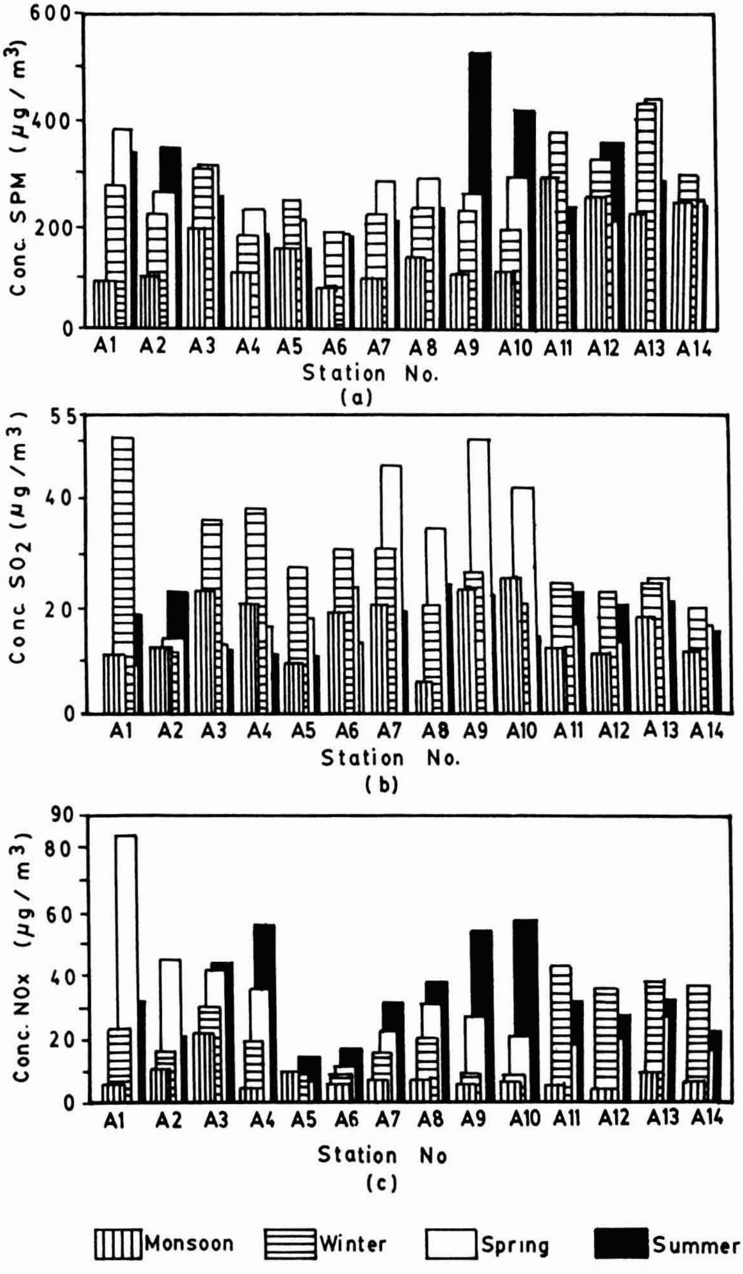

Fig. 2. Mean concentration of pollutants in different seasons.

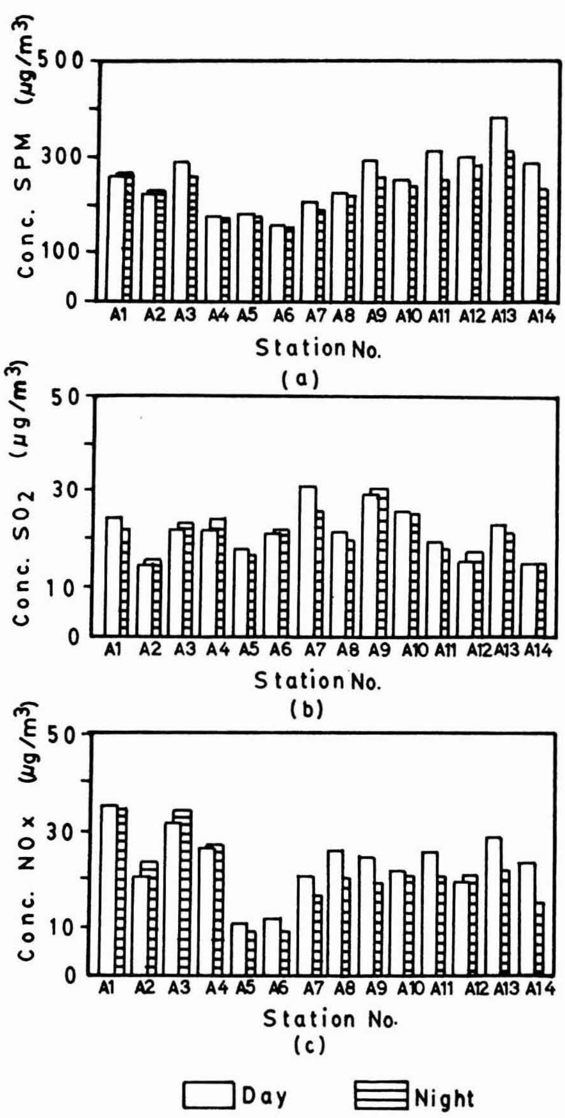

Fig. 3. Diurnal variation in pollutants concentration. (a) SPM; (b) SO_2; (c) NO_x.

the day, perhaps a diesel engine which is used for transporting coal from nearby railway siding.

Spatial distribution of sulphur dioxide. Isopleths for SO_2 levels for all the four seasons are given in Fig. 5. Isopleth diagrams for SO_2 indicate a minimum concentration of 10 µg/m³ in all the seasons except for winter, where no isopleth of less than 20 µg/m³ was obtained. Levels observed at different sampling stations do not show large variation. These observations suggest that these minimum concentrations observed in different seasons closely represent background levels of that particular season.

Seasonal variation of sulphur dioxide. Minimum levels of SO_2 were observed during monsoon and summer seasons, while levels were found to be higher during spring and winter seasons. The minimum levels in the monsoon season were due to washout caused by rains, while burning relatively less coal by local

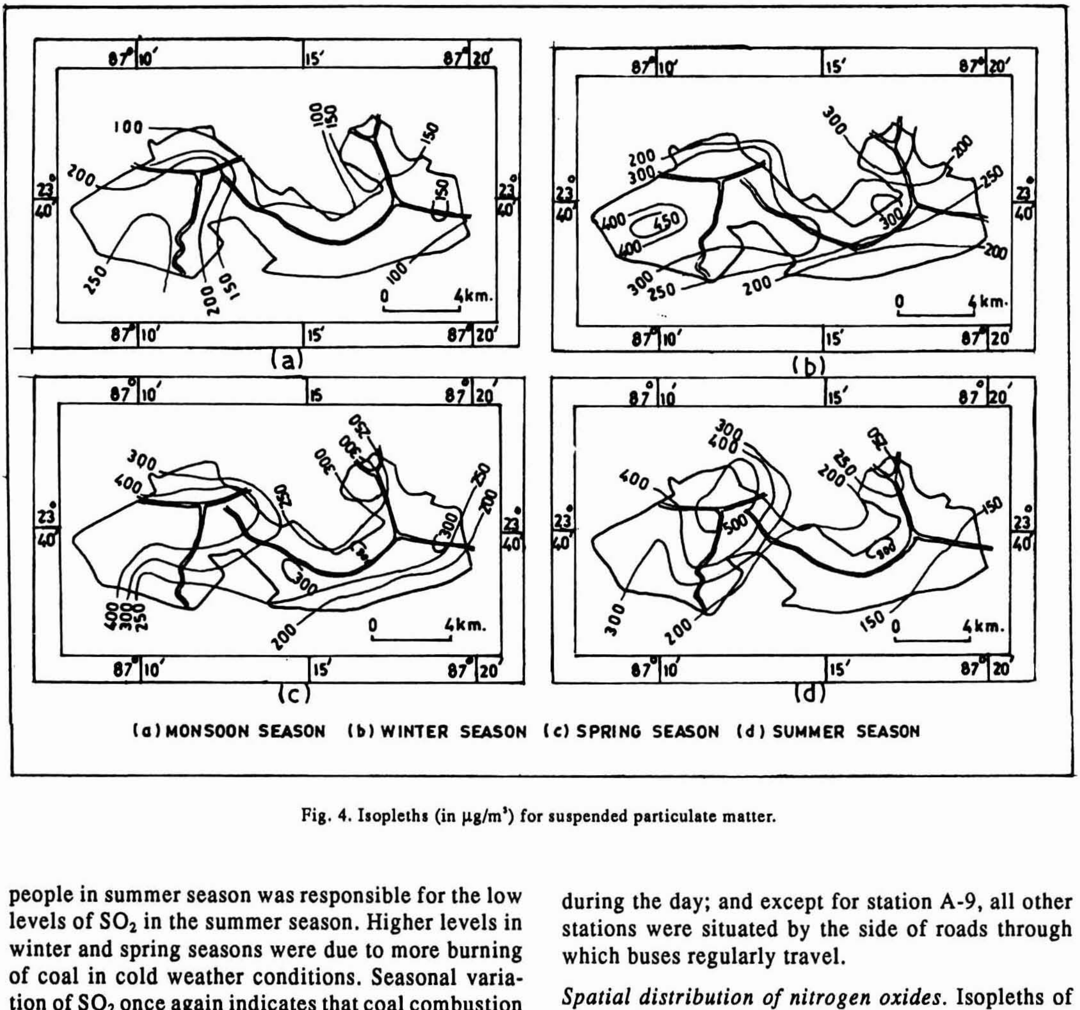

Fig. 4. Isopleths (in μg/m³) for suspended particulate matter.

people in summer season was responsible for the low levels of SO_2 in the summer season. Higher levels in winter and spring seasons were due to more burning of coal in cold weather conditions. Seasonal variation of SO_2 once again indicates that coal combustion could be a major source of SO_2 in the region.

Nitrogen oxides

Diurnal variations of nitrogen oxides. Most of the coal produced at mines is transported by trucks and dumpers to railway sidings and/or to consumers directly. As such, the major source of NO_x in the area is vehicular emission. Buses, which ply the area, also contribute to NO_x levels. NO_x levels do not show any remarkable diurnal variation which could be due to the fact that coal is transported all the time day and night. Day levels were found to be higher by more than 3 μg/m³ at stations A-7, A-8, A-9, A-10, A-11, A-13, and A-14. This appears to be due to the fact that the frequency of bus service is generally higher during the day; and except for station A-9, all other stations were situated by the side of roads through which buses regularly travel.

Spatial distribution of nitrogen oxides. Isopleths of NO_x concentrations for the four seasons are presented in Fig. 6, which indicate that minimum concentrations of NO_x in monsoon and summer seasons were 5 and 15 μg/m³, respectively, while they were 10 μg/m³ in winter and spring seasons. These levels were observed near station A-5 and represent approximate background levels. Agricultural fields in the summer season, during the months of May and June, remain uncovered after the harvesting of Rabi crops and before the harvesting of Kharif crops. Higher background levels in the summer season appear to be due to the contribution of NO_x from heavily fertilised agricultural fields. Since, in other seasons, the fields remain covered, NO_x emissions are comparatively less and background levels are lower. Roads and particularly road junctions in the area are sur-

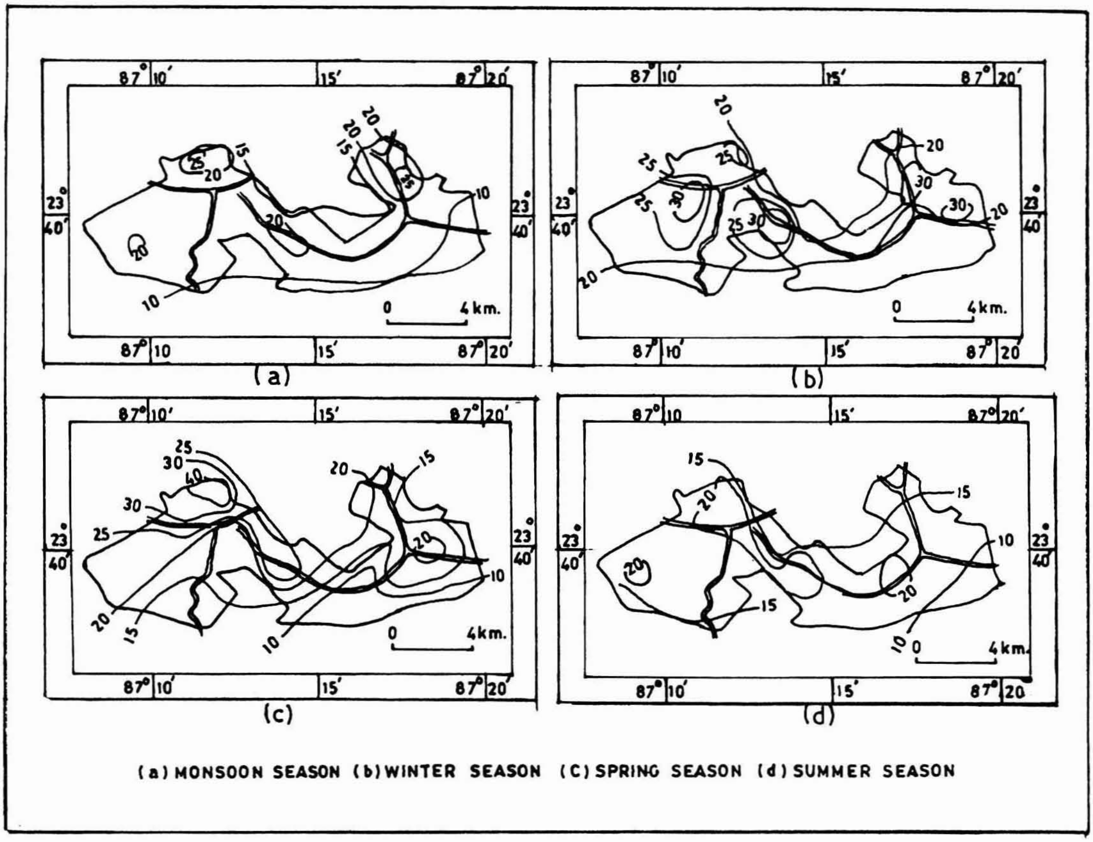

Fig. 5. Isopleths (in $\mu g/m^3$) for sulphur dioxide.

rounded by parallel lines of isopleth irrespective of the season which suggests that vehicular movement on roads acts as a line source of NO_x in the region.

Seasonal variation of nitrogen oxides. NO_x levels were found to be minimal in the monsoon season. This appears to be due to washout caused by rains. Otherwise, NO_x levels fluctuated randomly throughout the year and showed no seasonal variation.

Dustfall

Dustfall rate measurement. Dustfall rate measurement data are presented in Fig. 7. Of all stations, the dustfall rate was observed to be higher around the opencast mine area (station D-6). As observed earlier, a comparatively larger surface area exposed to the atmosphere is responsible for higher windborne soil and therefore for a higher dustfall rate. Of all the stations set up around underground mines, the dustfall rate was found to be higher at the D-2 and D-5 stations, which appears to be due to a large amount of coal stocked around station D-2 and a CHP situated near station D-5 where a lot of dust is generated during coal handling operations.

Seasonal variation of dustfall rate. Dustfall rates were observed to be lowest in the monsoon season at all the locations except for station D-6 where lowest rates were observed during the spring season. Minimum dustfall in monsoon season was caused by the washout of dust by rains. Maximum dustfall was generally observed in the winter season. A calmer period prevailing in the winter season appears to be responsible for this observation.

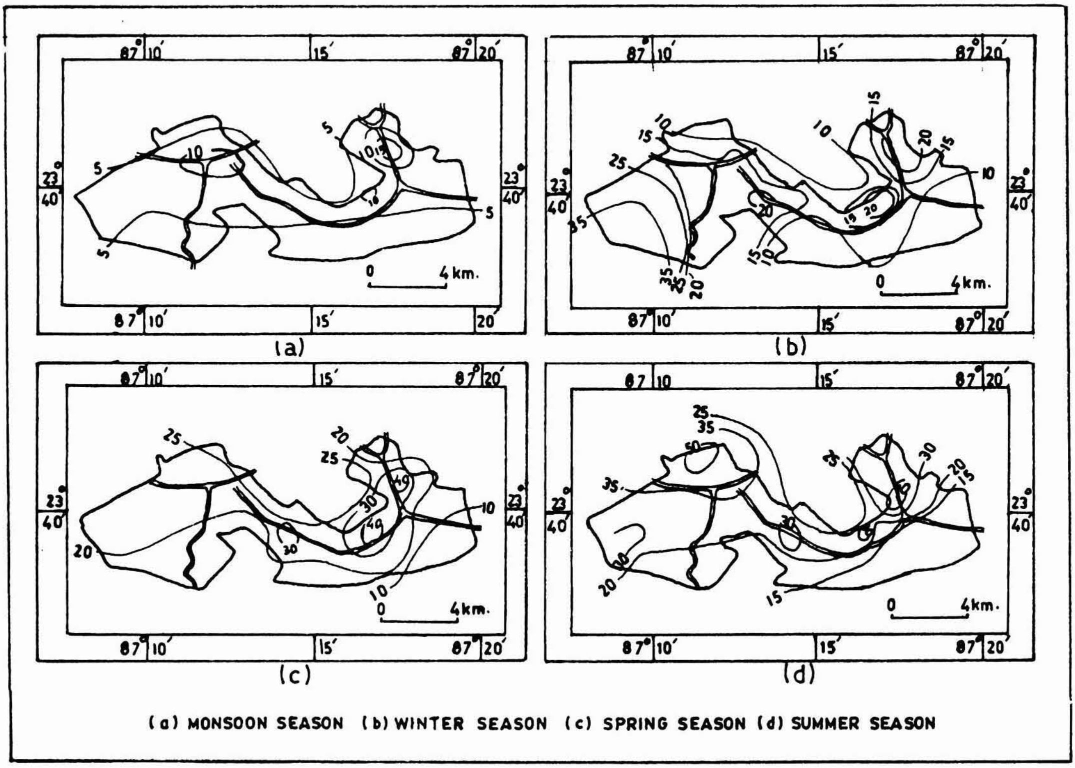

Fig. 6. Isopleths (in µg/m³) for nitrogen oxides.

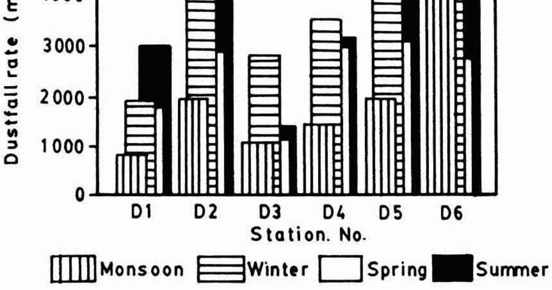

Fig. 7. Seasonal variation in dustfall rate.

Work zone air quality

Work zone air quality analysis results are given in Fig. 8. The concentration levels of SPM at workplaces were considerably higher than their corresponding levels in ambient air. Coal loading and unloading operations and the movement of trucks and loaders produce a lot of dust near the mining sites. In underground mines, blasting and loading operations generate a considerable amount of dust and gaseous pollutants such as SO_2 and NO_x which are ultimately released into the atmosphere through the mine's ventilation system.

Mean SO_2 levels were observed to be comparable to those observed at other ambient air sampling stations. Levels of NO_x were higher than those observed at ambient air sampling stations. Movement of vehicles, blasting operations, and operations of heavy earth-moving mining equipment appear to be responsible for the higher levels of NO_x observed.

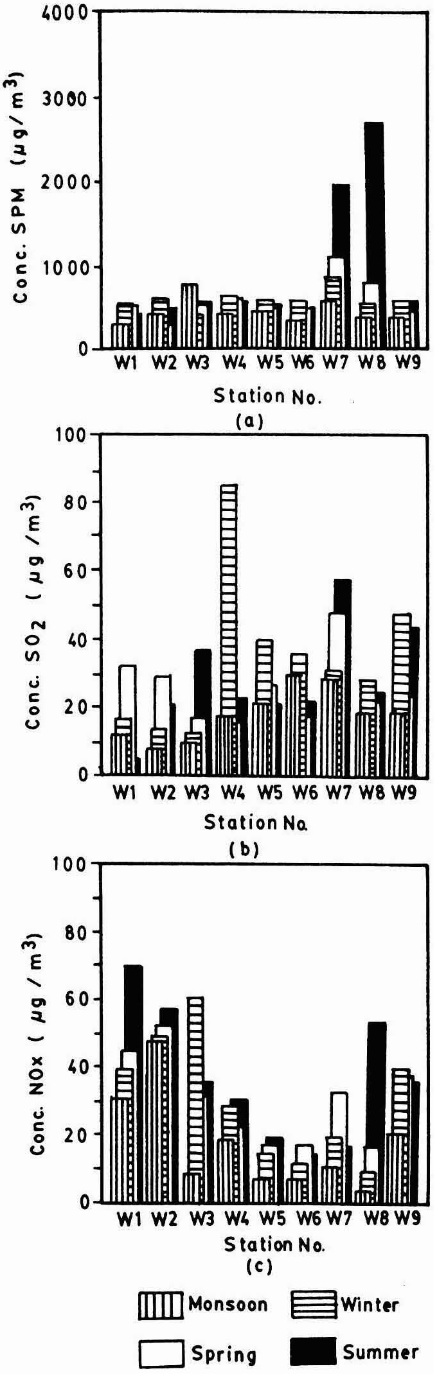

Fig 8. Mean concentration of pollutants in different seasons at workplaces. (a) SPM; (b) SO_2; (c) NO_x.

CONCLUSION

Ambient air monitoring results have shown that SPM emission due to mining and associated activities is a major pollution problem of coal mining areas.

Studies on spatial distribution of SO_2 have revealed higher levels in densely populated areas which gradually declined towards less populated areas. Studies indicate the contribution of NO_x from heavily fertilised agricultural fields resulting in higher background levels in the summer season. Results suggest transportation activities as a major anthropogenic source of NO_x in the region.

Work zone air quality analysis revealed very high SPM levels at workplaces. Since such high levels could be injurious to workers' health, an in-depth study is needed to further analyse this problem.

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THE USE OF SEWAGE SLUDGE AS BASAL DRESSING FOR VEGETABLE CULTIVATION

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Digested municipal sludge was found applicable as basal dressing for growing four Chinese varieties of leafy vegetables: lettuce, *Lactuca sativa* cv. local, Chinese flowering cabbage, *Brassica parachinensis* cv. 70-days, Chinese kale, *Brassica alboglabra* cv. late-flower, and Chinese white cabbage, *Brassica chinensis* cv. Kwei Sin Pak. Moderate loading rate of 50, 100, and 200 Mg/ha dewatered sludge did not cause increased plant mortality, metal toxicity symptoms, significant decrease in yield, or enhanced susceptibility to the attack of viruses, bacteria, or insect pests in the vegetables. Significant yield increase was detected (Anova, 5% confidence level) in the Chinese white cabbage between control and sludge-amended plants. The metal uptake response in the leafy portion of the vegetables demonstrated distinct species difference, with lettuce as a sensitive metal accumulator, and Chinese kale a metal excluder (non-accumulator), whereas the Chinese flowering cabbage and Chinese white cabbage were intermediates. Cu, Ni, and Zn (5.6-10.5, 0.3-8.9, 125.8-239.4 mg/kg dry wt., respectively) in the sludge-amended vegetables did not reach phytotoxic levels; Cr (except Chinese white cabbage) and Pb (0.3-2.7, 0.5-5.9 mg/kg dry wt., respectively) were generally lower than the background levels of soil. The highest Cd concentration of 1.5 mg/kg (dry wt.) found in lettuce did not exceed the WHO/FAO safety limit to a cause a health hazard for human consumers. However, it is necessary to screen for more metal non-accumulating crops for safe sludge farming.

INTRODUCTION

The application of municipal sludge on agricultural land is becoming a frequent practice to recycle the nutrients contained in sludge and dispose of such waste cost effectively. Sludge is widely recognized as a source of essential plant nutrients because of its high nitrogen, phosphorus, and carbon contents (Sommers 1977; King 1981; Scott et al. 1985). Heavy metals are other common components of sewage sludge, and depending on the type and degree of industrialization, high levels of Zn, Cd, Ni, Pb, and Cr may be present in sludge to arouse concern of soil contamination by these elements (Soon and Bates 1982; Davis et al. 1988). Crops grown on sludge-amended soils may contain high concentrations of metals (Kim et al. 1988) which can cause crop injuries, or can transfer their accumulated metals along food chains, and be harmful to consumers. Although using low metal sludges for soil amendment had been shown to cause little effect on food chain transfer, high Cd sludges increased Cd in crops and then increased Cd in kidney and liver in British Friesian steers (Rundle et al. 1984), guinea pigs (Chaney et al. 1978), goats (Bray et al. 1985; Telford et al. 1984), and other small mammals (Hegstrom and West 1989).

Soil pH generally influences the uptake of metals, particularly in sensitive plants studied such as lettuce, radish, green bean, and rape (Keefer et al. 1986; Narwal et al. 1983); metal concentrations will decrease when the soil pH is increased by liming. The impact of the pH on metal accumulation in plants has been noted (Lindsay 1972; Heckman et al. 1987) and is critically reviewed by Logan and Chaney (1983). The control of the pH would minimize the effect of plant metal uptake when sludge is used for farming.

The disposal of sewage sludges in Hong Kong is primarily by sanitary landfilling, and a small portion is by sea dumping. Marine disposal will receive greater emphasis in the future; however, the assimilative capacity of the sea should not be considered unlimited.

One of our investigators has studied and reviewed the economy and safety of utilizing sewage sludge on land in Hong Kong (Wu 1987). Wu demonstrated that such a practice can result in a fair saving on transportation costs for disposal of sludge. Wu is suggesting an integrated sludge-disposal strategy suitable to local conditions, including sanitary landfilling, land application of sludge for landscaping in the development of new towns, and as topsoil materials within or in the vicinity of the sewage treatment plants.

Land application of sewage sludge is not practiced presently in Hong Kong, although a nearby economic special zone, Shenzhen of mainland China, is utilizing sludge for gardening and growing some food crops. This produce is exported daily to Hong Kong for sale.

About 9% of Hong Kong's land is used for farming, and locally produced vegetables account for 40% of the total vegetable consumption. If sludge is utilized for growing food plants, vegetable cultivation is most likely to be involved. Hence, the main aim in the present study is to find out the feasibility of using municipal sludge as basal dressing for vegetable growth. This is achieved by comparing four popular local vegetable crops grown on sandy loam soil, with and without the amendment of municipal sludge, with regard to: (1) the percentage of seed germination; (2) crop susceptibility to bacterial, viral, and insect pest attack and presence of disease symptoms; (3) heavy metal concentrations in the plant tissue; and(4) mortality percentage and yield.

MATERIALS AND METHODS

Seed germination test

The four experimental crops were lettuce, *Lactuca sativa* cv. local, Chinese flowering cabbage, *Brassica parachinensis* cv. 70-days, Chinese kale, *Brassica alboglabra* cv. late-flower, and Chinese white cabbage, *Brassica chinensis* cv. Kwei Sin Pak. Some of these leafy vegetables are becoming popular elsewhere, e.g., the lettuce cv. local and other Chinese flowering cabbage varieties are grown in California and New Jersey of the United States.

One hundred sterilized seeds of each of the four experimental vegetables and six other crops (Table 1) were placed in the autoclaved medium (sandy loam or sludge) in petri dishes, kept at 22°C, and a photoperiod of 16:8 (L:D). The medium was watered to its 95% water-holding capacity, and the germinated seeds were counted daily for eight days.

Crop cultivation

The field experiments were carried out at the Government Tai Lung Experimental Station using sandy loam soil. Since soil can be rather heterogenous, a 4 treatments × 4 replicates in a Latin square design was employed to minimize experimental error. The four treatments were: 0, 50, 100, and 200 Mg/ha of dewatered sludge (moisture content of 53.3%) for each crop. A total of 64 plots were used, each measuring 6×1 m^2. Anaerobically digested and dewatered sludge from the Shek Wu Hui Sewage Treatment Plant was applied at the above mentioned rates by plowing sludge into the top 20 cm of soil as basal dressing and allowing to age for two weeks prior to seed sowing. Basal dressing for the control plots, using peanut cake to supply N, and bone meal to supply P, were decided to add after soil nutrient tests. The soil pH of both the control and experimental plots was determined and maintained at not lower than pH 6.5 by suitable liming prior to seed sowing.

Seeds were sown directly and thinned to suitable planting density identical for each vegetable when seedlings were established. A top dressing using compound fertilizer (N:P:K = 13:13:21) was administered

Table 1. Percentage of seed germination in pure gludge and control soil, at 22°C and photoperiod of 16:18 (L:D).

Seeds	% of Germination	
	Sludge	Soil
Experimental Crops		
Lettuce (local)	100.0	100.0
Chinese flowering cabbage (70-days)	100.0	96.7
Chinese kale (late-flower)	86.7	100.0
Chinese white cabbage (Kwei Sin Pak)	100.0	96.6
Other Crops		
Chinese spinach (round)	93.3	100.0
Water spinach (white-stalk)	73.4	75.0
Late mustard (Nam Fung)	100.0	96.7
Cucumber (Taiwan)	91.7	86.7
Hot pepper	86.8	95.0
Angled loofah	96.6	75.0

in amounts and at intervals recommended by the Agronomic Section of the Experimental Station. All plots of each crop received the same amount of fertilizer. Weeding was done by hand to avoid complications caused by using herbicides. Pest and disease assessment and their control were carried out by the Plant Protection Section. Field records included plant growth conditions, plant stands while growing and at harvest, weight of crop at harvest, observable phytotoxic symptoms, and meteorological data during the growth period.

Sludge and soil analysis

The air-dried sludge and soil samples (from top 20 cm) were passed through a 2 mm sieve, oven-dried at 105°C, and analyzed for pH (paste of 10 g sample in 25 mL distilled water, pH meter), oxidizable organic carbon (chromic acid/ sulfuric acid method, Walkley and Black 1934), total nitrogen (acid titration after Kjeldahl digestion, ASTM 1984), available phosphorus (direct colorimetric method, AOAC 1984), and electrical conductivity (10 g sample in 25 mL distilled water, conductivity meter). Total Cu, Ni, Zn, Cr, Cd, and Pb (conc. nitric acid, hot-block wet digestion) were determined by inductively coupled plasma atomic emission spectrometry (ICP-AES; AOAC 1984) using Instrumentation Laboratory Plasma 300. Recalibration was repeated every 12 determinations. Spectral interferences of Al and Zn were corrected by the side-line indexing method and interfering element correction method, respectively. For samples which had Ni, Cd, and Pb lower than the ICP detection limit of 100 ng/g, graphite furnace atomic absorption spectrometry (GFAAS; AOAC 1984) was employed to determine the sub-microgram amounts of Ni, Cd, and Pb, using a Varian Model Spectra AA-20 coupled with a GTA-96 graphite tube atomizer. To overcome chemical interferences, the calibration curve was established by standard additions; whereas spectral interferences wereminimized by instrumental background correction.

Plant metal analysis

Vegetables were harvested when they reached marketable size. Random samples of the edible aerial shoot portion from each treatment and replicates were washed in tap water, rinsed in deionized water, and dried at 70°C to a constant weight. The homogenized samples were weighed and then subjected to metal determination for Cu, Ni, Zn, Cr, Cd, and Pb, using the same methods described above for sludge and soil.

Quality control and statistical analysis

Apart from correcting interferences in instrumentation, all chemicals and reagents used were of analytical grade, cleansed glasswares were acid treated prior to use, samples and metal determinations were replicated. Because of the heterogenous nature of the soil and sludge, a large number of random samples per plot were pooled, and the pooled sample was reduced to appropriate size after mixing and quartering. Results obtained were analyzed by Student's t-test and the analysis of variance (Anova).

RESULTS

Seed germination test

Table 1 reveals that the percentage of seed germination in sludge and soil was significantly similar (Student's t-test) for the 10 crops tested; averaging 96.7% when germinated in sludge, and 98.3% when germinated in soil for the experimental crops. This indicated that although the sludge used contained high level of soluble salt (1.5 g/kg salt, determined from the electrical conductivity of sludge), and toxic components (heavy metals and other organics), they did not inhibit the process of seed germination.

Crop growth

Daily field records showed that the soil temperatures during the growth period varied from 5-32°C, a suitable range for the growth of the four vegetables. The pH was found to be fairly constant, about 6.5. Lettuce was free from viral, bacterial, and serious insect attack. Cabbage flea beetle, *Phylotreta striolata*, and diamondback moth, *Plutella xylostella*, were the major insect pests found on the Chinese flowering cabbage, Chinese kale, and Chinese white cabbage. But their occurrence and abundance were similar for the control and experimental plants, irrespective of the application of sludge. Details of field records would be available upon request.

All the four vegetables were successfully grown on sludge-amended soils. The mortality rate was low (less than 4%) for all levels of sludge loading, and in individual cases even lower than the control (Table 2). Observable phytotoxicity symptoms due to heavy metals, such as stunted growth and leaf chlorosis, were not detected in any of the test crops. The effect of sludge on increasing the yield per plant for the lettuce and Chinese white cabbage was evident when comparing the control and plants grown on soil receiving sludge as basal dressing. However, the opposite was detected, i.e. decreasing the yield per plant, for the Chinese flowering cabbage and Chinese kale. No significant difference in yield was found between different treatments of sludge loading (0-200 Mg/ha) in the lettuce, Chinese flowering cabbage, and Chinese kale (Anova, 5% confidence level). But significant difference in yield was found between the control and sludge-amended Chinese white cabbage; although, there was still no difference in yield between the different amounts of sludge applied.

Soil and sludge characteristics

The physical and chemical characteristics of the sludge, control soil, and soils amended with sludge, are compared in Table 3. Oxidizable organic carbon, total nitrogen, available phosphorus, and electrical conductivity of the sludge were 4.5, 15, 7.9, and 4.5 times higher than in the control soil, resulting in 1-3 times higher values of the above chemical properties in the sludge-amended soils which received higher sludge loading. Up to 200 Mg/ha of sludge amendment did not greatly alter the pH of the amended soils. During the period of vegetable growth, the soil pH was monitored, and no significant decline in the pH was found. The concentrations of Cu, Ni, Zn, Cr, Cd, and Pb in the control and sludge-amended soils are shown in Table 4. All the six metals present in the Shek Wu Hui sludge were within the general range of these heavy metals found in U.K. sludges which were considered safe for agricultural application (IOWPC 1979). The concentration of these metals in the sludge-amended soils did not exceed the upper limits for soil concentrations after sludge addition (Table 4), set up by the Ministry of Agriculture, Fisheries and Food of England (MAFF/ADAS/ASS 1985). In addition, the present highest loading rate of 200 Mg/ha was lower than the maximum rate of 412 Mg/ha (calculated for the Shek Wu Hui sludge according to the U.S. EPA guidelines, USEPA

Table 2. Average yield per plant, yield increase (compared to control), and mortality of vegetables grown on sludge-amended soil.

Sludge loading (Mg/ha)	Yield/Plant[a] (g)	Yield increase (%)	Mortality[b] (%)
Lettuce			
0	191.4 ± 19.8	-	0.57
50	217.8 ± 23.9	13.8	0.57
100	225.1 ± 13.0	17.6	0.00
200	221.2 ± 37.0	15.6	0.00
Chinese flowering cabbage			
0	87.5 ± 36.1	-	1.56
50	77.5 ± 34.4	-11.4	0.85
100	84.5 ± 34.6	- 3.4	3.03
200	75.7 ± 34.0	-13.5	0.87
Chinese kale			
0	101.3 ± 31.6	-	2.35
50	86.5 ± 34.6	-14.6	1.85
100	88.0 ± 36.9	-13.1	1.39
200	81.0 ± 31.3	-20.0	0.47
Chinese white cabbage			
0	89.6*± 17.1	-	2.54
50	141.6 ± 20.0	58.0	1.67
100	140.5 ± 24.0	56.8	1.67
200	160.5 ± 15.9	79.1	0.42

a = Mean of 35+5 plants.

b = Plant stand at establishment: lettuce (45+1), Chinese flowering cabbage (58+1), Chinese kale (53+1), and Chinese white cabbage (59+1).

* Significant difference in yield/plant (Anova, 5% confidence level) between control and other treatments.

Table 3. Physical and chemical characteristics of Shek Wu Hui sludge, control soil, and sludge-amended soil.

Sample	pH	Organic C (%)	Total N (%)	P_2O_5 (mg/100g)	EC* (mS)
Sludge	6.9	21.5	1.5	1050	3.6
Control soil	6.9	4.8	0.1	133	0.8
Amended soils	6.0-6.8	4.6-5.2	0.1-0.2	136-172	1.2-2.2

* Electrical conductivity of saturated extract at 25°C.

Table 4. Heavy metal contents (dry wt.) of experimental soils, Shek Wu Hui sludge, U.K. Sludges suitable for agriculture, and recommended limits of sludge metals for land application.

Sample	Cu	Ni	Zn	Cr	Cd	Pb
			(mg/kg)			
Control soil 0 Mg/ha	5.8	1.3	43.9	5.1	0.6	5.9
Sludge amended soil, 50 Mg/ha	6.4	1.4	53.0	6.9	0.9	5.7
Sludge amended soil, 100 Mg/ha	6.6	1.5	65.6	7.3	1.0	7.5
Sludge amended soil, 200 Mg/ha	6.8	1.7	68.4	8.9	1.9	8.1
Shek Wu Hui sludge	130	13.8	1358	90.2	7.7	9.1
U.K. sludges (IOWPC 1979)	600-800	50-80	1500-3000	-	7-10	200-700
Upper limits for soil conc after sludge addition (MAFF/ADAS/ASS 1985)	135	75	330	600	3.5	250

1983), that could be applied safely for agricultural purposes.

Metals in vegetables

Comparing the four kinds of vegetables (Table 5), the highest metal concentrations (except for Cr, highest in Chinese white cabbage) were found in the lettuce, including the control and plants grown on sludge-amended soil. The lowest metal concentrations were found in Chinese kale (except for Zn, Table 5). Thus, the degree of accumulation of these six metals in the shoot system was approximately in the order of lettuce > Chinese white cabbage > Chinese flowering cabbage > Chinese kale. It was interesting that the Chinese white cabbage accumulated the highest level of Cr in the edible shoot portion, including the control. This phenomenon perhaps was related to the Cr absorption and translocation tendency of the specific cultivar of Chinese white cabbage, and this proposed explanation would need further investigation. For each kind of vegetable, there was a slight elevation in plant Cu and Cd (except in Chinese kale), and a more conspicuous increase in plant Zn with increasing sludge loading. Ni and especially Cr and Pb did not show such a corresponding increase. Because of the moderate loading rate used in this experiment, a greater rise in plant Cu and Cd was only evident for the 200 Mg/ha treatment. Anova (5% confidence level) showed that the Cu content in the Chinese flowering cabbage and Chinese kale, and the Zn content in the four test crops, increased significantly with increasing sludge loading.

DISCUSSION

Germination and growth

In the present study, even pure sludge did not hinder normal seed germination, as the process requires mainly adequate temperature and moisture, and the water-holding capacity of sludge is superior to most loamy soils. Further development of the seedlings on the two kinds of media may be different, for substances in sludge toxic to growth may cause retardation of root elongation (Wong and Lau 1983; Wong et al. 1984).The low mortality rate, absence of metal toxicity symptoms in the experimental crops,

Table 5. Metal concentrations (dry wt.) in vegetable grown on sludge-amended soil.

Sludge loading (Mg/ha)	Cu	Ni	Zn	Cr	Cd	Pb
			(mg/kg)			
Lettuce						
0	9.7	7.4	108.8*	4.8	1.0	5.4
50	10.4	8.9	172.1	2.7	1.2	5.9
100	9.8	8.4	186.7	1.2	1.0	5.0
200	10.5	6.2	239.4	1.5	1.5	4.9
Chinese flowering cabbage						
0	6.2*	1.1	91.4*	1.7	0.4	1.8
50	7.3	0.8	139.1	1.1	0.4	1.6
100	7.2	2.9	146.0	1.7	0.5	1.7
200	7.8	1.6	198.4	0.6	0.7	1.5
Chinese kale						
0	5.7*	0.5	84.7*	0.8	0.4	0.6
50	5.6	0.4	139.4	0.3	0.4	0.5
100	6.2	0.3	130.6	0.3	0.4	0.5
200	6.9	0.6	200.7	0.3	0.4	0.6
Chinese white cabbage						
0	6.0	2.5	97.2*	6.3	0.6	1.7
50	7.2	2.7	144.9	10.6	0.7	1.2
100	6.8	2.6	125.8	4.0	0.7	1.5
200	9.3	2.4	207.6	4.8	0.8	1.1

*signficant difference in metal content (Anova, 5% confidence level) between control and other treatments.

and statistically nonsignificant difference in yield between the different amounts of sludge applied in the lettuce, Chinese flowering cabbage, and Chinese kale (Table 2), are due to the present low or moderate rate of sludge loading. The significant difference in yield between the control and sludge-amended Chinese white cabbage may indicate that sludge-treated soils promote growth for this particular cultivar.

Characteristics of sludge-treated soil

The organic C, total N, and available P content of the sludge-amended soil is 1-2 times higher than that of the control soil (Table 3); this illustrates the enrichment of the soil upon sludge amendment, and demonstrates the feasibility of using a moderate application of domestic sludge as basal dressing. Sewage sludge may need to be supplemented with extra potash required for most horticultural crops, as sludge usually is low in K content. The almost 3 times higher salt content resulting from sludge amendment may impede the normal growth of some vegetables.

Metals in vegetables

The accumulation of metals in the vegetables studied showed distinct species and variety difference, with lettuce being the sensitive metal accumulator and Chinese kale a metal tolerant excluder or non-accumulator, whereas Chinese flowering cabbage and Chinese white cabbage were intermediates between the two extremes. Lettuce cv. local can accumulate Cu, Ni, Zn, and Cd to a concentration higher than the concentration of these respective metals found in the growth media (control and sludge-treated soils). In contrast, Chinese kale contained a lower concentration of Cu, Ni, Cr, Cd, and Pb than the growth media. The four vegetables actively accumulated Zn and Cu (significantly Chinese flowering cabbage and Chinese kale), but accumulated little Cr, Cd (except lettuce), and Pb from the soil. The Ni content in the lettuce and Chinese white cabbage and to some extent in Chinese flowering cabbage became elevated, but not in the Chinese kale.

Comparing the metal concentrations between a sensitive crop like lettuce and a non-accumulator such as Chinese kale (both grown on 200 Mg/ha sludge-amended soil), by dividing the corresponding metal concentrations of the two vegetables, lettuce was shown to contain 1.5, 10.3, 1.2, 5.0, 3.8, and 8.2 times more Cu, Ni, Zn, Cr, Cd, and Pb than Chinese kale (Table 5). Variation in metal uptake by cultivars has been extensively studied for Cd in corn, lettuce, and soybean. Cultivar response has been found to vary from 2-5 fold (Page et al. 1989). The species and variety response to metals when grown on sludge-amended soil should be studied for more food crops and the non-accumulators or less metal sensitive crops should be identified for sludge farming.

With the present sludge loading rate, the plant Cu, Zn, and Ni had not reached phytotoxic levels to cause the appearance of phytotoxicity symptoms. In sludge-treated soils maintained at pH > 6.0, phytotoxicity due to Cu and Ni accumulation has rarely been reported (Marks et al. 1980). Of the four vegetables studied, the highest value of Cd detected was in lettuce grown on 200 Mq/ha sludge-treated soil (Table 5). Assuming a daily consumption of 300 g of fresh vegetable (typical for most Hong Kong inhabitants) and the vegetable consumed being lettuce containing 1.5 mg Cd/kg (conversion factor determined for converting dry wt. to wet wt. was 0.07), the calculated daily intake of Cd due to eating lettuce alone would be 31.5 µg Cd, which is lower than the maximum Cd intake limit of 52-71 µg Cd/day, established by WHO/FAO.

An important aspect prior to safe land application of sludge is to study the residual effect for many years after sludge amendment. Investigations on the metal accumulations following termination of sludge application show that bioavailability of sludge-borne metals will not increase but decline with time, and crops grown on these soils may at first show a slight rise in certain metals such as Cd and Zn, but later crops will eventually be similar to the control crops (Hinesly et al. 1979; Dowdy et al. 1978; King and Dunlop 1982). Presently, the sludge-treated plots at the Tai Lung Experimental Station are utilized for edible crop cultivation including egg plants, Chinese spinach, water spinach, leaf-mustard cabbage, green pepper, and cabbage. Representative plants have been harvested and metal concentrations were determined to accumulate data for future comparison and assessment.

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THE TRANSFER OF ^{137}Cs FROM SOIL TO PLANTS

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Radioactive clouds from the atmospheric release due to the reactor accident at Chernobyl reached Iraq on 5 May 1986. Considerable rainfall in the northern part of the country caused a ground surface contamination. Exposure rate measurements were used to select four farms in that region which gave the highest exposure rates due to Chernobyl fall-out. Gamma spectrometric analysis of fresh plants and dry soil samples was used to estimate the transfer factors of ^{137}Cs from soil to some agriculture products. The transfer factors of ^{137}Cs from soil to garlic, potato, celery, carrot, turnip, radish, wheat, barley, pomegranate, fig, green beans, lentil, and chick-pea were calculated as 0.0782, 0.0139, 0.0782, 0.0456, 0.11, 0.0333, 0.0622, 0.0253, 0.0224, 0.0257, 0.11, 0.0083, and 0.11, respectively.

INTRODUCTION

On 26 April 1986, a serious nuclear accident occurred at the Chernobyl nuclear power plant in the Soviet Union where 1×10^{18} to 2×10^{18} Bq of radioactivity were released into the atmosphere (IAEA 1986). The plume directions may be grouped into five periods, with the fifth period emission starting 1 May 1986 and the plume direction facing the area of Turkey (WHO 1986). The northern region of Iraq borders Turkey.

Radioecological assessments of the dose to man from radionuclides released to the environment are generally made using mathematical models that require as input transfer factor parameters to predict the concentration of radionuclides in food stuff (ICRP 1979 ; IAEA 1986; Wirth et al. 1985). For guidance in evaluating compliance with Federal Regulations, the U.S. Nuclear Regulatory Commission has provided generic transfer factors that may be used whenever site specific information is not available (Ng 1982). Similar values were published in the Federal Republic of Germany (Prohl et al. 1985).

Terrestrial food-chain transport starts primarily with reactive gases or particles that are readily deposited on the ground; they contaminate the edible plant tissue through rootuptake (Kaye 1982). The transfer factors of radionuclides (originated from weapon testing fallout) from soil to plants were estimated from field studies (Sheppard 1985; Bunzle and Krake 1986; Hakonson et al. 1981) or laboratory experiments (Steffen 1980).

The objective of the present work is to calculate the ^{137}Cs soil to plant transfer factor under field conditions in the northern region of Iraq affected from the Chernobyl fallout.

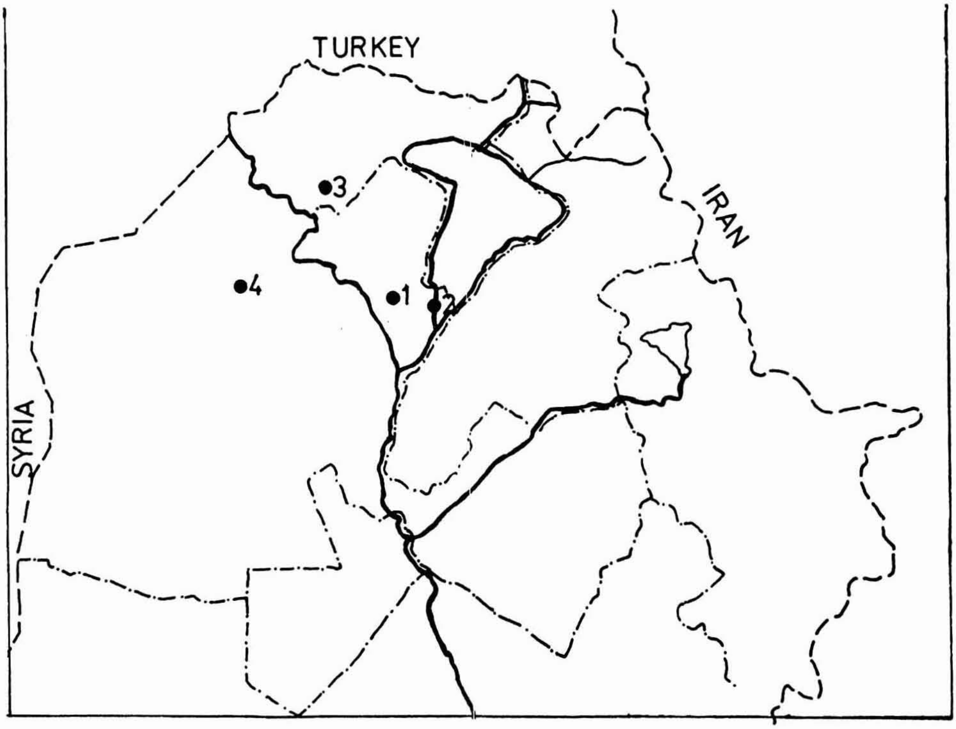

Fig. 1. Location of the farms used for the determination of the transfer factors of ^{137}Cs from soil to plants: 1. Bartulla, 2. Sartung, 3. Sheik Amir, 4. Tellafar.

MATERIALS AND METHODS

Exposure rate measurements were carried out with an environmental monitoring system RSS - 111, Reuter Stokes, U.S.A. Four farms with the highest exposure rates were selected (Fig. 1).

Soil samples were collected with an auger up to the depth of 30 cm. Agriculture samples were selected at the time of maturity. Soil textures were analyzed by the General Establishment for Designs and Researches, Ministry of Agriculture and Irrigation, Baghdad. The results of the analysis are given in Table 1.

Table 1. Texture analysis of soil samples obtained from farms used to derive ^{137}Cs soil to plants transfer factors.

Farm		Content		Type	Grain size
	Sand	Silt	Clay		
Bartulla	17	49	34	silty clay loam	medium
Sartang	03	55	42	silty clay	fine
Sheik Amir	05	50	45	silty clay loam	fine
Tellafar	22	52	26	silty loam	medium

Soil samples were dried at 105 °C for 24 h. Vegetation and organic debris was removed. The samples were grinded and passed through a 1 mm sieve. The agricultural products were cleaned and the edible portions retained for analysis.

Dry soil and fresh agricultural product samples were counted with an Ortec intrinsic germanium coaxial detector using a 1000 ml Marinelli beaker geometry. Efficiency calibrations were performed using a 1000 mL Marinelli beaker containing a certified nuclide mixture (Amersham). The data were analyzed on a Canberra 8100 multichannel analyzer.

The ^{137}Cs transfer factor from soil to garlic, potato, celery, carrot, turnip, radish, wheat, barley, pomegranate, fig, green bean, lentil, and chick-pea is the activity of ^{137}Cs in 1 kg fresh edible agricultural product divided by the activity of ^{137}Cs in 1 kg of dry soil.

RESULTS

The transfer factors from soil to agricultural products has been calculated from measurements of activity concentrations of ^{137}Cs in dry soil and fresh mature edible agricultural products.

In the farm located in Bartulla (Fig. 1), the transfer factors of wheat, barely, pomegranate and fig were calculated. The lowest transfer factor values for wheat, barley, pomegranate, and fig were 0.018, 0.013, 0.006, and 0.007, respectively. The highest transfer factor values for the above mentioned agricultural products were 0.0124, 0.087, 0.0045, and 0.052, respectively. The average transfer factor values are listed in Table 2.

The Sartung farm is an agricultural experimental station located in the Dhook governerate (Fig. 1). Measurements of the activity concentration of ^{137}Cs in chick-pea, lentil, and soil samples obtained from this farm were used for calculation. Eight samples for each one of them were analyzed. The highest transfer factors calculated for chick-pea and lentil were 0.23 and 0.017, respectively, while the lowest values were 0.045 and 0.003. The average transfer factor values are given in Table 2.

The third farm (Sheik Amir) is located in the Naynava governerate (Fig. 1). Cesium-137 soil to plant transfer factors were calculated. The highest values for barley and green beans were 0.022 and 0.177, respectively, while the lowest values were 0.006 and 0.04. The average transfer factor values are presented in Table 2.

Table 2. The average transfer factor values of ^{137}Cs from soil to agriculture products calculated for different farms located in the northern region of Iraq.

Farm	Bartulla	Sartung	Sheik Amir	Tellafar
Agricultural product				
Barley	0.004 ± 0.030		0.010 ± 0.005	
Carrot				0.030 ± 0.002
Celery				0.050 ± 0.004
Chick-pea		0.112 ± 0.066		
Fig	0.026 ± 0.018			0.050 ± 0.004
Garlic				0.050 ± 0.004
Green beans			0.036 ± 0.065	
Lentil		0.008 ± 0.002		
Pomegranate	0.003 ± 0.002			
Potato				0.009 ± 0.001
Radish				0.021 ± 0.002
Turnip				0.071 ± 0.005
Wheat	0.062 ± 0.046			

Table 3. Soil to plant transfer factors for ^{137}Cs calculated from the four sampling stations.

Agricultural product	Transfer factors	Soil texture
Garlic	0.050 ± 0.004	medium
Potato	0.009 ± 0.0008	medium
Celery	o.050 ± 0.004	medium
Carrot	0.029 ± 0.003	medium
Turnip	0.071 ± 0.006	medium
Radish	0.021 ± 0.002	medium
Wheat	0.062 ± 0.048	medium
Barley	0.010 ± 0.005	fine
Barley	0.044 ± 0.03	medium
Pomegranate	0.002 ± 0.0017	medium
Fig	0.026 ± 0.02	medium
Green beans	0.110 ± 0.096	medium
Lentil	0.008 ± 0.005	fine
Chick-pea	0.113 ± 0.070	fine

Many agricultural products were grown in the Tallafar farm situated in the Naynava governerate. The transfer of ^{137}Cs from soil to garlic, potato, celery, carrot, turnip, and radish were calculated. The highest values calculated for the transfer factors were 0.01, 0.054, 0.032, 0.077, and 0.023, respectively. The lowest transfer factors calculated were 0.046, 0.008, 0.046, 0.027, 0.065, and 0.019, respectively. The average transfer factor values are shown in Table 2.

The transfer factors of ^{137}Cs from soil to the agricultural products calculated from the analyses of samples obtained from the four farms located in the northern part of Iraq are given in Table 3.

We can divide the values calculated into three categories, the highest were 0.113 and 0.11 for the transfer factors of ^{137}Cs from soil to chick-pea and green beans, respectively. The medium values were of 0.050, 0.050, 0.071, and 0.062 for the transfer factors from soil to garlic, celery, turnip, and wheat, respectively. The lowest group values were 0.01, 0.03, 0.02, 0.025, 0.002, and 0.008 for the transfer factors of ^{137}Cs from soil to potato, carrot, radish, barley, pomegranate, fig, and lentil, respectively.

DISCUSSION

It was possible only to determine the ^{137}Cs soil to agricultural products transfer factors since it is the only fission product which could be measured in both agricultural products and soil samples. The transfer factor values are used in computer codes to predict radiation doses resulting from ingestion of contaminated food-stuff (Wirth et al. 1985; Kaye 1982). Although, there are transfer factor values available to be used as default values, it is advisable to use site specific data. In agreement, Ng recognized that transfer factors derived from the literature are subject to numerous shortcomings because reported values are often based on experiments that were designed for purpose other than the evaluation of transfer factors (Ng 1982). Indeed, on screening through the literature, we have found different values under different experimental conditions. For instance, the ^{137}Cs soil to plant transfer factor used in the AIRDOS-EPA computer code which is employed by us for dose assessment is 0.0093 (Moore et al. 1979). The U.S. Nuclear Regulatory Commission gives a value of 0.02 (NRC 1977). Other values given are 0.00005 to 0.0026 for medium soil texture and 0.0004 to 0.013 for fine soil texture (Ng et al. 1979), 0.02 in FOODMARK and 0.05 in ECOSYS codes (Prohl 1985), 0.03 (IAEA 1982; IAEA 1988), 0.018 to 0.045 for loamy soil and 0.049 to 0.108 for podsolic soil (Heine and Wiechen 1980), 0.02 (Whicker and Kirchner 1987), 0.05 (GRS 1980) and 0.00064 to 0.078 (Eisenbud 1987). In comparision, the average ^{137}Cs soil to plant transfer factor obtained from samples analyzed in this study is 0.0042 which is in good agreement with many values reported above regardless of soil texture or agricultural product. However, it is possible to be more specific for a given soil texture and agriculture product. Thus, the ^{137}Cs soil to plant transfer factors are derived and can be used from now on in Iraq and other countries in the area instead of the default values that are in use for dose assessment.

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BOOKS

Appropriate Development for Basic Needs. D.P. Maguire, ed. Thomas Telford Services Ltd. London; 1990. 360 pp. (ISBN 0 7277 1618 2) hardcover.

In October of 1990, the Institution of Civil Engineers of the U.K. held a conference in London. This book contains the proceedings of that symposium. The presentations included issues related to development, opportunities and constraints for development, energy, water, sanitation, food, and infrastructure.

Bioenergy and the Environment. Janos Pasztor and Lars A. Kristoferson, eds. Westview Press. Oxford, U.K.; 1990. 410 pp. (ISBN 0-8133-8062-6) £23.95 softcover.

This book contains contributions from a study conducted by the Stockholm Environment Institute for the United Nations Environment Program. The two parts of the book cover the fuels and their effect on the environment. Included are agricultural residues as fuels, biogas, producer gas, dry biomass, as well as common wood. The second part covers land use, air pollution, water, and health effects. The foreword is coauthored by Dr. Mostafa Tolba, Executive Director of the United Nations Environmental Program.

Hazards XI. New Directions in Process Safety. Institution of Chemical Engineers. Hemisphere Publishing Corporation, Bristol, PA; 1991. 440 pp. (ISBN 1-56032-233-0) hardcover.

The Institution of Chemical Engineers of the U.K. organized a symposium in April 1991. This book contains the text of the presentations of that symposium. The book contains a number of papers that describe explosions and other mishaps along with systematic assessments of them. The reader should not be distracted by the poor appearance of the text. The information in the book is reasonable and comprehensive. The book is recommended as a reference books for libraries and as a desk copy.

International Law and Pollution. Daniel Barstow Magraw, ed. University of Pennsylvania Press, Philadelphia, PA; 1991. 368 pp. (ISBN 0-8122-3052-3) hardcover.

This book provides an overview of international legal principles and institutional efforts relevant to pollution and then focuses on nuclear accidents and acid rain. A variety of substantive issues must be confronted in order to deal with the full range of international pollution, and various institutional approaches must be utilized in the prevention, cleanup, and compensation efforts. For example, pollution from nuclear accidents results from a single event, whereas acid rain is a product of chronic emissions; the legal and policy concerns differ accordingly. The book discusses fundamental concepts of international pollution, analytic distinctions among types of pollution, paradigmatic responses to pollution, and the relationship among environmental protection, economic development, and human rights. Other areas cover the existing and evolving principles of customary international law relevant to pollution, the U.N. International Law Commission's work on international liability and international watercourses, and a practitioner's perspective. Included is an analysis of the conventional regimes and customary principles applicable to nuclear accidents and the determination and measurement of damages. Finally, the chapters on acid precipitation summarize European efforts to control acid rain.

Monitoring Ecological Change. Ian F. Spellerberg. Cambridge University Press, Cambridge, U.K.; 1991. 334 pp. (ISBN 0 521 42407 0) $27.95/£15.95 softcover.

Living communities are continuously changing, as a result both of natural processes and the activities of man. Effective biological and ecological monitoring programmes are essential for detecting these changes and understanding the factors that influence them. This book provides an introduction to the subject. In the first part of the book, the roles of local, national, and international organizations which implement ecological monitoring programmes are discusses and assessed. In the second part of the book, a wide range of examples are used to explain and evaluate methods of data collection, analysis, and interpretation. The final part focuses on the important applications of biological monitoring, such as pollution control, land use management, monitoring rare species, and post-environmental impact assessment.

Packaging for the Environment. E. Joseph Stilwell, R. Claire Canty, Peter W. Kopf, Anthony M. Montrone. American Management Association, New York, N.Y.; 1991. 262 pp. (ISBN 0-8144-5074-1) $27.95 hardcover.

This book is a dispassionate discussion of major issues of the rather important area of packaging. It contains sections on solid waste problems, the packaging industry, materials infrastructure, international issues and a discussion of the need to understand environmental consequences of product life cycles. Included are also examples of successful actions by leading industries. The book is highly recommended as a desk copy for those concerned with packaging design or the environmental impact of packaging.

Radiation: Doses, Effects, Risks. United Nations Environment Programme, Blackwell Publishers, Oxford, U.K.; 1991. 89 pp. (ISBN 0-631-18317-5) £10.95 softcover.

This book describes and interprets the findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Risks from exposure to a range of natural and man-made radiation sources are evaluated. Some conclusions may be surprising to those who have not explored the scientific realities of the radiation debate. In this concise and authoritative survey of radiation hazards, fully updated with worldwide data from UN sources, information is given on natural sources of radiation, the risks and problems of nuclear power, the radiation exposures from human activities such as medical procedures and coal burning, and the acceptability of risks. In addition, the book examines the role of radiation in life and the effects of radiation on man. Written for the knowledgeable nonspecialist, the booklet is an outstanding contribution to the understanding of radiation. It is highly recommended for general distribution and for application in precollege education.

VD Codes and Standards. Verein Deutscher Ingenieure. VD-Kommission Reinhaltung der Luft, Düsseldorf, 1991, 1992.

The Association of German Engineers (Verein Deutscher Ingenieure) has published a number of new VD standards concerning air pollution control that are available from VD-Kommission Reinhaltung der Luft (VD-RdL) D-4000 Düsseldorf 1:

VD 3477: Biofilters (Dec 1991);

VD 3492 Part 1: Scanning Electron Microscopy Method (Aug. 1991);

VD 2467 Part 1: Measurement of the Concentration of Primary and Secondary Amines by Thin-Layer Chromatography Visual and Densitometric Methods (Aug. 1991);

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At the Desert's Edge. Oral Histories from the Sahel. Nigel Cross and Rhiannon Barker, eds. Panos Publications, Ltd. London, U.K.; 1991. 248 pp. (ISBN 1-870670-26-4) £12.95 softcover.

Energy for a Habitable World. Pierre Elliott Trudeau, ed. Taylor & Francis, Basing-stoke, Hants, U.K.; 1991. 174 pp. (ISBN 0-8448-1713-9) £18.00 softcover.

Nuclear Waste: The Problem that Won't Go Away. Nicholas Lenssen. Worldwatch Paper 106. Worldwatch Institute, Washington, D.C.; 1991. 62 pp. (ISBN 1-878071-07-6) $5.00 softcover.

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Editor-in-Chief: **DAVID C PROSPERI,** *School of Planning, University of Cincinnati,*
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Computers, Environment and Urban Systems is an integrated, multi-disciplinary forum focused on the development, enhancement, and use of computer-based methodologies for understanding and improving environmental and urban systems. Original high quality, theoretical, technological, or applied scholarship provides the basis for a lively presentation of perspectives, research advances, overviews of important new technologies and uses, innovations in major computing efforts, and current book and software reviews.

Theoretical papers focus on either the use of computer technology, or the scientific foundations of computer-based technology in the analysis and improvement of environmental and urban systems.Technology contributions include computer mapping, computer-aided design, data base design and development, desk top publishing, expert and knowledge engineering systems, geographic and land information systems, management information systems, and technological or application breakthroughs in main-frame and micro-based operating systems. Applied contributions clearly demonstrate how computer-based technology advances methodological competence in the analysis of, or policy recommendations in, environmental and urban systems.

A Selection of Papers
T J CARTWRIGHT (Canada), Information systems for urban management in developing countries: the concept and the reality.
P F FISHER & T M ORF (USA), An investigation of the meaning of near and close on a university campus.
M P ARMSTRONG *et al* (USA), Decision support for regionalization: a spatial decision support system for regionalizing service delivery systems.
N J OBERMEYER (USA), Bureaucratic factors in the adoption of GIS by public organizations: preliminary evidence from public administrators and planners.
J E FRANK & M K FALCONER (USA), The measurement of infrastructure capacity: theory, data structure, and analysis.
S A MATTHEWS (USA), Epidemiology using a GIS: the need for caution.
J SHEPHERD (UK), Advances and applications in geographic information systems in the United Kingdom: the contribution of the South East Regional Research Laboratory.

Indexed/Abstracted in: *Cam Sci Abstr, Comput Cont, Curr Cont ASCA, Curr Cont Compumath, Curr Cont / Eng Tech & Applied Sci, Curr Cont SCISEARCH Data, Engng Ind Monthly & Author Index, Geo Abstr, INSPEC, Psychol Abstr, PsycINFO, Sage Fam Stud Abstr*

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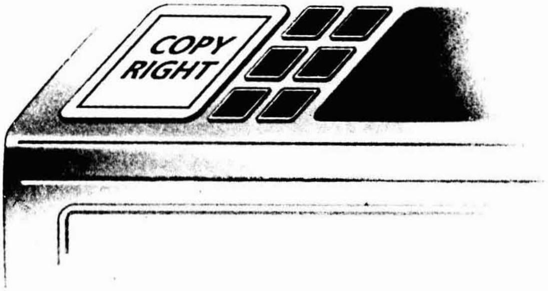
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Public awareness of, and interest in, environmental protection and planned use of natural resources is drawing increasing attention as we approach the end of the 20th century. If we are to understand the complex balance of our environment, interdisciplinary research on local, regional, national and global levels is necessary. The knowledge gained can then be used to provide a basis for environmental policy and legislation. The challenge is to find a way of utilizing the resources of the planet without destroying them, and to bring about necessary changes without catastrophic disruption of the economic and social fabric of civilization. *Ambio* serves the important function of putting into perspective significant developments in the pertinent fields of environmental research, policy, legislation, and related activities, and, most important of all, brings information to the attention of the international public.
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A W SETZER & M C PEREIRA (Brazil), Amazonas biomass burnings in 1987 and an estimate of their tropospheric emissions.
J H PRIMAVERA (Philippines), Intensive prawn farming in the Philippines - ecological, social, and economic implications (1).
A A Al-IBRAHIM (Saudi Arabia), Excessive use of groundwater resources in Saudi Arabia: impacts and policy options.
K TURNER (UK), Economics and wetland management.
A RANDALL (USA), The value of biodiversity.
J A DIXON & P B SHERMAN (USA), Economics of protected areas.
H RODHE, H ERIKSSON, K ROBERTSON & B H SVENSSON (Sweden), Sources and sinks of greenhouse gases in Sweden: a case study.
A H WESTING (USA), Environmental security and its relation to Ethiopia and Sudan.

Indexed/Abstracted in: *Air Poll Titles, Curr Cont ASCA, ASSIA, Aqua Abstr, Biosis Data, Cab Inter, Cam Sci Abstr, Chemical Abstracts Service, CABS, Curr Cont/Agri Bio Env Sci, Curr Cont/Eng Tech & Applied Sci, Eng Ind, Excerp Med*

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One of the oldest established journals in the field, *Atmospheric Environment* publishes papers on all aspects of man's interactions with his atmospheric environment, including the administrative, economic and political aspects of these interactions. Air pollution research and its applications are covered, taking into account changes in the atmospheric flow patterns, temperature distributions and chemical constitution caused by natural and artificial variations in the Earth's surface.
Atmospheric Environment has one of the largest circulations of scholarly journals of this kind. Its high reputation is reflected in the frequency of references to it.

A Selection of Papers
D P CHOCK (USA), A comparison of numerical methods for solving the advection equation - III.
R G DERWENT (UK), Evaluation of a number of chemical mechanisms for their application in models describing the formation of photochemical ozone in Europe.
J SCHAUG, J P RAMBÆK, E STEINNES (Norway) & **R C HENRY** (USA), Multivariate analysis of trace element data from moss samples used to monitor atmospheric deposition.
W M COX & J A TIKVART (USA), A statistical procedure for determining the best performing air quality simulation model.
S WUNDERLI & R GEHRIG (Switzerland), Surface ozone in rural, urban and alpine regions of Switzerland.

A New Patents section is included in this journal.

Indexed/Abstracted in: *Anal Abstr, Acid Pre Dig, Air Poll Titles, Curr Cont ASCA, Aqua Abstr, Biosis Data, CAB Inter, Cam Sci Abstr, Chem Eng Abstr, Chemical Abstracts Service, Curr Cont/Agri Bio Env Sci, Curr Cont/ Phy Chem & Earth Sci, CABS, Environ Per Bibl, Excerp Med, FLUIDEX, Geo Abstr, INSPEC Data, PASCAL-CNRS Data, Sci Cit Ind, SCISEARCH Data, TCEA*

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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.

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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.

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RESOURCES, CONSERVATION AND RECYCLING

Editors: **HARVEY ALTER,** *Resources Policy Department, Chamber of Commerce of the United States, 1615 H Street, NW, Washington, DC 20062, USA,* and **MICHAEL E HENSTOCK,** *Department of Metallurgy and Materials Science, University Park, Nottingham NG7 2RD, UK*

The journal is dedicated to detailed and comprehensive investigations, analyses and appropriate reviews of the interdisciplinary aspects of renewable and nonrenewable resource management, particularly their conservation. Topics include technological management and change for reduced consumption or substitution, recovery of materials and energy from old (established) and new sources, such as from processing wastes from domestic, commercial or industrial sources, management of natural resources including implementation of public policies for conservation, and management of processes and product design, fabrication, and production for efficient utilization of materials and energy. Also included are suitable topics regarding the efficient management and use of air, water and land resources.
Contributions may emphasize any of the aspects mentioned above as well as scientific, technological, or institutional methodology. The latter includes politics, resource management and allocation, social and legal aspects.

A Selection of Papers
R E DEYLE (USA), & **B F SCHADE** (FRG), Residential recycling in Mid-America: the cost effectiveness of curbside programs.
T J BUCKLEY (USA), Calculation of higher heating values of biomass materials and waste components from elemental analyses.
T R CURLEE & S DAS (USA), Identifying and assessing targets of opportunity for plastics recycling.
J-K KOO, S-W KIM & Y-J SEO (Korea), Characterization of aromatic hydrocarbon formation from pyrolysis of polyethylene-polystyrene mixtures.
J-H TAY (Singapore), Complete reclamation of oil palm wastes.
V ANAND, H N CHANAKYA & M G C RAJAN (India), Solid phase fermentation of leaf biomass to biogas.
M BARTOLOZZI, P F MARCONI, G BRACCINI & G MAGNANI (Italy), Cadmium recovery in batch and flow reactors from solutions at different pH.

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