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EDITORIAL

SAFE IS NOT RISK-FREE

There is a great desire in the public to breathe clean air, drink clean water, and eat healthy food. This desire is demonstrated by the passage of an entire set of laws in many industrial countries limiting the discharge of industrial emissions and setting up limits for a number of pollutants in air, water, and food. The public officials have long recognized that chemical, radiological, and biological materials can cause both acute and chronic effects. Therefore their concentration in environmental media must be controlled not only to avoid acute effects, but also chronic effects.

The scientific method for evaluating the impact of chemical, biological, and radiological agents is risk assessment. In the context of environmental protection, risk is defined as the potential for an adverse effect. Risk assessment is the scientific and technical method for systematically evaluating the risk associated with an action or an existing condition.

Due to the preoccupation of the public with cancer risk, cancer risk assessment is being performed routinely in most countries of the industrialized world and in recent years in many developing countries. Cancer assessment is usually based on the assumption that the adverse effect (cancer induction and progression) is linearly proportional to the exposure (or dose) and the dose-response function at low doses is linear and has no threshold. In effect, it is assumed that exposure to carcinogens at any level, even at extremely low levels, is associated with a certain risk. This has led to the statement that there is no safe level of exposure to carcinogens. There has been always a school claiming that carcinogenicity, like any other effect, has a threshold below which no effect is observable. This school is finding increasing number of supporters. However, the mechanism of cancer induction and progression is so poorly understood that both sides can cite significant, but insufficient evidence in support of their argument. Facing such an uncertainty the regulatory agencies have chosen to accept the linear nonthreshold hypothesis as a matter of prudence. Regardless of the acceptance or rejection of the linear nonthreshold theory, the statement that there is no safe level of exposure to carcinogens is incorrect. The fallacy of the argument is the fundamental misunderstanding of what constitutes safety. Safety does not mean absence of risk, and a safe condition does not and cannot imply a risk-free condition.

Most people feel safe in their homes. Yet, we know that living at home is by no means risk-free. All people rightfully demand safe working conditions. However, there is virtually no risk-free working condition. The sight of a young mother taking care of a newborn baby is probably the most expressive demonstration of natural safety. Nevertheless, a small number of small babies are injured or otherwise adversely affected by the actions of their mothers. In fact, a careful observer will have difficulties identifying any human action or situation that is risk-free. There are, however, many human activities and situations that are safe.

The subject is considerably more significant than mere semantics. The public demands safe air, safe water, and safe food. The public cannot and will never achieve risk-free air, water, or food.

In recent months, several new books have exemplified the problem. Dixy Lee Ray and Lou Guzzo in their new book, *Environmental Overkill,* ask whatever happened to common sense (Regnery Gateway, Washington D.C. 1993). This book is a followup to their previous book *Trashing the Planet* (Regnery Gateway, Washington, D.C. 1990). These authors discuss subjects ranging from asbestos to wildlife management, and essentially every environmental issue. Dr. Ray, who has been known as an advocate of nuclear power, demonstrates her independence by questioning the current political acceptance of greenhouse effect. *Trashing the Planet* has been used as a textbook at certain universities and *Environmental Overkill* is likely to find a similar acceptance. Both books are required readings for those who would like to be informed on a different perspective than normally found in environmental advocacy literature.

Elizabeth M. Whelan provides an indepth description of food safety in two recent books, both appearing in their second and revised editions. In *Panic in the Pantry*, Whelan in collaboration with Fredrick Stare and Stephen Barret (Prometheus Books, Buffalo, NY 1992) identifies individuals who have made unsubstantiated or fraudulent claims, some of which continue to this date. She correctly suggests that "natural" is not equivalent to healthy. There are numerous naturally occurring poisons that if consumed in high enough dose are fatal. She points out that many food items contain carcinogens that, if they were not naturally occurring, would be prohibited by the U.S. law. In *Toxic Terror* (Prometheus Books, Buffalo, NY 1992), she discusses scientific aspects of food safety in detail. In addition, she disputes claims by environmental advocacy groups on materials such as asbestos, DDT, PCB, and many other chemicals. She calls for rational scientific assessments in societal decision-making. Whelan convincingly argues that science and not advocacy must be used as a basis for societal decision-making.

These four books and numerous others clearly indicate that the mere presence of a risk does not justify banning a chemical, an industry, or an action. Safety does not and should not imply absence of risk. Instead, the scientific community must provide the public with information indicating that all human activities, even the safest ones, are not free of risk. Instead, human activities should attempt to define what level of risk is acceptable and thus constitutes safety.

A. Alan Moghissi

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INDOOR AIR POLLUTANTS IN A BUILDING BLOCK IN PARMA (NORTHERN ITALY)

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Sixty flats, located in a building block at Parma, were surveyed in order to get information about radon and carbon monoxide concentrations. The measurements of radon, collected using activated carbon canisters, gave an average concentration (23.4 Bq/m^3) close to that obtained in a preceding survey carried out in 97 dwellings in Parma. The values of the readings were relatively independent of the height of the storey from the ground. Also, no significative differences were noted between rooms with double-glazed windows and rooms with single-pane windows. Fifty four additional measurements inside two rooms of adjoining similar flats, one with double-pane windows, the other with ordinary windows, showed a mitigation of the difference in radon concentrations to the extent that the ventilation rate of the two rooms was increased by simply opening the windows a few minutes a day. The measurements of CO, performed with a gas filter correlation CO analyzer, gave an average concentration (3.3 mg/m^3) comparable to that reported for American houses. It has been shown that double-pane windows have moderate influence on the CO concentration. Whereas, it has been demonstrated that flats heated with gas stoves exhibit a higher concentration (3.9 mg/m^3) than flats heated with a furnace-radiators system (2.6 mg/m^3).

INTRODUCTION

It is now recognized that the greatest exposures to airborne combustion products, volatile toxic chemicals and radioactivity, typically occur inside residences rather than outdoors. Althoug indoor pollutants are similar to those found outdoors, sometimes they can reach indoor concentrations comparable in magnitude with those of chemicals or radiation in industrial settings. Various indoor pollutants are known including carbon oxides, nitrogen oxides, organic chemicals, methylene chloride, formaldehyde, radon gas, fibers of asbestos, bacteria, fungi, and so on.

Among the most important are the radon decay products. Prolonged exposure to elevated concentrations of radon has been associated with an increase in the risk of lung cancer (AMACS 1987). Carbon monoxide, a combustion product, can lead to chronic disease or, when present at extremely high levels, even provoke immediate death.

Several factors such as concentration of radium in soil, soil permeability, openings in the building shell, etc., are known to effect the radon concentration inside homes. Likewise, different heating and cooking appliances as well as different habits of the householders may lead to CO concentrations varying over a wide range.

It is known that the indoor Rn concentration is strongly affected not only by the radium content in the soil or walls but also by the ventilation rate, that is the natural or controlled exchange of indoor air with outdoor air (Stranden and Berteig 1980). By using a mathematical model, it can be seen that the Rn concentration is inversely proporpional to the ventilation rate (Nero 1988a). However, surveys carried out in U.S. housing indicated little correlation between Rn concentration and infiltration rate (Nero et al. 1983).

In the U.S., as well as in most northern European countries, people generally live in single-family detached houses where the radon enters the structure from the underlying soil driven by the small difference in air pressure between indoors and outdoors. The pattern for the Rn accumulation is different in flats where radon exhaling from building materials can be the most significant contributor to indoor Rn concentration (Nero and Nazaroff 1984).

This study aimes primarily at the determination of Rn and CO concentrations in a group of 60 flats placed in a building flat block located in Parma and to get insight into the way of accumulation of both of the gases.

EXPERIMENTAL PROCEDURES

As most Italian people live in old houses, a large flat block built in 1926 was chosen for our survey. The construction is a rectangular, masonry building, 170 m long, with 80 flats in it. The flats, all equal to each other, are placed on four storeys. Also, 80 cellars are placed in the basement of the building. In the past years, some of the flats have suffered transformations necessary to fulfill the needs of modern life. In particular, in order to save energy and get a uniform heating of the rooms, ordinary single-pane windows have been replaced by double-glazed windows and stoves by furnace and radiators. Every flat has one cooking range in the kitchen. All the furnaces but one and the stoves are located in the kitchens; in a few flats, a second stove is placed in the corridor. The gas burned by these appliances is methane. Sixty out of 80 householders gave permission of carrying out the measurements in their flat.

A further set of measurements was taken inside two rooms of adjoining similar flats, both placed on the second floor of a building located in front of the surveyed flat block and constructed in 1930 with the same materials. The first room chosen for the test is 4.75 × 3.0 × 3.3 m high with one new wooden door and an aluminium double-pane window. The other three windows of the flat are of the same kind. The second room is 4.75 × 4.0 × 3.3 m high with an old wooden door and a wooden single-glazed window.

The Rn concentrations were measured in the rooms during a two-months experimental protocol. Two distinct periods were considered. In the first one, the windows were kept open 10 min in the morning and 10 min in the afternoon while the doors were only opened to let people in. In the second period, the two windows were kept constantly closed. During the considered periods, the other windows in the flats were open or closed according to the weather. For the sampling of radon gas into the rooms, charcoal canisters were exposed in the rooms for 24 - 48 h.

The charcoal canister method (Cohen and Cohen 1983) was used for sampling Rn in 60 flats in the period starting from December 1992 to March 1993. As people spend at least 8 h daily in bedrooms, the canisters were exposed in bedrooms for 48 - 72 h to provide integrated environmental levels of Rn. None of the rooms had air conditioning or forced ventilation. The windows in the rooms where the canisters were placed were closed and people asked to open the windows as usual.

The amount of radioactivity absorbed in the canisters during the exposure was counted by a gamma spectrometer equipped with 163 cm^3 HPGe and 7.6 × 7.6 cm NaI(Tl) detectors (Malanca et al. 1992).

The measurements of CO were performed with a gas filter correlation CO analyzer (Thermo Electron Co., USA). The minimum detectable limit of the equipment was 0.12 mg/m^3; its precision was ± 0.12 mg/m^3 and the linearity ± 1%. The span was done by using a special air-CO mix for analyzers in which the content of CO was certified to be 40 ppm (40 μL/L). The zero was checked before every reading by insufflating pure synthetic air (21% O_2, 79% N_2) into the analyzer through a pressure reducer.

Since the kitchens are large and used by people as living area, and since the CO sources are located there, measurements of CO were taken twice inside the kitchens, the first time when the charcoal canisters were opened, the second time, 48 or 72 h later, when the canisters were withdrawn. The mean values obtained by averaging these two data were then used for the statistical calculations.

Table 1. Arithmetic mean (AM), standard deviation (SD), geometric mean (GM), and maximum Rn concentration in flats as a function of the distance of the storey from the ground.

Floor	N°	AM ± SD	GM	max
		(Bq/m³)		
Ground	17	20.1 ± 8.8	18.5	41.8
First	14	20.9 ± 6.6	19.8	34.6
Second	17	24.8 ± 9.2	23.2	45.1
Third	12	30.4 ± 13.7	27.8	64.4

RESULTS AND DISCUSSION

The arithmetic mean concentration of Rn in the 60 flats resulted to be 23.4 Bq/m^3 with a standard deviation of 10.8 Bq/m^3. The geometric mean was 21.7 Bq/m^3. These data are in good agreement with the results of preceding measurements carried out by our group in 97 dwellings in Parma (Malanca et al. 1992).

Several authors noted a correlation between the indoor radon concentration and the distance of the storey from the ground level. This pattern was due to the contribution of the radon entry from the soil (Abu Jarad and Fremlin 1982). In Table 1, the Rn concentration in the rooms is plotted against their distance from the ground. Two important facts result:

(1) It seems clear that there is not an appreciable effect due to the subsoil contribution. This is probably explained by the fact that the rooms on the ground floor are separated from the soil by a "layer" of well-ventilated cellars. In such a way, the Rn generated by the radium disintegration in the underlying soil can hardly pass into the upper floors.

(2) The Rn concentration shows a small but positive correlation with the height of the storey. This trend may be produced by convective transport of Rn from the lower floors to the higher floors. It was found that several common services (water and gas pipes, chimney ducts, drains, etc.) might carry the radon from the lower parts of the building to the upper parts owing to numerous faults in seals around pipes and wires penetrating the flats.

Table 2. Comparison of Rn concentrations in flats with single-pane windows vs. flats with double-pane windows.

Windows	N°	AM ± SD	GM	range
		(Bq/m³)		
Single-pane	25	24.5 ± 9.8	22.6	10.0 - 42.9
Double-pane	35	23.1 ± 10.8	19.6	8.9 - 64.4

Table 3. Rn concentrations inside a room with double-pane windows vs. a room with single-pane windows under two different ventilation conditions. a: windows opened 10 min in the morning and 10 min in the afternoon; b: windows constantly closed.

Window	N°	AM ± SD	GM	range
		(Bq/m³)		
Single-pane [a]	11	16.8 ± 3.5	16.4	9.2 - 21.8
Double-pane [a]	11	21.8 ± 3.5	21.5	17.0 - 27.7
Single-pane [b]	16	15.2 ± 3.3	14.8	9.6 - 20.0
Double-pane [b]	16	43.9 ± 7.6	43.2	28.5 - 56.2

To elucidate any connection between Rn stagnation and energy saving devices, the concentration of Rn in rooms with ordinary wooden windows was compared with the concentration of that gas in flats with double-pane windows. The results are shown in Table 2. The emerging datum is that there is not a significant difference between the two groups of flats. This is probably explained by living habits together with an enhanced air exchange rate through the door and the chimney ducts.

The results of the measurements in the adjoining flats are shown in Table 3. As expected, the strongest difference between the Rn concentration in the two rooms was attained during the second period when both of the windows were kept continuously closed. On the other hand, this difference was clearly mitigated by simply opening the windows 20 min a day.

On the whole, the outcome of this experiment indicates a tendency of Rn to accumulate in a room with double-pane windows. Average values found in living areas of 50 dwellings at Reggio Emilia (Malanca et al. 1991) showed slight excess of Rn (37 Bq/m^3) in daily ventilated rooms with double-pane windows compared to rooms with single-glazed windows (32 Bq/m^3). Based upon our experience in radon surveys, householders are generally used to daily ventilate their flats more often when they have double-glazed windows. This practice will contribute to reduce the excess of indoor Rn concentration in flats with energy conservation devices.

The arithmetic mean, standard deviation, and geometric mean of the CO concentrations were 3.3 mg/m^3, 2.6 mg/m^3, and 2.6 mg/m^3, respectively. These values are comparable to those reported by Nero (1988b) for thousands of American houses.

In Table 4, arithmetic and geometric means of the CO concentration in the rooms with double-pane windows are compared to the corresponding values for rooms with old wooden windows. Likewise radon, no significant differences can be found between the two groups.

On the contrary, a clear-cut difference was noted when the CO average concentrations were calculated against the kind of heating system (Table 5). Both arithmetic and geometric means as well as the range of values were higher in flats where one or more gas stoves were used for heating. Some factors contribute to this result:

(1) No stoves are outfitted with thermostats. In cold weather, people generally leave them on continuously for several hours a day whereas furnaces have an intermittent operation.

(2) Furnaces have been installed quite recently. They are more modern and efficient than stoves and also produce hot water for hygienic purposes. Stoves do not produce hot water which is warmed up by gas boilers. The amount of methane burned in flats with stoves and boilers is a great deal higher than that burned in flats with furnaces.

(3) All of the furnaces are properly connected to their chimney duct and an external air supply is frequently present. Sometimes, stovepipes connect-

Table 4. Comparison of CO concentration in flats with single-glazed windows vs. flats with double-glazed windows. a: average values.

Windows	N°	AM ± SD	GM	range [a]
		(mg/m^3)		
Single-pane	25	3.4 ± 2.7	2.6	0.9 - 12.9
Double-pane	35	3.3 ± 2.5	2.5	0.5 - 12.0

ing the stoves to their chimneys are too long (up to 7 m) and air supply is never present. However, this drawback is partially counterbalanced by the higher percentage (56%) of flats endowed with stoves and ordinary windows. The CO median concentration inside these flats (2.7 mg/m^3) is indeed lower than the corresponding value in flats with stoves and double-pane windows (3.3 mg/m^3).

The highest instantaneous CO concentrations (15.8 mg/m^3 and 14.6 mg/m^3) were recorded in two flats heated with stoves. In the latter flat, the stovepipe valve was found closed; it was promptly opened and the householder, an elderly single person, was warned about the danger. Whenever high CO values were detected in the kitchen, measurements were also taken in the lounge and bedrooms where high values were also observed. As expected, the minimum instantaneous CO concentration (0.2 mg/m^3) was recorded in a flat with a furnace. Slightly higher values (0.7 mg/m^3) were measured in five flats heated with furnaces.

CONCLUSIONS

In this report, it has been shown that the concentration of Rn and CO does not depend significantly on the presence of devices (double-glazed windows) aimed to save energy, provided that the

Table 5. CO concentrations in flats heated with stoves vs. flats heated with a furnace-radiators system. a: average values.

Heating appliances	N°	AM ± SD	GM	range [a]
		(mg/m^3)		
Stoves	32	3.9 ± 2.8	3.1	0.7 - 12.9
Furnace	28	2.6 ± 2.0	2.1	0.5 - 9.6

householders take care of ventilating the flat once or twice a day.

It has also been shown that gas stoves, operated without an external air supply and connected to their chimney ducts by long stovepipes, are responsible for an excess CO concentration inside homes.

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EXPOSURE TO PARTICLE-BOUND POLYAROMATIC HYDROCARBONS IN THE AL-MANSORIA RESIDENTIAL AREA DURING THE KUWAIT OIL FIRES: A QUALITATIVE APPRAISAL OF THE ADSORPTION ROLE

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High ambient levels of inhalable particulate matter (PM_{10}) were detected in residential areas during the oil well burning in Kuwait (February-November 1991). Because inhalation exposures to PM_{10} were significant (data on PAH quantification are scarce), it became possible to describe the exposure to PM_{10}-associated PAHs of alternative courses of events, such as PAH-particle interaction mechanisms. Depending on particle adsorption characteristics (affinity and site availability), it is concluded that, contrary to what is currently believed, low levels of ambient PM_{10} levels did not indicate low PAH exposures in Al-Mansoria residential area during May 10-31, 1991. Due to the frequent presence of dust particles in the ambient air caused by the heavy dust fallout in Al-Mansoria (average > 65 tons/km^2) during May, 1991, the predicted patterns can be explained by two hypothesized mechanisms. The first is a two-step process: loss of PAHs from low affinity sites and reabsorption onto stronger affinity ones leading to low surface coverage at high PM_{10} concentrations. The second involves dilution of PAH-containing soot with aeolian particles. Both events can lead to low ambient PAHs at high PM_{10} levels or high ambient PAHs at low PM_{10} levels.

INTRODUCTION

Polyaromatic hydrocarbons (PAHs), products of incomplete combustion of organic matter, are classified as genotoxic carcinogens according to their mechanistic activity (Weisburger and Williams 1980). They are easily adsorbed onto atmospheric particulate matter due to their low vapor pressure (Yamasaki et al. 1982). Animal studies have shown that this PAH/particle association gives a marked increase in their carcinogenicity (Saffioti et al. 1968). According to the model of Gerde et al (1991), low and frequent exposure to particle-bound PAHs, common for humans, should lead to tumors at the site at which particles are initially deposited.

Inhalable particles (PM_{10}, particles with diameter less than or equal to 10 µm) contain the greatest abundance of PAH compounds (Lioy and Greenberg 1990) and can penetrate to the thoracic region of the lung. These particles are deposited on the lining layer of the upper bronchial tree, which is the location of the preferential sites of origin of bronchial carcinoma (Schlesinger and Lippman 1978; Lippman and Schlesinger 1984).

The burning of oil from more than 700 wells in oil fields located both north and south of Kuwait City (Fig. 1) and the release of nearly 70 million m^3 of gases and incomplete combustion products daily (WMO 1991) raise concerns about levels of PM_{10} (EPC 1991) and associated PAHs (El-Desouky and Abdulraheem 1991) in residential areas. Growing concern about immediate as well as long-term effects associated with exposure to these contaminants makes the prediction of human health risks a task of increasing urgency. The continuous 9-month exposure to oil-related contaminants can lead to a wide variety of effects on human health. A prevalence of symptoms pertaining to the respiratory system was indicated in the study of DIER/KISR (1991). A comparison between the incidence rate of respiratory illness before exposure to the oil fire pollution (1987, 1988, and 1989) and after exposure (1991) revealed a statistically significant increase in frequency ($P < 0.01$) after the oil fire exposures in the Al-Ahmadi residential area (Daoud 1991). According to Snashall (1991), the development of respiratory cancers in Kuwait is of concern because the levels of PAHs were quite high at times, although very variable. He stated that measurements from a slight increase to an increase of about 150-fold in PAH concentrations existed due to the oil fires in Kuwait but he included no data in his report.

During the oil well fires in Kuwait, high levels of PAHs in air were believed to be associated with high PM_{10} levels. Most investigations involved with health impacts of oil fires were concerned with effects associated with exposure to particulate matter without sufficient estimation of particle-bound PAHS. This is evident in the amount of measurements

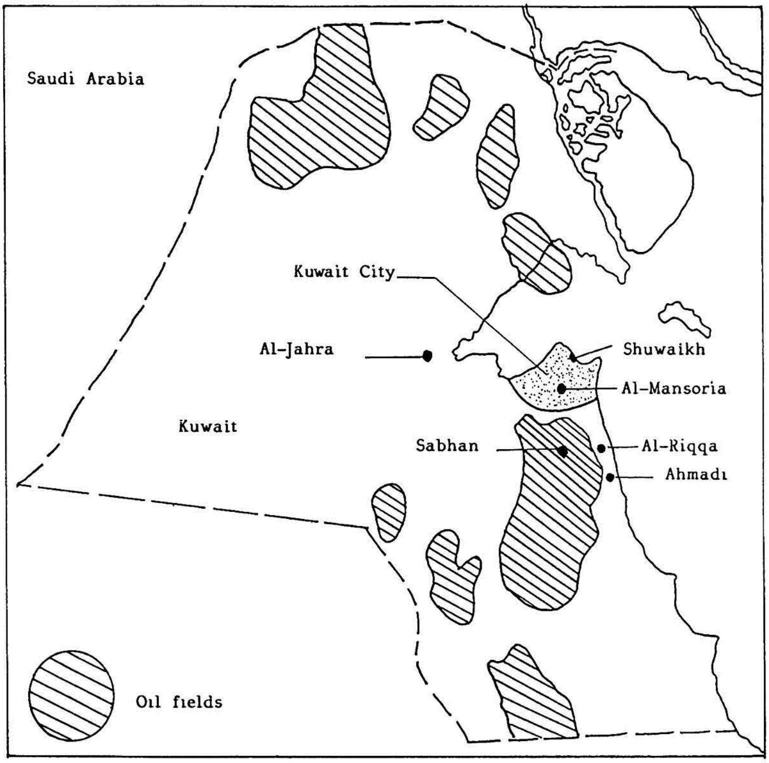

Fig. 1. Some residential areas and oil fields on fire in Kuwait.

of particulate matter levels (EPC 1991) compared with the few determinations of associated PAHs (El-Desouky and Abdulraheem 1991). Mulholland et al. (1991) detected PAHs both in white smoke and ambient dust. Maximum levels of PAHs were usually higher than the maximum permissible limit of 1 ηg/m^3 as included in the USSR Report (Tsaturov and Nazarov 1991). The concentration of particle-bound benz(a)pyrene ranged between 0.41 and 30.57 ηg/m^3 during the period April-July 1991 (El-Desouky and Abdulraheem 1991).

For PAHs to constitute a health risk, they must be present at the exposure site at a certain concentration and for a length of time sufficient to initiate the toxic effect. The evaluation of possible risks to the exposed population is significantly influenced by the atmospheric removal of PAHs through physical, chemical, and biological mechanisms (Valerio et al. 1984). Processes determining the presence and fate of PAHs in the ambient air include chemical conversion, volatilization and condensation (Lioy and Greenberg 1990; Pistikopoulus et al. 1990; Greenberg and Darack 1987; Nikolau et al. 1984; Nielsen et al. 1983).

Because consistent exposure monitoring of PAHs was not conducted in Kuwait, predictive and modelling studies must be utilized to contribute to an understanding of the long-term effects on public health. De Raat et al. (1987) demonstrated that volatility of PAHs predominated the variation in the relative concentration of PAHs species with time and space. According to Yamasaki et al. (1982), it is the low vapor pressure of PAHs that causes them to adsorb or condense onto airborne particulate matter. Pistikopoulos et al. (1990) distinguished between two mechanisms of formation of particle-associated PAHs: rapid adsorption of PAHs onto preexisting particles forming particles below 1 µm, and condensation forming particles above 1 µm.They confirmed by factor analysis that the volatility of the PAHs is the essential parameter determining the relative importance of these mechanisms. Funckle et al. (1986) concluded that "PAH, as less volatile and typically pyrolytic products, are enriched in small particles ($\leq$ 0.063 µm) and uniformly distributed on larger particles".

The PAH particle association was described by Yamasaki et al. (1982) as being in the form of a physical adsorption equilibrium. In addition, they observed that in ambient air the state of three- to five-ring PAHs is considered to be well explained by using the Langmuir adsorption concept. Consequently, association between PAHs and particles must be influenced by particle adsorption characteristics: affinity and site availability. Nielsen et al. (1983) indicated that the accessibility of active surface adsorption sites for PAH molecules depends on particle size, shape, and specific surface area. They pointed out that the adsorption affinity of particles is influenced by the chemical structure of sites available for PAH adsorption. Although PAHs are highly particle associated, they only achieve low surface coverage in the presence of excess surface adsorption sites (Gerde et al. 1991).

Based upon existing data and physical and chemical mechanisms, human exposure to PM_{10}-bound PAHs must be thoroughly evaluated. With the limited nature of PAH data during the oil fires in Kuwait, an estimation of health risks requires a descriptive process for retrospective reconstruction of exposure estimates. Due to its important role in determining the fate and presence of ambient PAHs, adsorption could be the descriptive process required. This paper is an attempt to utilize particle adsorption characteristics to predict the pattern of daily exposure levels to PM_{10}-bound PAHs over a period when both PM_{10} (May 10-31, 1991) and associated PAHs' levels (10, 15, 23, and 31 May, 1991) were measured.

THEORETICAL DEVELOPMENT

The huge release of incomplete combustion products (WMO 1991) and the presence of significant levels of PM_{10} in some residential areas in Kuwait (EPC 1991) are expected to have been major contributors to human exposure to a mixture of PM_{10}-bound PAHs. Due to the limited data on the effects of atmospheric mechanisms on ambient PAH levels in Kuwait, it is useful to examine the contribution of particle-PAH interaction characteristics to the levels of PM_{10}-bound PAHs at the exposure site. While few efforts were directed towards evaluating PAHs associated with finer particle fractions, most measurements were concerned with PAHs associated with total suspended particles (TSP). During May 1991 in the Al-Mansoria residential area, PM_{10} samples were collected daily using a PM_{10} sampler with Glass Fiber Filters (GFF) (EPC 1991). Samples collected on the 10th, 15th, 23rd, and 31st of May, 1991 were analyzed for six PAH compounds (El-Desouky and Abdulraheem 1991). Results of PM_{10} and PAH analyses are presented in Tables 1 and 2. To our knowledge, these PAH measurements were the only published figures simultaneously recorded with ambient PM_{10} determinations during the oil fires.

To optimize utility of the available data, the atmospheric adsorption density of PAHs (Q), expressed as

Date May 1991	PM$_{10}$ (μg/m^3)
10	507.2
11	270.2
12	158.9
13	154.1
14	186.9
15	162.8
16	714.8
17	249.3
18	598.4
19	282.9
20	189.2
22	3091.1
23	435.2
24	304.1
25	134.9
26	231.1
27	634.2
28	300.0
29	181.1
30	243.8
31	156.9

Table 1. Daily PM$_{10}$ levels measured in Al-Mansoria during 10-31 May, 1991 (EPC 1991).

Date May 1991	PM$_{10}$ (μg/m^3)	Phenanthrene (ηg/m^3)		Flouranthene (ηg/m^3)		Pyrene (ηg/m^3)		Benz(a)anthracene (ηg/m^3)		Benz(a)pyrene (ηg/m^3)		Benz(g,h,i)perylene (ηg/m^3)	
		Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
10	507.2	1.4	0.038	5.39	0.168	8.41	0.38	2.02	0.11	4.19	0.16	1.83	0.04
15	162.8	1	0.025	5.22	0.21	6.58	0.25	10.05	0.48	15.33	0.79	59.24	1.14
23	435.2	0.81	0.025	4.54	0.19	6.11	0.25	4.86	0.23	0.41	0.14	6.8	0.098
31	156.9	1.62	0.048	4.28	0.16	6.8	0.29	5.18	0.27	30.57	1.17	17.09	0.21
Average	315.5	1.21		4.85		6.98		5.53		12.63		21.24	

Table 2. Mean (N=3) and standard deviation of PAH measurements (El-Desouky and Abdulraheem 1991).

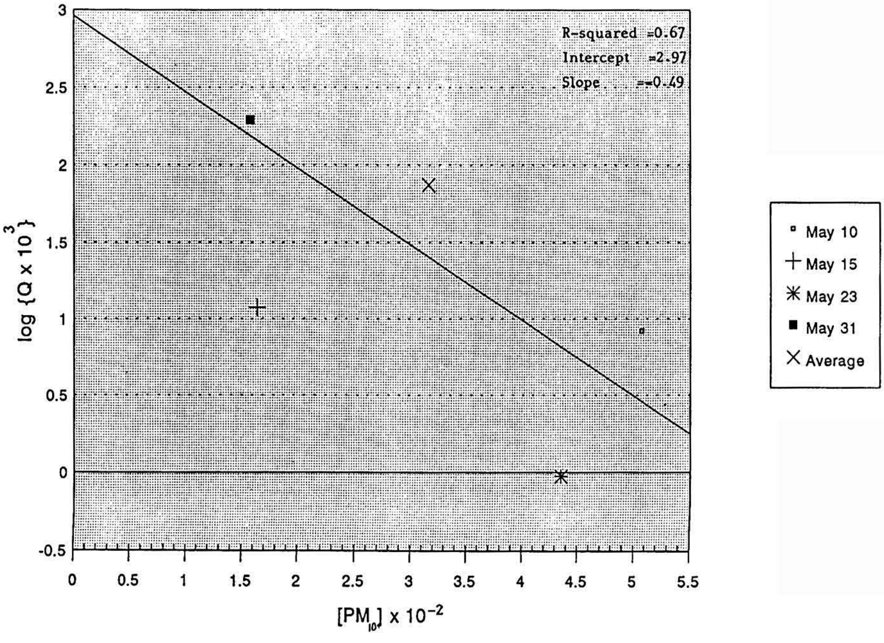

Fig. 2. Influence of ambient PM$_{10}$ levels on adsorption density (Q) of benz(a)pyrene in the Al-Mansoria residential area (May 10-31, 1991).

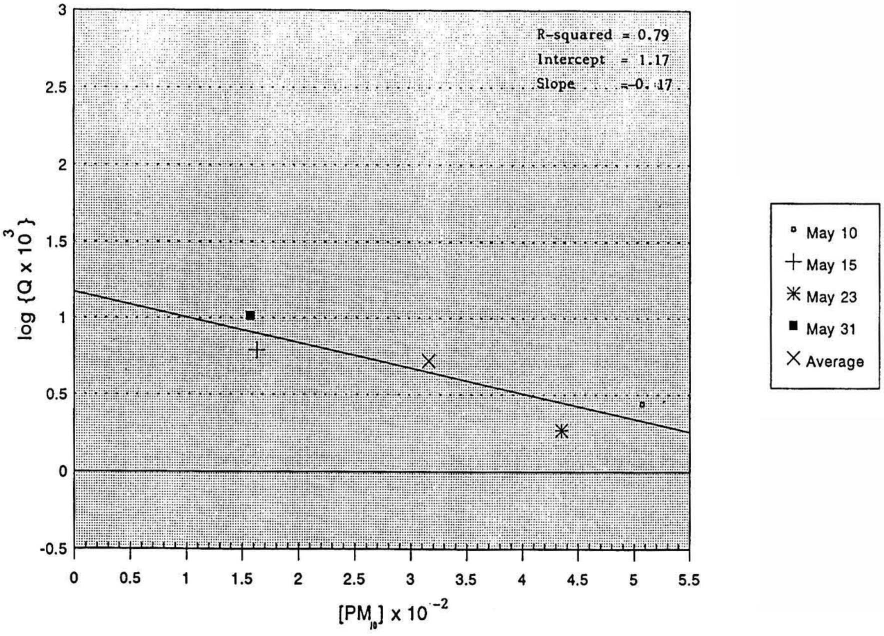

Fig. 3. Influence of ambient PM$_{10}$ levels on adsorption density (Q) of phenanthrene in the Al-Mansoria residential area (May 10-31, 1991).

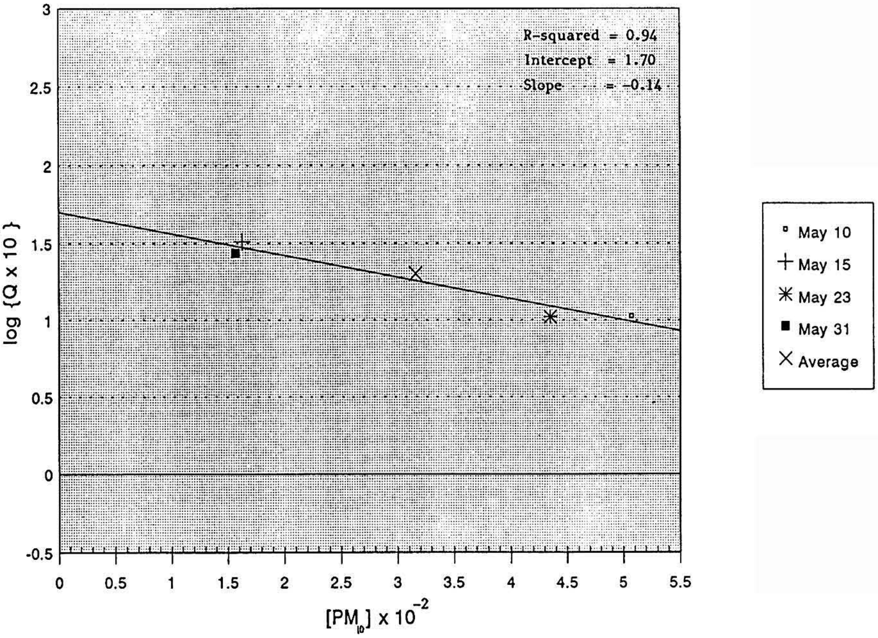

Fig. 4. Influence of ambient PM_{10} levels on adsorption density (Q) of fluoranthene in the Al-Mansoria residential area (May 10-31, 1991).

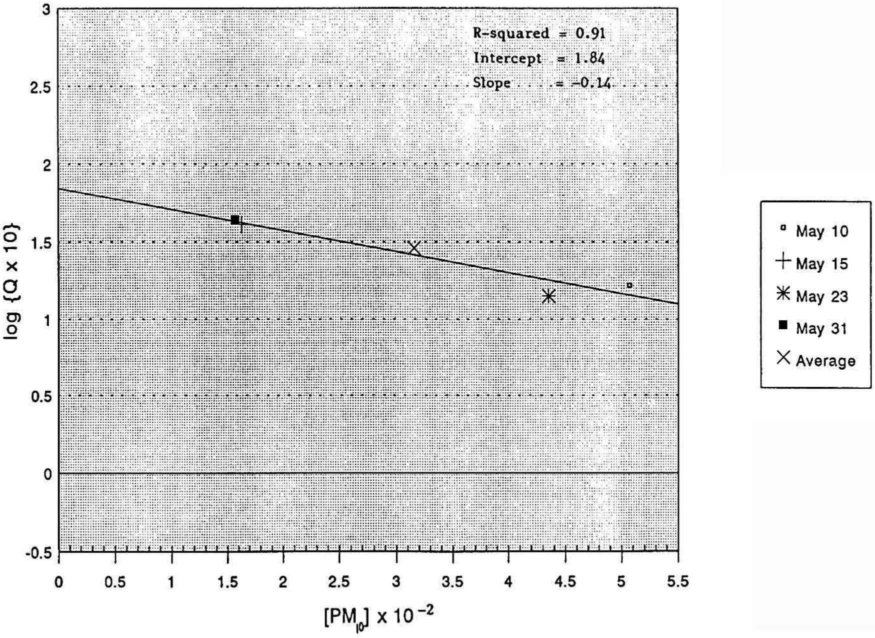

Fig. 5. Influence of ambient PM_{10} levels on adsorption density (Q) of pyrene in the Al-Mansoria residential area (May 10-31, 1991).

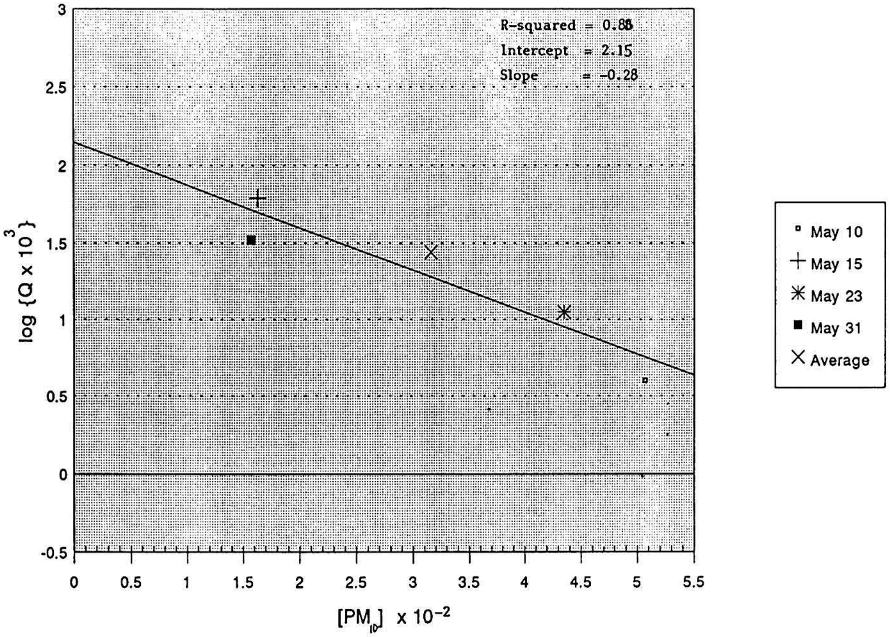

Fig. 6. Influence of ambient PM_{10} levels on adsorption density (Q) of benz(a)anthracene in the Al-Mansoria residential area (May 10-31, 1991).

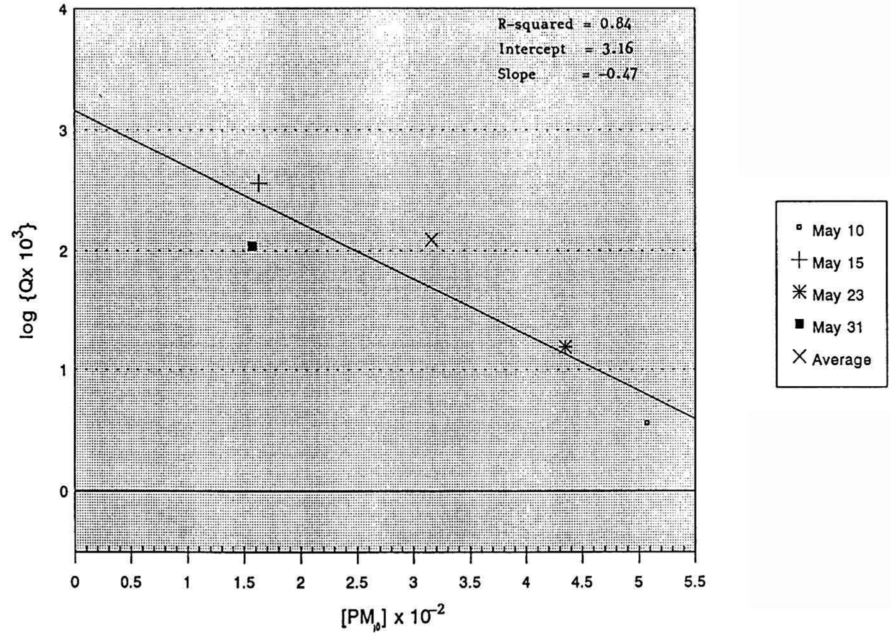

Fig. 7. Influence of ambient PM_{10} levels on adsorption density (Q) of benz(g,h,i,)perylene in the Al-Mansoria residential area (May 10-31, 1991).

the mean concentration of PAH in particulate phase ($\eta g/\mu g$), was studied as a function of ambient [PM_{10}] ($\mu g/m^3$).

Plots of logQ vs. [PM_{10}] for benz(a)pyrene, phenanthrene, fluoranthene, pyrene, benz (a) anthracene, and benz(g,h,i)perylene are presented in Figs. 2, 3, 4, 5, 6 and 7. As indicated in the figures, the decrease in logQ as PM_{10} increases is the general trend characterizing these relationships. To examine the meaningfulness of and to utilize these relationships in estimating the effects of adsorption characteristics on ambient PAH levels, these relationships were linearized using regression analysis:

$$\log Q_{ij} = I_i + S_i\,[PM_{10}]_j \qquad (1)$$

where:

Q_{ij}: average atmospheric adsorption density of the ith PAH on the jth day ($\eta g/\mu g$),

$[PM_{10}]_j$: average concentration of inhalable particles on the jth day $\mu g/m^3$, and

I_i and S_i: intercept and slope of the line and are characteristics of the ith PAH.

Based on existing data and relevant adsorption mechanisms, relating ambient PAH concentrations to PM_{10} levels during this period is useful. The ambient level of the ith PAH on the jth day, $[PAH]_{ij}$ ($\eta g/m^3$), can be calculated as:

$$\begin{aligned}[PAH]_{ij} &= [PM_{10}]_j\, Q_{ij} \\ &= [PM_{10}]_j\, 10^{I_i + S_i [PM_{10}]_j} \qquad (2)\end{aligned}$$

The average outdoor level of the ith PAH over n days can then be calculated as:

$$\sum_j \frac{[PAH]_{ij}}{n} = \frac{1}{n} \sum_j [PM_{10}]_j\, 10^{I_i + S_i [PM_{10}]_j} \qquad (3)$$

INFLUENCE OF ADSORPTION ON PAH EXPOSURES

The linear decrease shown in Figs. 2-7 describes the atmospheric adsorption behavior over the range of PM_{10} levels observed on the four days of PAH analysis: 156.9-507.2 $\mu g/m^3$ (Table 2). Assuming that PAHs achieve low surface coverage in the presence of excess surface adsorption sites (Gerde et al. 1991), this behavior can characterize PAH adsorption occurring during the studied period (May 10-31, 1991, 134.9 $\mu g/m^3$ < [PM_{10}] < 3091.1 $\mu g/m^3$) (Table 1). Further, the dependence of daily outdoor levels of PAHs on [PM_{10}], which describes the exposure scenario during that period, can be investigated. Based on Eq. 2, two patterns were observed. The first shows that, with increasing [PM_{10}], ambient phenanthrene, fluoranthene, and pyrene levels were increasing at [PM_{10}] < 290 $\mu g/m^3$ and decreasing at [PM_{10}] > 290 $\mu g/m^3$ (Fig. 8). The second shows that ambient benz-(a)-anthracene, benz(a)pyrene, and benz(g,h,i)-perylene were decreasing with increasing [PM_{10}] in the full-studied range of PM_{10}.

In his assessment of air pollution impacts, Özkaynak (1992) observed that ambient PM_{10} concentrations do not usually represent the signature of the oil fires alone; rather they combine crustal dust resuspended by wind and oil-fire soot. According to El-Desouky and Abdulraheem (1991), because calm winds did not effectively ventilate the plume at times, a higher proportion of PM_{10} was from the soot. They noticed that with calm winds most of the PM_{10} filter papers were black, while with windy conditions filter papers were mostly yellow or brown. Kuwait is known for the highest levels of suspended particulate matter in the world (Al-Majed 1992). Because Kuwait City is bordered to the north, west, and south by deserts covered with loose sediments that lack significant protective vegetation cover, large amounts of dust and sand are raised and carried by the dry, fresh prevailing northwesterly winds to residential areas (Safar 1985). Fig. 10 shows the average dust fallout during May, 1991 in 5 locations in Kuwait (Fig. 1) (EPC 1991). Among these locations, Al-Mansoria showed the highest average dust fallout (65 tons/km^2). The levels of suspended particulate matter at an exposure site is influenced by wind speed (Al-Majed et al. 1992) (Fig. 11).

Under such conditions, two mechanisms (Figs. 12a, b) can be hypothesized to explain the predicted patterns. These patterns could be consistent with either one or both mechanisms. The first is valid if PAHs were strongly bound to the soot portion of PM_{10}, Studies have confirmed the high adsorption of PAHs to graphitized soot (Kalashnikova et al. 1979). Therefore, levels of ambient PM_{10}-bound PAHs are determined by the input of soot to the atmosphere and the degree of dilution with dust particles. Under calm conditions, the only input of PM_{10} to the atmosphere would be soot from the oil fires and, due to the strong affinity of soot for PAHs, increases in soot levels in the atmosphere will be accompanied with increases in PAH ambient levels.

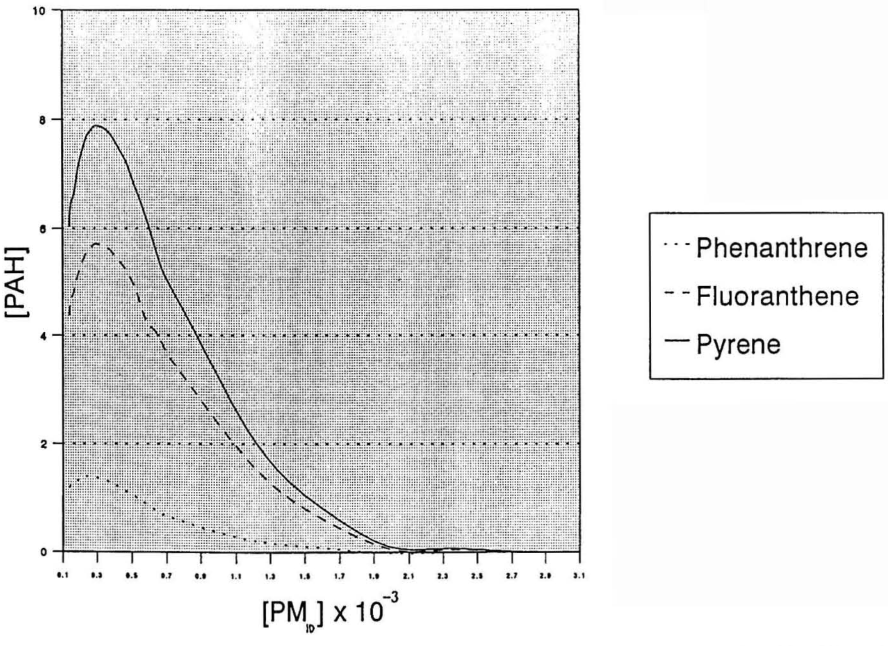

Fig. 8. Predicted influence of ambient PM$_{10}$ levels on PAH exposure concentrations in the Al-Mansoria residential area (May 10-31, 1991).

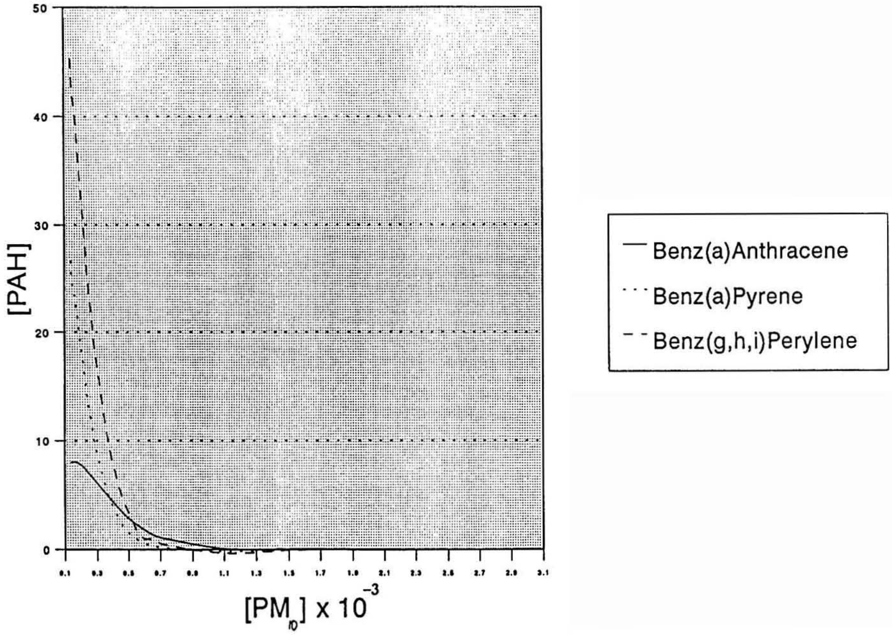

Fig. 9. Predicted influence of ambient PM$_{10}$ levels on PAH exposure concentrations in the Al-Mansoria residential area (May 10-31, 1991).

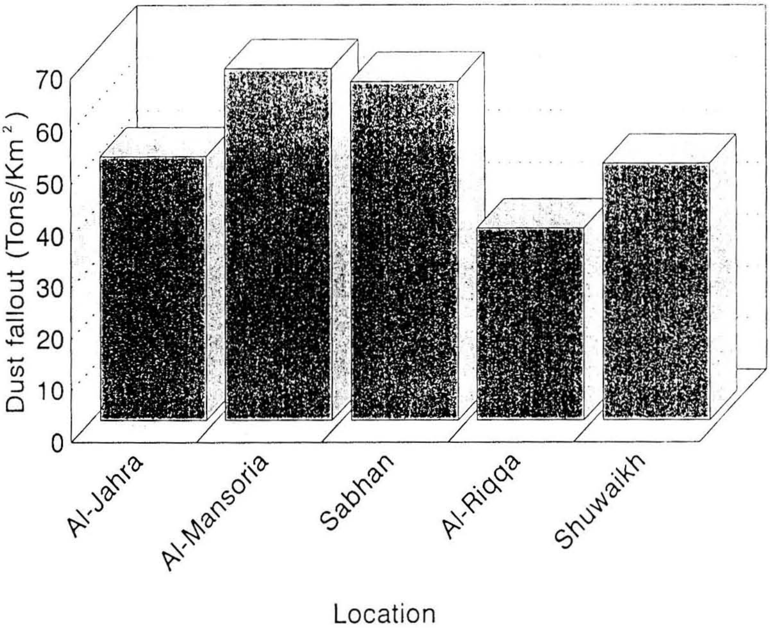

Fig. 10. Average dust fallout during 1991 in some residential areas in Kuwait during May 1991 (after EPC 1991).

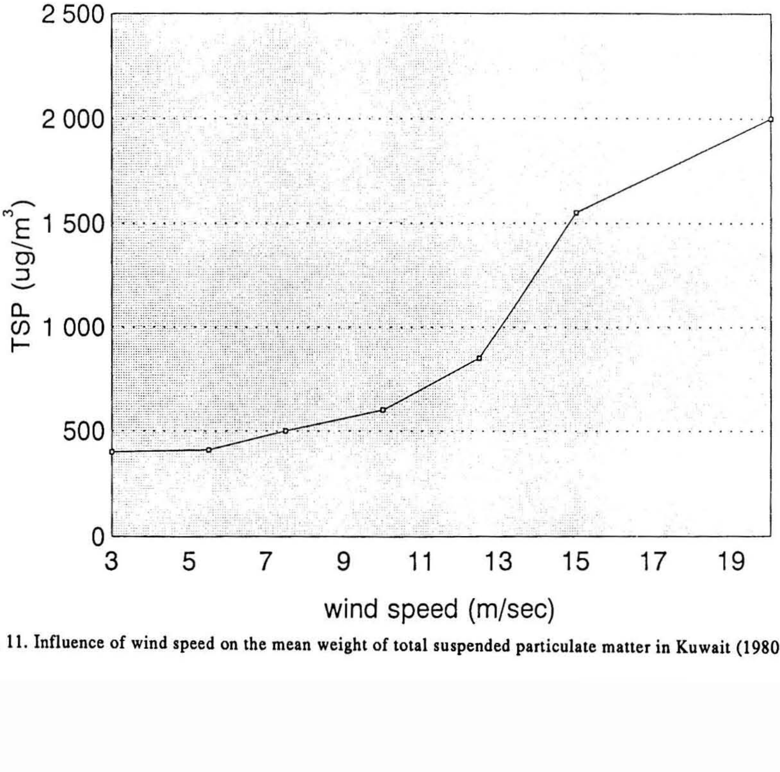

Fig. 11. Influence of wind speed on the mean weight of total suspended particulate matter in Kuwait (1980-1984).

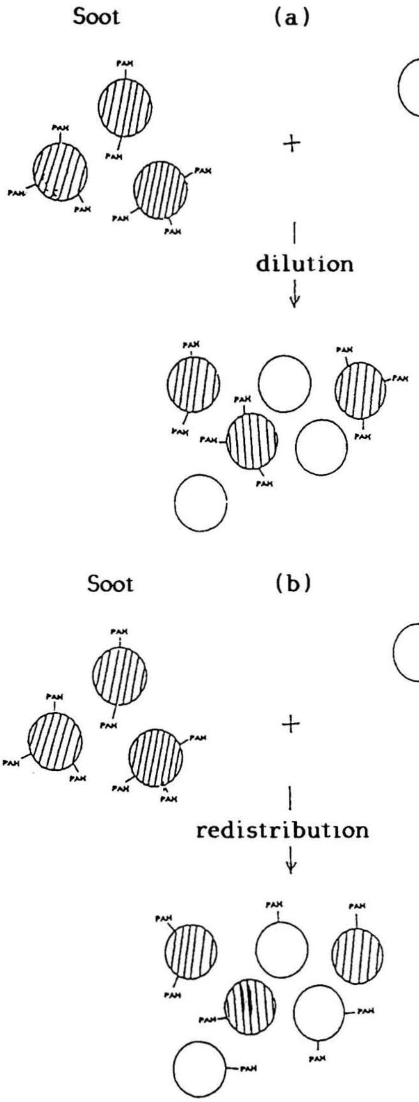

Fig. 12. Hypothesized mechanisms of PAH-particle interaction during the Kuwait oil fires.

Under stormy conditions, soot particles emitted from oil fires will combine, depending on wind speed and direction, with dust, as they travel to the exposure site, forming a mixture of dust and soot. The distance of downward transport and the extent of mixing and dilution are determined by wind speed. Levels of adsorbed PAHs at the exposure site will be determined by the degree of dilution with dust particles. At low dilution, high ambient PAHs levels will occur. In contrast, lower levels of PAHs will be present at higher degrees of dilution. The dilution effect is illustrated in Fig. 8. The increase in ambient phenanthrene, fluoranthene, and pyrene levels at $[PM_{10}] < 290$ mg/m^3 indicates that the main source of these contaminants to the atmosphere in that range was PM_{10} from oil-fire soot. At $[PM_{10}] > 290$ µg/m^3, levels of these PAHs were decreasing with increasing [PM_{10}] indicating a dilution effect caused by PM_{10} other than soot.

The second mechanism is redistribution of PAHs among particle surface sites according to particle adsorption characteristics (affinity and site availability). It involves two steps: (a) loss of PAHs from carrier particles (Miguel 1984), which can be caused by competition imposed by stronger affinity sites and by transformation and transport processes (Nielsen et al. 1983), and (b) reabsorption onto stronger adsorption affinity particles. Under windy conditions, depending on wind speed and direction, soot particles released from oil fires will combine with dust particles as they travel to the exposure site forming a heterogeneous mixture of adsorption surface sites: silt, clay, sand, and soot. The degree of particle heterogeneity will be mainly influenced by the wind speed and the structure and quantity of dust particles. At elevated PM_{10} levels, the high heterogeneity in the PM_{10} structure leads to variability in both adsorption affinity and adsorption site availability for PAHs. In the presence of excess surface sites, a high degree of PAH redistribution could occur while these particles travel, leading to low surface coverage by PAHs. Under calm conditions where particulate levels are lower, reabsorption would be minimal and PAHs would achieve higher surface coverage. The patterns in Fig. 9 did not show the dilution shift indicating the possibility of the occurrence of contaminant loss and reabsorption in soot as well as in the soot-dust mixture.

CONCLUSIONS AND RECOMMENDATIONS

Relying on only 4-d data to predict a 22-d exposure scenario makes the interpretation of such patterns an effort of equivocal validity and a task of questionable statistical significance. However, the domination of adsorption as a major determinant of spatial and temporal variations of relative PAH ambient concentrations and indications of field observations during the oil fires provide a rational support for the predicted patterns. In addition to the limited quantitative assessment, this logical foundation promotes a qualitative evaluation conveying that, contrary to what is currently perceived about PAHs released from oil fires, low levels of PM_{10} at an exposure location do not necessarily reflect low inhalation exposures to PAHs. As a result, this paper was intended to be more of a qualitative evaluation of the role of particle adsorption characteristics in assessing exposure to PM_{10}-bound PAHs in Kuwait. Due to the limited database, quantification is seen as a useful supplement, rather than vice versa. Adsorption of PAHs onto particulate matter plays a significant role in their distribution and partitioning in the air and contributes greatly to their presence at an exposure location. Thus, the outcome of this assessment can be supported with information on meteorological conditions and transformation/transport mechanisms to provide a basis for future investigations that involve interrelating environmental fate to human exposure.

Because residential areas received varying contributions of soot and aeolian dust, these scenarios are site specific and can not be used to describe exposures occurring at other locations. Depending on (a) distance from burning oil wells, (b) geographic location, and/or (c) meteorological conditions, each site must be studied individually.

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SMOKING HABITS, ATOPY, AND PREVALENCE OF SICK BUILDING SYNDROME SYMPTOMS AMONG OFFICE WORKERS IN NORWAY

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The relative influence of sex, atopy, smoking habits, and age on reported sick building syndrome (SBS) symptoms among office workers was investigated through questionnaire studies among 1293 employees in 10 nonindustrial buildings. The occurrence of atopy among the office workers was not found to be different from that of the general population. Both sex and atopy were found to be important for the prevalence of SBS symptoms. The prevalence of symptoms was higher among atopic individuals than among nonatopics, and higher among females than among males. While sex was found important for some symptoms, atopy was important for all of them. Statistically significant differences in the prevalence of symptoms between smokers and non-smokers (i.e., never smokers) were not found. The results indicated interrelations between smoking and atopy, with enhanced prevalence of some symptoms. Age of the persons were also included in the present analyses. Different ways of grouping age indicated different trends in associations between age and the prevalence of symptoms, but the study did not show any unambiguous associations between the age and the prevalence of symptoms.

INTRODUCTION

The sick building syndrome (SBS) includes a broad range of symptoms such as irritative symptoms in eyes, nose, throat, and lower airways, and also skin reactions, unspecific hypersensitive reactions, mental fatigue, headache, nausea, and dizziness (WHO 1983). A building is classified as sick on the basis of prevalence of these symptoms in the building population. The symptoms are nonspecific in origin and are common in the general population. The prevalence of the various symptoms may be influenced by both personal and environmental factors. An increased prevalence is difficult to determine and it is even more difficult to identify the cause for increased prevalences. Although numerous investigations have been reported, there still appears to be much controversy about the primary cause and the mechanism of the appearance of symptoms (Hedge et al. 1989a; Zweers et al. 1990; Menzies et al. 1990; Kirkbride et al. 1990; Miller 1990; Robertson et al. 1989; Woods et al. 1987; Morris et al. 1987; Burge 1990; Gibert et al. 1992; Hodsgon et al. 1987; Bluyssen 1992; Jaakkola 1991).

As for personal factors, most investigations have shown higher occurrence of symptoms among females than among males (Burge 1990; Norbäck et al. 1987; Finnegan and Pickering 1987; Lenvik 1990). Both atopy and tobacco smoking are factors that may very well affect the prevalence of SBS symptoms. Some of the SBS symptoms are commonly associated with allergic reactions or hyperreactivity. Tobacco smoke can provoke allergy-like reactions in hypersensitive individuals. Tobacco smoke can cause irritative symptoms and airway disorders. Exposure to environmental tobacco smoke (ETS) is also a well-known cause of discomfort. Although both atopy and smoking have been dealt with in several investigations, there is still a need for improving the knowledge base.

There are extensive differences in the data on the prevalence of atopy. Reported prevalence ranges from less than 10% to more than 50%, depending on the methods used and the types of allergy and populations studied. There are only a few studies on the cumulative prevalence in the general populations. A Swedish study among school children showed a cumulative prevalence of 25.5% (Åberg 1988). An investigation in Finland (Haahtela 1979) among persons aged 14-16 y, showed a prevalence of 32%. A German study among preschool children showed a prevalence of 28.8% for atopic diseases (Kunz et al. 1990). Only a few studies have considered atopy and SBS. An accumulation of sensitive individuals, a healthy worker effect in atopics, was not found to be significant (Norbäck et al. 1987; Arundel 1987). Associations between presence of allergic disease and symptoms of SBS have been reported (Jaakkola et al. 1991). It has been reported that the differences between the sexes regarding symptoms disappear when adjusted for atopy (Norbäck 1990a), indicating that atopy may be the cause of the difference in the prevalence of symptoms in the two sexes.

Smoking habits vary greatly between different populations. For instance, among females in Norway with primary education only, 68%, 56%, and 25% are daily smokers in the age groups of 25-35 y, 36-49 y, and older than 49 y, respectively. Among males with higher education, the rates range from 21% to 29%, depending on age, and among males without higher education, between 41% and 66% are daily smokers, again depending on age. Accordingly, there may be some interactions between smoking habits, atopy, age, and SBS symptoms; and tobacco smoking can easily become a confounding factor in evaluations of SBS problems. In fact, some studies report correlations between tobacco smoking and SBS symptoms (Norbäck 1990b; Valbjørn et al. 1987), and some do not (Hedge 1989b). The latter investigation, however, reported an association between passive smoking and disorder ailments.

Further studies are needed in order to assess the influence of personal factors on the prevalence of SBS symptoms. This paper deals with the relationships between the personal factors sex, sensitivity of the individual, smoking habits, and prevalence of SBS symptoms. This analysis is part of ongoing investigations regarding possible relationships between occupational, environmental and personal factors, and the prevalence of SBS symptoms.

MATERIALS AND METHODS

Study population

Employees in ten private and public nonindustrial buildings were asked about their working situation and about "sick building syndrome" symptoms by questionnaires.

The study was conducted at the request of the health personnel in the buildings. Thus, the buildings were already suspected of being "sick".

The questionnaires were performed in the period of 1989-1992.

Questionnaire

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

Information was asked for on 223 items. This paper deals with the items relevant to the specific problem discussed. Information was requested not only on typical SBS symptoms, but also on colds and sinus trouble.

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

The questionnaires were organised and distributed by the health personnel at the offices under investigation. The importance of high response rates and complete answers from the employees was stressed. All staff members were encouraged to participate, regardless of their rank.

The question about atopy was: "Have you ever suffered from allergic reactions (eczema, asthma, hay fever, allergy to pollen)?" The categories of answer were "yes" or "no". Unlike many investigations on allergy, this investigation was not orientated towards specific types of allergy. The question was intended to show a cumulative prevalence of allergy.

Statistical analyses

The prevalence of each health symptom in the different population groups was compared, using the χ^2 test.

The relative influence of sex, atopy, and smoking habits upon the prevalence of symptoms was analysed using logistic regression. Tests for interrelations between smoking and atopy, smoking and age, sex and smoking and between atopy and sex were also performed.

The regression analysis was performed stepwise until the parameters of significance level < 0.05 were included in the model. Adjusted odds-ratios (OR) with a 95% confidence interval were calculated from the logistic regression models. In all the statistical analyses, a 5% level of significance was used.

RESULTS

Study population

The study base consisted of approximately 1500 persons, most of whom were engaged in clerical work. From these, 1293 completed the questionnaire; 51 were omitted from the analyses because of the lack of statement of sex. The number of respondents ranged from 14 in the smallest company to 595 in the largest. The response rate was above 70% for each company.

Sick leave, maternity leave, and vacation were in about 85% of the cases of the nonrespondents stated as the reason for nonparticipation. For the rest, unwillingness to participate, short-time absence, etc. are assumed to be the reason. No further analysis of the nonparticipants was done.

There was no significant difference between the mean age of the atopics and of the nonatopics, or between the mean age of the these two groups and that of the whole study population (Table 1). As in regard to daily cigarette consumption, there was no significant difference between the atopic and non-atopic smokers or between females and males. However, the proportion of smokers among males is significant less than that among females, which is commented later on in this paper.

The prevalence of atopy among employees with different historical smoking habits is shown in Table 2. The prevalence of atopy is significantly higher among

Table 1. Demographic data for females and males. M.A = mean age (y). P = proportion (%). D = Daily cigarette consumption (number of cigarettes smoked).

	All	Atopics				Non-atopics			
	M.A	P	M.A	Smokers		P	M.A.	Smokers	
				P	D			P	D
All (n=1242)	39.2	30.1	39.5	29.7	10.5	64.2	39.0	31.1	11.7
Female (n=759)	38.2	33.3	38.8	32.8	9.8	60.3	37.5	34.5	10.6
Male (n=483)	40.9	25.1	41.1	23.1	12.7	70.2	41.0	26.5	13.9

Table 2. Prevalence of self-reported atopy among groups with different historical smoking habits.

	Current smokers	Current non-smokers	Never smoked	Ex-smokers
Females (n=759)	31.8 % (n=83)	34.4 % (n=169)	30.2 % (n=103)	46.3 % (n=61)
Males (n=483)	21.9 % (n=28)	25.8 % (n=91)	21.1 % (n=52)	35.5 % (n=34)

exsmokers than among the other groups, between which there is no significant difference in this respect. The prevalence of symptoms, controlled for sex, atopy, and smoking habits, is displayed in Table 3.

The results from the logistic regression analyses, i.e., adjusted OR-values, are displayed in Table 4. Non-atopic males aged 45 y or more, who had never smoked, were used as reference in the calculation of OR-values.

Table 3: The prevalence (%) of symptoms for females (3a - upper table) and males (3b - lower table).
(*) Two-tailed p-value calculated by χ^2- test.

	Female, atopics			Females, non-atopics		
Type of symptom	Smokers	Non-smokers	p (*)	Smokers	Non-smokers	p (*)
Headache	44.0	41.1	0.71	28.5	26.0	0.62
Heavy head	62.3	59.6	0.71	45.3	47.0	0.74
Tiredness	46.7	44.7	0.80	23.1	29.9	0.16
Poor concentration	12.5	20.7	0.17	10.9	10.4	0.90
Cold	20.8	20.2	0.92	7.9	12.4	0.18
Sinus trouble	13.5	14.0	0.94	5.0	5.4	0.87
Itching/smarting in face	26.8	27.1	0.97	8.7	18.2	<0.05
Stuffy/runny nose	45.3	44.3	0.90	13.6	13.2	1
Itching/irritating eyes	55.3	41.7	0.08	26.4	35.7	0.07
Dry/irritating throat	56.6	55.9	0.93	28.9	29.8	0.85
Dry skin/hands	76.0	67.4	0.22	51.0	48.7	0.67
Dry/irritating skin in face	75.3	64.5	0.13	44.4	43.1	0.81
Skin diseases	28.3	16.2	0.09	3.9	3.7	0.91
Dizziness	16.7	12.8	0.49	7.2	8.2	0.74

	Male, atopics			Male, non-atopics		
Type of symptom	Smokers	Non-smokers	p (*)	Smokers	Non-smokers	p (*)
Headache	26.1	14.9	0.26	9.8	11.9	0.61
Heavy head	42.9	32.7	0.37	19.8	18.6	0.82
Tiredness	33.3	21.3	0.27	11.9	13.5	0.73
Poor concentration	26.1	15.6	0.30	11.1	7.7	0.38
Cold	30.4	17.0	0.20	11.1	8.8	0.56
Sinus trouble	13.6	6.5	0.33	1.3	5.3	0.14
Itching/smartingin face	13.6	9.1	0.57	3.8	3.0	0.73
Stuffy/runny nose	47.8	34.0	0.27	19.5	16.1	0.50
Itching/irritating eyes	50.0	41.7	0.50	15.0	18.3	0.52
Dry/irrating throat	30.4	27.1	0.77	20.2	20.2	1
Dry/irritating skin on hands	30.4	17.4	0.22	9.9	15.7	0.21
Dry/irritating skin in face	25.0	20.5	0.67	14.6	13.3	0.77
Skin diseases	19.0	7.0	0.15	1.4	3.0	0.44
Dizziness	18.2	10.9	0.41	4.9	3.6	0.63

Table 4. The relative degree of association between sex, smoking habits, atopy, and age and reported symptom prevalences, expressed in adjusted odds-ratios (OR). 95% confidence intervalls in parenthesis.

Type of symptom	Sex	Atopy	Age	Interactions
Headache	3.00 (2.02-4.47)	1.94 (1.34-2.75)		
Heavy head	3.43 (2.47-4.76)	1.98 (1.43-2.74)		
Tiredness	2.46 (1.70-3.57	2.36 (1.41-2.57)	0.66 (0.46-.95)	
Poor concentration		1.83 (1.16-2.88)		
Cold		2.39 (1.55-3.68)		
Sinus trouble		3.91 (2.15-7.10)		
Itching/smarting in face	3.84 (2.10-7.02)	2.47 (1.57-3.88)		
Stuffy/runny nose		4.07 (2.87-5.78)		
Itching/irritating eyes	1.88 (1.33-2.66)	1.56 (1.01-2.41)	0.68 (0.48-0.97)	Atopy and smoking 2.63 (1.33-5.21)
Dry/irritating throat	1.90 (1.35-2.68)	2.64 (1.89-3.69)		
Dry/irritating skin on hands	6.00 (4.16-8.64)	2.42 (1.71-3.42)		
Dry/irritating skin in face	5.10 (3.49-7.45)	2.23 (1.45-3.42)		Atopy and smoking 2.63 (1.33-3.04)
Skin diseases		3.05 (1.38-6.75)		Atopy and smoking 4.71 (1.66-13.4)
Dizziness		2.71 (1.61-4.56)		
Other unspecific diseases	2.51 (1.01-6.24)	2.86 (1.18-6.92)		

Grouping: Age; "Older or equal 45 y", and "younger than 45y". Smoking habits; "Current smokers" and "never smoked". Atopy; "Yes" and "no", according to self-reporting. Reference group used: Nonatopic males who have never smoked and of age 45 y and older.) (Only OR-values with statistically significant outcome in the regression analyses are included in the table).

It was also asked whether problems had led to consultation with a physician. Among the atopic individuals, 56.1% of the females and 38.0% of the males replied in the affirmative. The mean for the whole study population was 35.5% and 20.6%, for females and males, respectively.

Distribution of symptoms

As reported elsewhere, the prevalence of symptoms (Table 3) shows that sex significantly influences the reporting of symptoms. In both sexes, the prevalence of symptoms is higher among atopic individuals than among nonatopics.

For all symptoms, statistically significant correlations were found between prevalence of the various symptoms and atopy.

Atopics report higher prevalences than nonatopics. For most of the symptoms, sex also correlated to the reported prevalence. Sex was the best explanatory variable for the general symptoms headache (OR=3.00) and heavy head (OR=3.50) and for the symptoms dry hands (OR=6.28), dry face (OR=5.10), and itching face (OR=3.84). For the following symptoms, statistically significant correlations were found only to atopy; sinus trouble (OR=3.98), cold (OR=2.39), poor concentration (OR=1.83), stuffy nose (OR=4.07) and dizziness (2.71). Since skin diseases are common symptoms in atopy, it is not surprising that these are strongly related to atopy (OR=3.05). For some symptoms, the analyses showed interactions between atopy and sex and atopy and smoking. There was no significant correlation between any of the symptoms and smoking alone. Itching of the eyes was strongly dependent upon an interaction between atopy and smoking. When controlled for atopy, there was a significant correlation between eye problems and smoking habits among the atopics (OR=1.76), while sex was found to be the best explanatory variable (OR=2.41) among the nonatopics. A significant correlation was found between smoking and prevalence of unspecific skin problems among the atopics (OR=2.47), but the correlation was insignificant among the nonatopics. When controlled for smoking habits, atopy was the only significant factor for the prevalence of unspecific skin diseases among smokers (OR=10.80) and nonsmokers (OR=3.73) alike. The tendency towards enhanced importance of atopy among smokers compared with nonsmokers was also found for itching face, with OR=3.86 among smokers and OR=1.86 among nonsmokers. The outcome from the regression analyses showed that age, as a separate factor, was statistically significant for the prevalence of tiredness and eye problems, with fewer problems among employees younger than 45 y. Analyses controlled for sex and atopy showed this result for females, but showed no difference between the males younger than and the males older than 45 y. Further analyses with different ways of grouping the age did not show any unambiguous association between prevalence of symptoms and age.

DISCUSSION

The prevalence of symptoms found in this study is somewhat higher than that reported from other studies among office workers. These differences, and the general differences between such studies, could be explained partly by variations in the definition of questions. In this study, information was requested on symptoms over a period of one year, while many studies cover shorter periods.

The prevalence of atopy in the whole study population was 30.1%, 33.3% for females, and 25.1% for males. It is the general impression that about 1/4-1/3 of the general Scandinavian population suffer from atopy. The population of the present study does not show any deviation from the general population in this respect, and there is no indication of any healthy worker effect. However, individuals who are atopic do report higher occurrence of symptoms than nonatopics.

The present work shows a higher prevalence of atopy among females than among males. However, no reports have been discovered which establish any differences in the tendency of atopic in the two sexes. A plausible explanation for the present findings might be the higher smoking rate, and hence more development of atopic symptoms among females than among males. However, Table 2 shows a higher prevalence of atopic females than males also among persons who had never smoked.

The highest prevalence of atopy was found among exsmokers. The lowest prevalence was found among individuals who have never smoked. Since atopics are more susceptible to SBS symptoms than nonatopics, this shows that nonsmokers consists of two groups which are diametrically opposed to each other regarding sensitivity to SBS symptoms.

It does not seem unlikely that some people who experience special skin or airway disorders consider themselves to be atopic without really being so according to medical criteria. This will cause an overestimation of prevalence. On the other hand, some people who are disposed to allergy, are not aware of it, and hence the prevalence may be underestimated. The net effect of such phenomena is not known. However, if overestimation is more widespread among females than among males, and/or underestimation is greatest among men, the result will be a higher prevalence among females than among males.

To conclude, among the nonatopics, no differences were found in the prevalence of the various symptoms among smokers as compared with nonsmokers (Table 3). Among atopics, the prevalence of the symptoms was higher among the smokers than among the nonsmokers, although the difference was not statistically significant. This may indicate interrelations between smoking and atopy, which was also indicated in the regression analyses. This does not necessarily mean that biological interactions occur, but may just as well indicate that smoking generates atopy and that atopics are more susceptible to the SBS symptoms than nonatopics are. Such trends are not so prominent in the results for females. As mentioned above, overestimation of the prevalence of allergy will tend to mask any real effect of smoking on atopy.

Some reports indicate that SBS is correlated to passive smoking rather than personal smoking habits. This study does not show such an association. Smoking in areas where several people congregate, including indoor working areas, was prohibited in Norway by law in 1988. In principle, no smoking and no exposure to ETS should occur in working areas. However, 32.2% of the females and 36.3% of the males reported that tobacco smoking takes place in their own office, and about 11.8% of males and 13.2% of females reported discomfort from tobacco smoke. Even if tobacco smoking does occur, it may not be heavy enough to cause obvious problems.

In the general Norwegian population, 33% of females and 36% of males are daily smokers. The present study showed smoking habits close to this mean for females, but about 10% lower for males. The proportion of smokers decreases with the level of education. Office work has been a typical employment for females, especially in secretarial functions, not requiring higher education. Males in this occupation often have specific executive positions requiring special qualifications and education.

The relative influence of sex and atopy varied from symptom to symptom. The symptoms that are specific and easily recognisable, such as cold and stuffy/runny nose, seem to be dependent on atopy and less influenced by sex. The more unspecific symptoms, such as headache and feelings of dryness, seem to be very dependent on the respondent's sex. This may indicate that some groups of symptoms are more influenced than others by different subjective perceptions in the two sexes. Not all of the symptoms need to be present to classify a building as sick. It may be that any cluster of several symptoms might be adequate, and symptoms influenced as little as possible by subjective perceptions, would be desirable. Further work should be done on this question.

The logistic regression analyses showed only a marginally higher occurrence of tiredness and of eye problems among employees aged 45-75 y than among younger persons. However, preliminary analyses controlled for sex, atopy, and smoking habits, indicated differences in the prevalence of symptoms, depending on the age grouping. The differences were not statistically significant, owing to the small number of individuals in the sub-populations. The data base did not permit closer examination of these findings.

CONCLUSION

The personal factors atopy and sex are both of major importance for the prevalence of SBS symptoms, as reported by questionnaire studies. Smoking seems influence the prevalence of the different symptoms among atopics, but not among nonatopics.

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A METHOD TO ASSESS ENVIRONMENTAL ACCEPTABILITY OF RELEASES OF RADIONUCLIDES FROM NUCLEAR FACILITIES

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A method to evaluate the potential of radionuclide releases to harm the environment is presented. The method employs four steps. First, humans are used as an indicator species because of their known radiosensitivity and because assessment methodology has been well developed. Second, predicted or measured radionuclide concentrations in soil, water, and air are compared to environmental increment values for each radionuclide. The environmental increment values are mostly based on natural variability and are useful for screening potentially unacceptable concentrations. Third, radiological doses are calculated to generic target organisms and compared to a dose criterion. We define a generic plant, fish, mammal, and bird using available methods and data. We suggest that if the calculated dose < 1 $mGy \cdot a^{-1}$, radiological impacts on nonhuman biota should be negligible. The fourth step is an in-depth assessment, which would only be required if doses to the generic target organisms exceed the criterion. This method was used to evaluate environmental protection from geological disposal of nuclear fuel wastes in Canada, and may be applicable in other cases.

INTRODUCTION

The need for firm procedures

The importance of ecological risk assessment has increased as we strive to design industrial and other developments with minimal impact on nonhuman biota and the general environment. Much of the discussion that has ensued has highlighted ecological principles and the immense complexity of ecosystems. Some general and specific assessment methodologies have been proposed (Menzie et al. 1992; Graham et al. 1991; Hunsaker et al. 1990; O'Neill et al. 1982), but often the discussions are restricted to concepts without a clear methodology to help evaluate potential impacts (e.g., Burger and Gochfeld 1992). A framework is needed that can be used practically with our present knowledge and would allow continuous improvements in a given direction for a range of environmental assessments. The lack of a defined framework is not cost-effective and is not conducive to incremental improvements in models and data by the scientific community at large.

In the nuclear industry, human safety has often been the focus of environmental assessments. However, environmental protection is also of concern, encompassing both the abiotic environment and nonhuman biota (e.g., Kahn 1992). Given this need, how can environmental protection be ensured from potential releases of radionuclides from nuclear facilities? What is a suitable assessment framework that can be implemented to harmonize with existing assessments for human safety? These questions are addressed in the Canadian nuclear fuel waste management program (Dormuth and Nuttall 1987), but no previously established methodology could be found to meet these needs. The present paper outlines a new methodology, which can also be applied to releases of radionuclides from many types of facilities.

Required components of a usable method

This method for assessing acceptability of radionuclide releases to the environment is based on potential impacts to nonhuman biota and to the abiotic parts of an ecosystem. To be practical, a usable method must be:

1. easily integrated into existing methodologies used to assess human safety,

2. applicable to a variety of individuals, populations or species, and allow whole communities and ecosystems to be evaluated,

3. applicable to changes in environmental conditions over long periods of time,

4. monitorable, and

5. flexible and allow for more than one criterion to be used.

The first point is important because human safety assessment methodologies are well developed for the nuclear industry, and the inclusion of environmental assessments would be most easily done with a parallel methodology. Points two and three acknowledge that assessments must often encompass very long times (e.g., thousands of years for nuclear waste), and that we need to address the whole environment at the ecosystem level. The method must also be monitorable to some degree to assure compliance and to provide feedback to improve the assessment methodology. Also, the method should not rely on a single rigid criterion (e.g., Chapman 1991). This is especially important when the level of contamination cannot be related to ecological impact with a high degree of certainty. Although, in principle, the term "risk" assessment implies an evaluation of this uncertainty, we rarely have sufficient data to properly characterize this variability. The described method is not a risk assessment in the sense that probabilities of an impact are not calculated. However, probabilistic distributions of transfer factors are allowed in the evaluation of radionuclide transport through the biosphere.

Outline of the method

The described method builds on available assessment methodology and data, and has four main steps:

1. determine if safety criteria are met for a sensitive indicator species, represented by humans;

2. evaluate protection of the abiotic environment by comparing the potential increase in concentration of each radionuclide added to the environment to an appropriate baseline concentration;

3. evaluate the radiological dose received by generic target organisms; and

4. evaluate impacts further, if required.

The methodology for the first three steps is outlined and the last step is briefly discussed. If the radionuclide release to the environment exceeds the limits set using the first three steps, then additional assessment methods are required. The method was used in an environmental assessment of potential impacts of geological disposal of used nuclear fuel in Canada (Davis et al. 1993; Grondin et al. 1993; Goodwin et al. 1993).

HUMANS AS A CRITICAL INDICATOR SPECIES

In the nuclear industry, the level of safety required for protection of human individuals from radiological effects is often thought likely to be adequate to protect populations of other species, although not necessarily individual members of those species (ICRP 1977; 1991). This assumes that humans are one of the most radiation-sensitive species because they are long-lived mammals. It also implies that individual human life is valued more than individuals of other species, and that it is the health of the population of nonhuman biota that is of prime importance. The assumption translates into the use of human protection to infer ecological protection, which implies that humans are selected as a critical indicator species.

The assumption has been widely supported (IAEA 1992; NCRP 1991), but many organisms have not been tested and the argument is based on limited evidence. Also, this can only be valid when both humans and other biota inhabit the same part of the environment. In some instances, nonhuman organisms could be exposed to higher concentrations because of habitat differences, and there could be an impact on certain species without a concomitant impact on humans (Thompson 1988). This could be so when a "critical group" of humans is selected for assessment purposes, as is often the case. The critical group may be defined as a group of humans that receive the largest radiological dose. However, this may be outside of some exclusion zone, so that some parts of the environment may be exposed to higher radiological doses. Also, humans may only partially use a contaminated resource (such as water) whereas other biota (such as fish) may totally depend on it. Therefore, humans are best thought of as one of several indicator species.

THE ABIOTIC ENVIRONMENT

Protection of the abiotic environment will also protect the biota. This holistic approach protects the ecosystem and implicitly protects whole biotic communities. Often, the status of the abiotic environment is more easily monitored than the health of biota. If radionuclides are released to the environment, air, soil and water concentrations can be measured to provide data on the levels of contamination. However, we still require criteria to assess acceptability of these levels.

Potential radionuclide contaminants can be divided into those present naturally and those mostly introduced into the environment through human activities. Therefore, some radionuclides are naturally present in every ecosystem, and we can assume the biota have adapted to these concentrations. There are a few areas of exceptionally high natural background levels where this may not be the case (BEIR 1990).

The concentration of radionuclides in the abiotic part of the ecosystem varies in time and space. This variability must be considered if abiotic concentrations are to be used as an indicator of ecosystem health. Variability in radionuclide concentration increases with increasing spatial and temporal scales. The appropriate range in scales depends on the nature of the ecosystem. Here, it is assumed that a definable ecosystem has a temporal scale of greater than one year, and a spatial scale of more than one hectare. Variations within these scales are assumed to be tolerated by ecosystems. Although smaller or shorter-lived ecosystems occur, they are not often the object of environmental protection.

It is suggested that an environmental increment (EI) value can be set for each radionuclide, based on knowledge of the variability in abiotic parts of the ecosystem (Amiro 1993). The EI value defines an additional level of contamination that can be tolerated by the ecosystem. The EI values for naturally occurring radionuclides are mostly based on one standard deviation of the variability in concentration, consistent with the scales of variability defined previously. For anthropogenic radionuclides, values are not quite so easily defined. For radionuclides such as ^{137}Cs, today's variability in concentrations in the far-field from sources is used. These concentrations are mostly caused by nuclear weapons fallout. EI values should be set with caution because background levels of radionuclides become inflated with sequential releases to the environment. Also, the consequence of multiple sources could result in unacceptable concentrations, even if each individual source complies with

Table 1. Background concentrations and environmental increments (EI) of some radionuclides (from Amiro 1993).

Radionuclide	Half-life (years)	Concentrations			
		Water Mean	Water EI	Soil Mean	Soil EI
		($Bq \cdot m^{-3}$)		($Bq \cdot kg^{-1}$ dry)	
$^{14}C^*$	5.7×10^3	2.3×10^2	1.	2.3×10^2	1.
^{90}Sr	2.9×10	2.5×10^1	3.	7.	0.5
^{99}Tc	2.1×10^5	1.5×10^{-5}	$2. \times 10^{-6}$	$6. \times 10^{-3}$	6.6×10^{-4}
^{129}I	1.6×10^7	$3. \times 10^{-5}$	4.3×10^{-5}	$3. \times 10^{-5}$	1.2×10^{-5}
^{137}Cs	3.0×10	1.5	0.2	$9. \times 10^1$	6.6×10^1
^{226}Ra	1.6×10^3	5.	1.	2.6×10^1	4.4×10^1
^{238}U	4.5×10^9	1.3	2.	1.2×10^1	2.6×10^1

* Units for ^{14}C are $Bq \cdot kg^{-1}$ ^{12}C in soil and water

the EI value. EI values for selected radionuclides are presented in Table 1.

These EI values can be used to screen whether an additional concentration of a radionuclide has the potential to cause an environmental problem. For example, if the ^{226}Ra concentration in a lake is increased by 0.01 Bq·m^{-3}, it is unlikely that this addition will cause significant environmental injury. This concentration is much below background, and is much less than the EI value, based on natural variability (Table 1). However, if the ^{226}Ra concentration in a lake was increased by 100 Bq·m^{-3}, potential radiological effects should be assessed further. EI values can also be set for nonradioactive toxic elements (Amiro 1992a).

EVALUATION OF RADIOLOGICAL DOSE TO TARGET ORGANISMS

In the ecological hierarchy, absolute protection of individuals implicitly protects all other ecological units, such as populations and communities. Of course, there must be total protection, including the ability to reproduce. The difficulty occurs when a single indicator species is selected to represent protection of all species, because there is no guarantee that the indicator species is really critical (Cairns 1975). Here we suggest some generic target organisms to be used for radiological dose assessment.

For radiological protection, we recognize that injury is caused by absorption of energy in living tissue from the decay of radionuclides. This allows radiological dose from different radionuclides to be added to determine total dose to the target organisms. The radiological uptake and dose absorbed by individual biota is dependent on the physiological, anatomical and ecological nature of the individual and species. The vast diversity of the biota, in even a small area, has implications on radionuclide exposure and dose consequences. We consider the selection of target organisms, the absorption of radionuclides by target organisms, the radiological dose caused by the radionuclides, and the impact of the dose.

Generic target organisms

Generic target organisms are defined because:

1. Some generic features of organisms are already incorporated into commonly used models of food-chain transfer and radiation exposure for humans. There is already an extensive data base for these models that is relevant for a wide range of biota.

2. Generic target organisms can be selected to represent features of a large range of biota. This can be accomplished by selecting a series of organisms with different characteristics, considering a variety of exposure pathways, and using a broad distribution of radionuclide transfer parameters.

3. There is no prejudged human value attached to a generic organism.

4. The dosimetry can be simplified by selecting features of the generic organism that result in a conservatively high dose.

5. The predicted dose can be compared to the dose-response relationships developed for a wide range of biota.

Generic target organisms could be selected to reflect a wide range of ecosystems. As an example for a terrestrial ecosystem including a lake, four generic target organisms can be easily evaluated. These are:

Plant: A plant with contaminant uptake characteristics similar to a broad range of terrestrial vascular plants. This would include many grasses, herbs, and trees.

Fish: A fish with the attributes of many bony freshwater fish species. It may be a free-swimming individual (pelagic), which spends most of its life in the water column (e.g., lake trout, walleye), or a bottom-feeder (benthic), which spends its life near the sediments of the lake (e.g., white sucker, mottled sculpin).

Mammal: A large herbivorous terrestrial mammal, most similar to a wide range of ungulates (e.g., white-tailed deer, moose), but also including other mammals (e.g., beaver).

Bird: A terrestrial, nonpredatory bird, largely feeding on seeds or fruit (e.g., ruffed grouse, evening grosbeak).

These target organisms represent different trophic levels. The plant is a primary producer. The fish, mammal, and bird are mostly primary consumers, but also reflect higher trophic levels provided that the food-chain transfer data include such levels. Although ^{137}Cs may biomagnify slightly, most radionuclides have not been shown to increase in concentration at higher trophic levels (Zach and Sheppard 1993), so that carnivores are included to some extent. The target organisms are easily assessed because they are similar to organisms in the human food-chain. However, this selection is limited and does not include the vast diversity of invertebrate and vertebrate animals, or the many life-forms of plants. The inclusion of additional target organisms would greatly strengthen the methodology but more data are required.

Food-chain transfer to target organisms

Many models of transfer of radionuclides from the abiotic environment to humans have been developed (Zach and Sheppard 1991; CSA 1987; USNRC 1977). They include plants and animals as part of the food-chain to humans. Therefore, many of the pathways and transfer factors have already been developed that describe radionuclide transfer through biota. Although these usually refer explicitly to agricultural ecosystems, the processes, pathways, and transfer factors are similar for natural ecosystems (Zach and Sheppard 1993). These available food-chain models, with suitable modifications, can then be used to simulate radionuclide transfer to the chosen target organisms. The principal pathways are shown in Fig. 1.

Environmental transfer models predict concentrations in air, water, soil, plants and animals. Radionuclides incorporated into the biota cause an internal exposure. Concentrations in air, water and soil cause an external exposure to biota. Also, biota can receive an external exposure from contaminated vegetation. The equations are of the general form:

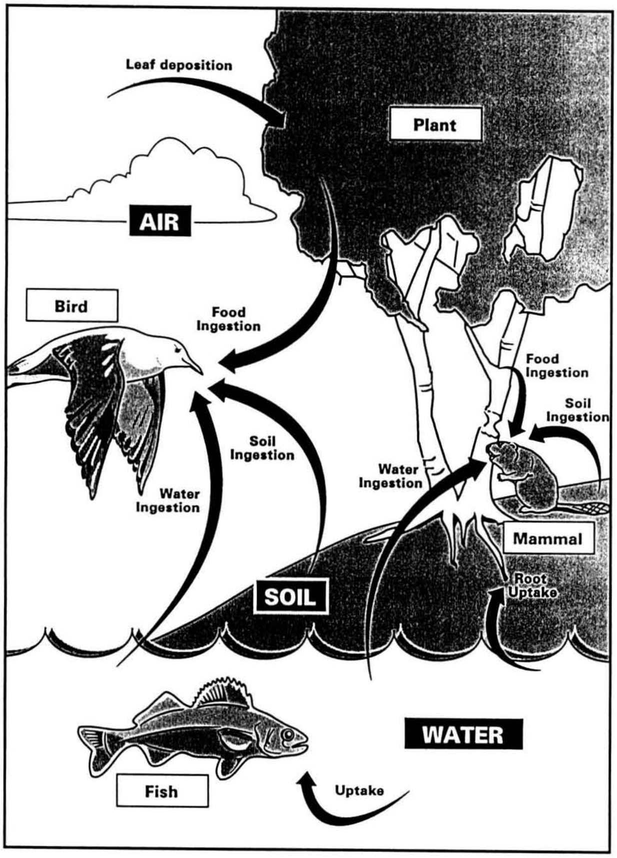

Fig. 1. Exposure pathways to the generic target organisms.

$$\text{Internal Dose} = DCF_I \cdot C \cdot TF \text{ and}$$

$$\text{External Dose} = DCF_E \cdot C,$$

where DCF_I and DCF_E are internal and external dose conversion factors, respectively, C is the concentration in the abiotic part of the environment (e.g., soil or water), and TF is a transfer factor for radionuclides from the abiotic environment to the organism. In Appendix A, the radionuclide transfer equations are detailed by discussing internal and external exposure pathways for each of the target organisms. The modes of exposure are further discussed in the following derivation of the dose conversion factors.

Dose conversion factors

The radiological dose received by an organism is determined by adding the dose contributions from all radionuclides and from all pathways. Doses are divided into those received from external and internal exposures.

The radiological dose from external exposure can come from energy emitted by contaminated air, water, soil or vegetation (Table 2). The following exposures for the different target organisms are considered:

Plant: roots immersed in soil or water, foliage immersed in air or water;

Fish: immersed in water and in lake sediments;

Mammal and bird: immersed in air, water, soil, and vegetation.

The dose conversion factors for each of these pathways depend on the type, size, and geometry of the organism, the location of the organism relative to the source, the extent of the contaminated source, and the energy emissions of the radionuclide. The target organisms should reflect some conservative characteristics of a wide range of real organisms. This allows some simplifications to be made. It is assumed that the organisms are totally immersed in a semi-infinite medium, similar to the scheme used for humans (Holford 1989).

The calculation of doses from internal radioactivity has been well developed for humans (ICRP 1977; 1991) and for other organisms (IAEA 1976). This depends on the type, size, and geometry of the organism. The dosimetry is based on some conservative assumptions so that a wide range of species is included in the generic target organisms. It is conservatively assumed that all radiation emitted within the organism is absorbed by the tissues. This can be an overestimate for small organisms where not all photon radiation is absorbed. A uniform distribution of radionuclides throughout the body, which may underestimate the dose to some organs, is also assumed. This was explicitly addressed for ^{129}I by increasing the dose conversion factor by an order of magnitude to account for iodine accumulation in animal thyroids. The methodology for calculating our dose conversion factors is outlined in Appendix B. As an example, the dose conversion factors for four radionuclides are presented in Table 3. On balance, the presented dose conversion factors seem to be realistic for assessment purposes.

Criteria for acceptability

The radiological doses predicted for target organisms need to be compared to a criterion to assess environmental protection. A methodology to convert radiological dose to risk has not been developed to encompass a wide range of plants and animals. Therefore, the radiological doses experienced by non-

Table 2. Sources of external exposure for generic target organisms.

Source	Organism			
	Fish	Plant	Mammal	Bird
Water Immersion	X	X	X	X
Air Immersion		X	X	X
Soil or Sediment Immersion	X	X	X	X
Vegetation Immersion			X	X

Table 3. Dose conversion factors (total dose, electron, and photon).

Source	Radionuclide			
	^{14}C	^{99}Tc	^{129}I	^{137}Cs
Internal (all organisms) $\left[\frac{Gy\cdot a^{-1}}{Bq\cdot kg^{-1}\text{ fresh weight}}\right]$	$2.50\mathrm{x}10^{-7}$	$5.11\mathrm{x}10^{-7}$	$4.46\mathrm{x}10^{-7}$ (plants) $4.46\mathrm{x}10^{-6}$ (animals)*	$4.11\mathrm{x}10^{-6}$
Water Immersion for Fish $\left[\frac{Gy\cdot a^{-1}}{Bq\cdot m^{-3}\text{ water}}\right]$	$1.38\mathrm{x}10^{-10}$	$2.43\mathrm{x}10^{-10}$	$2.70\mathrm{x}10^{-10}$	$3.24\mathrm{x}10^{-9}$
Water Immersion for Terrestrial Organisms $\left[\frac{Gy\cdot a^{-1}}{Bq\cdot m^{-3}\text{ water}}\right]$	$6.51\mathrm{x}10^{-12}$	$8.62\mathrm{x}10^{-11}$	$1.19\mathrm{x}10^{-10}$	$2.82\mathrm{x}10^{-9}$
Air Immersion $\left[\frac{Gy\cdot a^{-1}}{Bq\cdot m^{-3}\text{ air}}\right]$	$6.01\mathrm{x}10^{-9}$	$7.96\mathrm{x}10^{-8}$	$5.73\mathrm{x}10^{-8}$	$1.81\mathrm{x}10^{-6}$
Soil/Sediment Immersion $\left[\frac{Gy\cdot a^{-1}}{Bq\cdot kg^{-1}\text{ dry soil}}\right]$	$9.77\mathrm{x}10^{-9}$	$1.29\mathrm{x}10^{-7}$	$1.79\mathrm{x}10^{-7}$	$4.23\mathrm{x}10^{-6}$
Vegetation Immersion $\left[\frac{Gy\cdot a^{-1}}{Bq\cdot kg^{-1}\text{ wet biomass}}\right]$	$6.01\mathrm{x}10^{-9}$	$7.96\mathrm{x}10^{-8}$	$5.73\mathrm{x}10^{-8}$	$1.81\mathrm{x}10^{-6}$

* The factor for ^{129}I for animals is increased by a factor of 10 to account for thyroid accumulation.

human biota cannot be easily related to risk, as is done for humans. Instead, the predicted radiological doses are evaluated in the context of the large number of scientific studies that have investigated the effects of chronic radiation exposure on plants and animals.

Rose (1992) reviewed much of the scientific literature on the effects of ionizing radiation on non-human biota. The conclusions were that a dose rate of 1 $Gy\cdot a^{-1}$ caused some minor, subtle effects on several groups of plants and animals, so that the predicted dose rate should be less than 1 $Gy\cdot a^{-1}$. IAEA (1992) believes that there is no convincing evidence in the scientific literature that dose rates less than about 0.4 $Gy\cdot a^{-1}$ will harm plant or animal populations.

Plants and animals thrive at background dose rates and it can be assumed that these do not pose significant environmental effects, at least outside of those imposed by nature. Dose rates from natural, external sources are typically about 0.7 $mGy\cdot a^{-1}$ in Canada (Health and Welfare Canada 1987). However, plants and animals experience higher dose rates because of the additional dose caused by uptake of natural radionuclides. For example, total dose rates

Table 4. Radiological dose rate and consequence.

	DOSE RATE	RANGE	CONSEQUENCE
	100 $Gy \cdot a^{-1}$		some organisms affected
	10 $Gy \cdot a^{-1}$		
	1 $Gy \cdot a^{-1}$		potential subtle, chronic effects
	10^{-1} $Gy \cdot a^{-1}$		
Range of negligible impact from additional dose rate	10^{-2} $Gy \cdot a^{-1}$		range of natural background dose rate to a wide variety of plants and animals
	10^{-3} $Gy \cdot a^{-1}$		
	10^{-4} $Gy \cdot a^{-1}$		
	10^{-5} $Gy \cdot a^{-1}$		much below background dose rate; effects unlikely, and not detectable
	10^{-6} $Gy \cdot a^{-1}$		

from natural sources for fish range up to 3 $mGy \cdot a^{-1}$ (IAEA 1976).

Table 4 summarizes the potential effects from various environmental dose rates. Rates greater than about 10 $Gy \cdot a^{-1}$ will likely cause some effect. There may be subtle effects on certain biota at dose rates greater than 0.4 $Gy \cdot a^{-1}$. Background dose rates range between 1 and 100 $mGy \cdot a^{-1}$, and this is likely a range of environmental safety. Radiological dose rates less than 1 $mGy \cdot a^{-1}$ are below background, and at a level where radiological impacts on nonhuman biota are assumed to be negligible.

The value of 1 $mGy \cdot a^{-1}$ is much below the level of 0.4 $Gy \cdot a^{-1}$ suggested by IAEA (1992) to protect plant and animal populations. NCRP (1991) suggests that 4 $Gy \cdot a^{-1}$ would still protect aquatic organisms. This level is a conservative underestimate and it is likely that much greater levels can be tolerated by a wide range of ecosystems.

FURTHER EVALUATION OF IMPACTS

The method calls for further evaluation of impacts if the radiological dose received by a generic target organism exceeds 1 $mGy \cdot a^{-1}$. At a specific site for example, a valued species (e.g., tree swallow) could be identified as an improvement over the use of a generic target organism. This would allow a more specific assessment of the pathways to a known organism, including reducing the variability in transfer factors. The effect of the calculated dose could then be related to a known response (e.g., Zach et al. 1993). Such species-specific evaluations might require extensive supporting studies. Also, a broader evaluation at the community and ecosystem levels may be warranted. The advantage of the authors' approach is that more in-depth analyses are only required if the previous three steps indicate a potential impact.

MONITORABILITY

Measurement of radionuclide concentrations in the abiotic parts of the environment is a monitorable part of the decscribed method. This is directly related to the derivation of EI values, and can also be used to help calculate doses to humans and nonhuman biota.

Radionuclide concentrations can also be determined within biota. This is easily done for plants, and is also practical for some animal species. The direct determination of these concentrations bypasses the need for food-chain modelling. Therefore, radiological doses can be calculated directly from the radioactivity in the organism.

Radiological doses from external exposures can also be monitored by measuring ambient radiation at several locations, but this may not always be practical. Unfortunately, radiological doses from internal exposures cannot be monitored easily.

Monitoring of concentrations provides feedback to help identify appropriate EI values and to improve dose calculations to biota. The actual impact of radionuclide emissions to the environment should also be monitored.

APPLICATION TO GEOLOGIC DISPOSAL OF NUCLEAR FUEL WASTE

The described method was applied to assess environmental protection in the evaluation of the concept of geological disposal of Canada's nuclear fuel waste. It was assumed that some radionuclides will enter the biosphere in the future. First, models of radiological transport through the biosphere to predict radiological doses to humans (Davis et al. 1993) were used. If the resulting dose exceeds the regulatory criteria for humans, it was concluded that the concept is also environmentally unacceptable, and further assessment of environmental protection is not required. If the criteria for humans are met, assessing environmental protection was continued. In the described example, the human criterion of an annual dose less than 50 $\mu Sv \cdot a^{-1}$ (AECB 1987) was met (Goodwin et al. 1993).

Second, the predicted concentrations of radionuclides in soil and water were compared to the EI values (e.g., Table 1). If the predicted concentrations are much below the EI values, the disposal concept is likely environmentally acceptable and further analysis is not needed. However, if the predicted concentrations for some radionuclides are greater than the EI values, then the potential impacts of these particular radionuclides need to be assessed. In this example, only ^{129}I clearly exceeded the EI values for soil and water at very long times into the future. Soil and water concentrations were about five orders of magnitude greater than the EI values (Goodwin et al. 1993).

The assessment of the impact to nonhuman biota is done by calculating the radiological dose to the four target organisms. If the total radiological dose to all organisms is less than 1 $mGy \cdot a^{-1}$, a negligible environmental impact can be concluded. If the dose is greater than 1 $mGy \cdot a^{-1}$, impacts should be assessed further. In this example, the radiological dose from ^{129}I was of the order of 10^{-5} $Gy \cdot a^{-1}$. Therefore, it was concluded that there should be no environmental impact associated with long-term release of radionuclides to the biosphere from this disposal concept, and the fourth step need not be invoked. The decision-making process is outlined in Fig. 2.

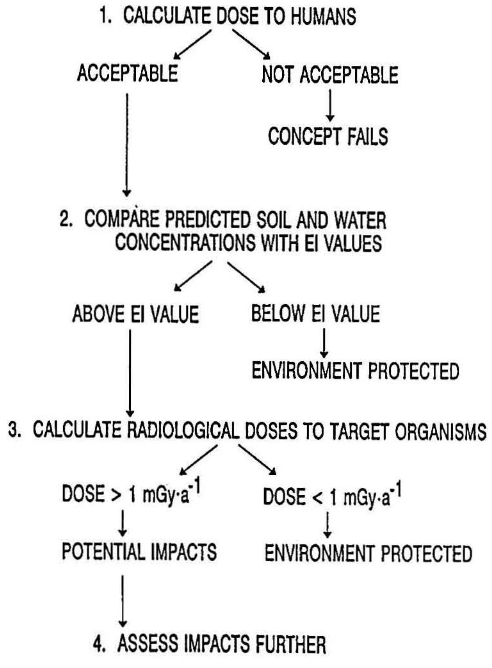

Fig. 2. Steps to assess environmental protection.

CONCLUSIONS

A method to evaluate the acceptance of the release of radionuclides to the environment from nuclear facilities is presented. The method is based on a four-step evaluation, to ensure that nonhuman biota and the general environment will be protected. This methodology is compatible with models used to ensure human safety, along with comparisons to background concentrations of radionuclides. This method was used to evaluate the impacts of geological disposal of used nuclear fuel as an example, and it was found that it gave practical results that were useful for making decisions.

The described method is largely based on existing knowledge. However, it can be improved through continued research, especially in the development of transfer parameters and dosimetry for nonhuman biota. Additional measurements of the effects of radiation at the population, community, and ecosystem level are also needed.

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APPENDIX A

RADIONUCLIDE TRANSPORT CALCULATIONS TO TARGET ORGANISMS

In the following equations, it is assumed that soil and water concentrations and air deposition rates are available from measurements or models. Representative parameter values are also given. A full description of the model is given by Amiro (1992b) and Davis et al. (1993).

INTERNAL EXPOSURE PATHWAYS

Internal exposure to plants

Plants can accumulate nuclides from the soil via root uptake and from aerial deposition. The internal dose to the plant from nuclide i, DBi_p^i ($Gy \cdot a^{-1}$), is given by

$$DBi_p^i = \left\{C_s^i \cdot Bv^i + \left[D_b^i \cdot (r/Y) \cdot \left[1 - \exp(-\lambda_E^i \cdot te)\right] / \lambda_E^i\right]\right\} \cdot (DCF_p^i)_I \qquad (A1)$$

where

C_s^i	is the soil concentration ($Bq \cdot kg^{-1}$ dry soil),
Bv^i	is the plant/soil concentration ratio for nuclide i (($Bq \cdot kg^{-1}$ wet biomass)/($Bq \cdot kg^{-1}$ dry soil)),
D_b^i	is the rate of deposition of nuclide i to vegetation ($Bq \cdot m^{-2}$ soil$\cdot d^{-1}$),
r	is the plant interception fraction (unitless),
Y	is the yield of vegetation (kg wet biomass$\cdot m^{-2}$ soil),
λ_E^i	is the effective removal constant of nuclide i from vegetation (d^{-1}),
te	is the time of above-ground exposure for the plant during the growing season (d), and
$(DCF_p^i)_I$	is the dose conversion factor for internal exposure of plants to nuclide i (($Gy \cdot a^{-1}$)/($Bq \cdot kg^{-1}$ wet biomass)).

Internal exposure to terrestrial animals

Terrestrial animals can accumulate nuclides internally through ingestion of contaminated food, water and soil. Here, it is assumed that the inhalation dose is negligible compared with the ingestion dose for many radionuclides. However, inhalation should be considered in some cases, such as for radon from a ground source containing ^{226}Ra or if animals are immersed in a reactor plume.

The internal dose to the target mammal and bird from nuclide i, DBi_b^i ($Gy \cdot a^{-1}$), is given by

$$\begin{aligned} DBi_b^i = \Big[&\left[C_s^i \cdot Bv^i \cdot F^i \cdot Qf\right] \\ &+ \left\{D_b^i \cdot (r/Y) \cdot F^i \cdot Qf \cdot \left[1 - \exp\left[-\lambda_E^i \cdot te\right]\right] / \lambda_E^i\right\} \\ &+ \left[C_s^i \cdot F^i \cdot Qs\right] + \left[C_w^i \cdot F^i \cdot Qdw\right]\Big] \cdot (DCF_b^i)_I \end{aligned} \qquad (A2)$$

where

DBi^i_b refers to either the mammal, DBi^i_M, or the bird, DBi^i_B,

F^i is the terrestrial animal transfer coefficient for nuclide i ($d \cdot kg^{-1}$ wet biomass),

Qf is the rate of feed or forage ingestion (kg wet biomass$\cdot d^{-1}$),

Qs is the rate of soil ingestion (kg dry soil$\cdot d^{-1}$),

C^i_w is the annual average concentration of nuclide i in animal's drinking water ($Bq \cdot m^{-3}$ water),

Qdw is the drinking water ingestion rate (m^3 water$\cdot d^{-1}$), and

$(DCF^i_b)_I$ is the internal dose conversion factor for nuclide i for either mammals, $(DFB^i_M)_I$, or birds, $(DFB^i_B)_I$ (($Gy \cdot a^{-1}$) /($Bq \cdot kg^{-1}$ wet biomass)).

Internal exposure to fish

Fish inhabiting a lake may become contaminated through ingestion of food and sediment, and through osmotic exchange of fluids. The dose to the fish from nuclide i from internal exposure, DBi^i_F ($Gy \cdot a^{-1}$), is given by

$$DBi^i_F = C^i_W \cdot B^i \cdot (DCF^i_F)_I \qquad (A3)$$

where

C^i_w is the concentration of nuclide i in water ($Bq \cdot m^{-3}$ water),

B^i is the aquatic concentration ratio for nuclide i (m^3 water$\cdot kg^{-1}$ wet biomass), and

$(DCF^i_F)_I$ is the dose conversion factor for internal exposure of the fish to nuclide i (($Gy \cdot a^{-1}$)/($Bq \cdot kg^{-1}$ wet biomass)).

EXTERNAL EXPOSURE PATHWAYS

The generic target organisms can be immersed in four different media, depending on their habitat. The relevant media are given in Table 2 for each target organism.

Immersion in water

All the target organisms are assumed to be immersed in water. Fish spend their whole lives in water; plants can be aquatic or have their roots submerged in soil pore-water; and a large range of animals can spend a portion of their time swimming, wading or lying in water.

The doses ($Gy \cdot a^{-1}$) from nuclide i from immersion in water for the plant $(DBe^i_P)_W$, for the mammal $(DBe^i_M)_W$, and for the bird $(DBe^i_B)_W$, are identical based on submersion at a depth of 0.1 m (Amiro 1992b). They are given by

$$(DBe^i_P)_W = (DBe^i_M)_W = (DBe^i_B)_W = C^i_W \cdot (DCF^i)_W \qquad (A4)$$

where

$(DCF^i)_W$ is the water immersion dose conversion factor for the plant, the mammal, and the bird for nuclide i (($Gy \cdot a^{-1}$)/($Bq \cdot m^{-3}$ water)).

For the fish, the dose from nuclide i from immersion in water, $(DBe^i_F)_W$ ($Gy \cdot a^{-1}$), is given by

$$(DBe^i_F)_W = C^i_W \cdot (DCF^i_F)_W \qquad (A5)$$

where

$(DCF^i_F)_W$ is the water immersion dose conversion factor for the fish for nuclide i (($Gy \cdot a^{-1}$)/($Bq \cdot m^{-3}$ water)).

Immersion in soil or sediment

Plants are rooted in soil and they may also accumulate soil particles on foliage from aerial deposition, terrestrial animals may lie or burrow in soil or be covered with contaminated soil particles, and bottom-feeding fish can be essentially immersed in sediments. Therefore, we assess the external exposure of all the target organisms to soil or sediment.

The dose ($Gy \cdot a^{-1}$) from nuclide i from immersion in soil for the plant $(DBe^i_P)_S$, for the mammal $(DBe^i_M)_S$, and for the bird $(DBe^i_B)_S$, is given by

$$(DBe^i_P)_S = (DBe^i_M)_S = (DBe^i_B)_S = C^i_s \cdot (DCF^i)_S \qquad (A6)$$

where

$(DCF^i)_S$ is the soil immersion dose conversion factor for nuclide i (($Gy \cdot a^{-1}$)/($Bq \cdot kg^{-1}$ dry soil)).

For the fish, the dose from nuclide i from immersion in sediment, $(DBe^i_F)_s$ ($Gy \cdot a^{-1}$), is given by

$$(DBe^i_F)_S = C^i_{se} \cdot (DCF^i_F)_S \tag{A7}$$

where

C^i_{se} is the concentration of nuclide i in sediments (Bq·kg^{-1} dry sediment), and

$(DCF^i_F)_s$ is the sediment immersion dose conversion factor for fish for nuclide i ((Gy·a^{-1})/(Bq·kg^{-1} dry sediment)).

Immersion in air

We assume that plants, mammals, and birds can be immersed in air, but fish cannot (Table 2). The dose (Gy·a^{-1}) from nuclide i from immersion in air for the plant, $(DBe^i_P)_A$, for the mammal, $(DBe^i_M)_A$, and for the bird, $(DBe^i_B)_A$, is given by

$$(DBe^i_P)_A = (DBe^i_M)_A = (DBe^i_B)_A = C^i_a \cdot (DCF^i)_A \tag{A8}$$

where

C^i_a is the concentration of nuclide i in air (Bq·m^{-3} air), and

$(DCF^i)_A$ is the air immersion dose conversion factor for nuclide i ((Gy·a^{-1})/(Bq·m^{-3} air)).

Immersion in vegetation

Terrestrial animals can be surrounded or immersed in vegetation during much of their lives. For example, many birds nest and roost in vegetation, many small mammals burrow and feed in vegetation, and forest dwellers are surrounded by trees and other plants. We assess the dose from external exposure to vegetation that has been contaminated from a variety of sources. We assume that exposure to contaminated vegetation is unimportant for fish because most of their external dose should come directly from water and sediment, and water forms an efficient shield against radiation penetration from remote sources.

We do not calculate external exposure to the plant from other plants. This situation is implicitly included in our dose conversion factors, which conservatively assume that all the radiation is absorbed by the plant (Appendix B). Therefore, we only calculate external exposure for the mammal and bird from vegetation (Table 2).

The concentrations in vegetation are calculated using both soil and air pathways, and the resulting dose is given by

$$(DBe^i_M)_V = (DBe^i_B)_V = \left[\left[C^i_s \cdot Bv^i\right] + \left\{D^i_D \cdot (r/Y) \cdot \left[1 - \exp(-\lambda^i_E \cdot te)\right]/\lambda^i_E\right\}\right] \cdot (DCF^i_M)_V \tag{A9}$$

where

$(DBe^i_M)_V$ and $(DBe^i_B)_V$ are the doses from nuclide i to the mammal and the bird, respectively, from immersion in vegetation (Gy·a^{-1}),

and

$(DCF^i_M)_V$ is the dose conversion factor for nuclide i for the mammal or the bird from external exposure to vegetation ((Gy·a^{-1})/(Bq·kg^{-1} wet biomass)).

CALCULATION OF TOTAL RADIOLOGICAL DOSES

The total dose (Gy·a^{-1}) for each target organism is simply the sum of all external and internal doses from all nuclides.

The total dose to the fish is given by

$$\sum_{i=1}^{m} \left[DBi^i_F + (DBe^i_F)_W + (DBe^i_F)_S\right] \tag{A10}$$

where

m is the number of nuclides.

The total dose to the plant is given by

$$\sum_{i=1}^{m} \left[DBi^i_P + (DBe^i_P)_W + (DBe^i_P)_S + (DBe^i_P)_A\right] . \tag{A11}$$

The total dose to the mammal is given by

$$\sum_{i=1}^{m} \left[DBi^i_M + (DBe^i_M)_W + (DBe^i_M)_S + (DBe^i_M)_A + (DBe^i_M)_V\right] . \tag{A12}$$

The total dose to the bird is given by

$$\sum_{i=1}^{m} \left[DBi^i_B + (DBe^i_B)_W + (DBe^i_B)_S + (DBe^i_B)_A + (DBe^i_B)_V\right] . \tag{A13}$$

Table A1. Parameter values (from Zach and Sheppard 1993).

		Radionuclide			
Parameter	Units	^{14}C	^{99}Tc	^{129}I	^{137}Cs
B^i	$L \cdot kg^{-1}$ wet	5.0×10^4	1.5×10^1	5.0×10^1	1.0×10^4
Bv^i	$\frac{\text{kg dry soil}}{\text{kg wet plant}}$	5.5	2.4	3.8×10^{-2}	2.0×10^{-2}
F^i mammal	$d \cdot kg^{-1}$ wet	6.4×10^{-2}	8.5×10^{-3}	7.0×10^{-3}	2.6×10^{-2}
bird		6.4	1.9	2.8	4.4
Qdw mammal	$m^3 \cdot d^{-1}$	$4. \times 10^{-2}$	$4. \times 10^{-2}$	$4. \times 10^{-2}$	$4. \times 10^{-2}$
bird		$4. \times 10^{-4}$	$4. \times 10^{-4}$	$4. \times 10^{-4}$	$4. \times 10^{-4}$
Qf mammal	$kg \cdot d^{-1}$	5.0×10^1	5.0×10^1	5.0×10^1	5.0×10^1
bird		0.4	0.4	0.4	0.4
Qs mammal	kg dry soil$\cdot d^{-1}$	0.8	0.8	0.8	0.8
bird		6.0×10^{-3}	6.0×10^{-3}	6.0×10^{-3}	6.0×10^{-3}
r	unitless	1.0	1.0	1.0	1.0
te	d	5.0×10^1	5.0×10^1	5.0×10^1	5.0×10^1
Y	kg wet$\cdot m^{-2}$	0.8	0.8	0.8	0.8
λ_E^i*	d^{-1}	0.1	5.9×10^{-2}	5.8×10^{-2}	8.5

* λ_E^i = radiological decay constant + ln2/12 d where 12 d represents an average environmental half-time.

PARAMETER VALUES

Values for the parameters defined in Equations (A1) to (A13) are required to calculate radiological doses to the target organisms. The dose conversion factors are described in Appendix B and are summarized in Table 3 for four radionuclides. The parameters used to model food-chain transfer are often distributed probabilistically to account for variability caused by the inclusion of many types of organisms and uncertainty in the estimation of a value (e.g., Zach and Sheppard 1993). Table A1 gives some median values of the parameters for four radionuclides.

APPENDIX B

DOSE CONVERSION FACTORS FOR NONHUMAN BIOTA

The following methodology to calculate dose conversion factors for nonhuman biota is based on Amiro (1992b). As an example, we calculate values for ^{14}C, ^{99}Tc, ^{129}I and ^{137}Cs from internal and external exposures (Table 3).

GENERAL RADIOLOGICAL CONSIDERATIONS

The decay of radionuclides can cause the release of an α-particle, electron (β) radiations or photon (γ) radiations. Of these, α-particles are highly attenuated and can be a significant source of internal radiation absorption. However, none of the four example radionuclides emits α-particles, so our discussion is restricted to electron and photon radiation. We define the amount of radioactivity in units of bequerels (Bq) = disintegration·s^{-1}, and dose in units of gray (Gy) = J·kg^{-1} of tissue. For electron and photon radiation, 1 Gy is equivalent to 1 sievert (Sv) of dose equivalent, which is the unit of human dose. An additional quality factor is required when α radiation is considered.

The energy of emissions for each of the four radionuclides is listed in Table B1. The entries for ^{137}Cs include the decay of the daughter, ^{137m}Ba, which has only a 2.6-min half-life and is included implicitly.

INTERNAL DOSE CONVERSION FACTORS

The internal doses arise from radionuclides present in the body, and we follow the methodology of IAEA (1976) to estimate electron and photon radiation doses. Models based on radionuclide transfer to humans (e.g., Zach and Sheppard 1993) often calculate concentrations in tissues eaten by humans and not in individual organs of the biota. Therefore, our method does not calculate doses to individual organs, but only to the whole body. However, accumulation of ^{129}I in the thyroid gland of animals must be considered separately. The models do not estimate ^{129}I transfer to thyroids of nonhuman animals. For most animals, more than half of the whole body iodine is located in the thyroid (Maynard et al. 1979); in humans, about 70% to 80% is in the thyroid; and in reference man, used for human dosimetry estimates, 92% is assumed to be in the thyroid (ICRP 1975). We assume, conservatively, that about 90% of the iodine in the body is in the thyroid of all animals. Therefore, we increase the internal dose to animals from ^{129}I by a factor of 10, to compensate for the underestimation of total body ^{129}I, which is based on animal flesh in the transport models.

We assume, conservatively, that our generic organisms are of sufficient size that the fraction of absorbed electron radiation approaches that absorbed in an infinitely contaminated volume. This assumption would be very conservative for small organisms, but is appropriate for larger ones (IAEA 1976). Therefore, for electron radiation, the internal

Table B1. Energy emissions from radioactive decay (ICRP 1983).

Radionuclide	Average Energy per Disintegration (J·(Bq·s)$^{-1}$)	
	Electron	Photon
^{14}C	7.93×10^{-15}	
^{99}Tc	1.62×10^{-14}	
^{129}I	1.02×10^{-14}	3.94×10^{-15}
^{137}Cs	3.98×10^{-14}	9.04×10^{-14}

dose (D_I) caused by radionuclide i depends directly on the energy emitted, E_i, by the radioactivity in the organism, C_i ($Bq\cdot kg^{-1}$ wet weight):

$$D_I = E_i \cdot C_i \qquad (B1)$$

E_i equals the average energy per disintegration from Table B1, with unit conversion of $Gy = J\cdot kg^{-1}$ and $3.16 \times 10^7 s\cdot a^{-1}$, to calculate the internal dose conversion factors listed in Table B2.

Unlike electron radiation, not all photon radiation will be absorbed inside the body; some will escape depending on the size of the organism. For example, a fish with cylindrical dimensions of 0.5-m length and 0.1-m diameter would only absorb about 10% of the internal photon energy emitted from natural radioactivity (IAEA 1976). To be conservative, we assume that all of the internally emitted photon radiation is absorbed by our generic target organisms. This assumption automatically includes organisms of all sizes. Equation (B1) and the values from Table B1 are used to estimate the dose conversion factors presented in Table B2. As in the case for electron radiation, the dose conversion factors for ^{129}I for animals have been increased by a factor of 10 to account for thyroid accumulation.

The total dose conversion factor for each radionuclide (DCF_i) is the sum of the electron and photon radiation contributions shown in Table B2. It can be seen that the conservative assumption for the photon radiation absorption increases the total dose conversion factor for ^{137}Cs by a maximum of a factor of three and for ^{129}I by less than 40% (Table B2). Hence, the assumption of total photon radiation absorption does not impose extreme conservatism.

EXTERNAL DOSE CONVERSION FACTORS

Immersion in water

The estimates of water immersion dose conversion factors for aquatic biota calculated by NRCC (1983) were adopted and were used for the generic fish (Table B3).

Holford (1989) calculated water immersion dose conversion factors for humans and his calculations were applied to the generic plant, mammal, and bird. It is assumed that the electron radiation dose received 70 µm below the skin surface gives a good representation of the maximum electron radiation dose that an organism would receive. Internal parts of the organism would receive a much lesser dose. The electron radiation dose at the skin surface is higher than this, but some shielding is created by the epidermal cells of plants and animals and it is likely that the surface dose would be a large overestimate. For photon radiation, the dose at the surface is calculated because this energy is not as easily attenuated, and internal doses will be similar to surface doses for high-energy photons. In the calculations of Holford (1989), the organism is assumed to be submerged in a semi-infinite, uniformly contaminated water medium, with the organism centroid located at a depth of 0.1 m below a plane boundary at the water surface. This would be conservative for plant roots exposed to soil pore water or for the aerial portions of plants with water drops on them. It would be a

Table B2. Dose conversion factors from internal sources.

	Dose Conversion Factor ($Gy\cdot a^{-1}$ per $Bq\cdot kg^{-1}$ wet weight)		
Radionuclide	Electron	Photon	DCF_i
^{14}C	2.50×10^{-7}	0	2.50×10^{-7}
^{99}Tc	5.11×10^{-7}	0	5.11×10^{-7}
^{129}I : Plants	3.22×10^{-7}	1.24×10^{-7}	4.46×10^{-7}
: Animals	3.22×10^{-6}	1.24×10^{-6}	4.46×10^{-6}
^{137}Cs	1.26×10^{-6}	2.85×10^{-6}	4.11×10^{-6}

Table B3. Water immersion dose conversion factors for fish.

Radionuclide	Dose Conversion Factor ($Gy \cdot a^{-1}$ per $Bq \cdot m^{-3}$ water)	
	Photon Only	Total Electron + Photon
^{14}C	0	1.38×10^{-10}
^{99}Tc	0	2.43×10^{-10}
^{129}I	1.24×10^{-10}	2.70×10^{-10}
^{137}Cs	2.67×10^{-9}	3.24×10^{-9}

reasonable assumption for animals wading, swimming, or lying in shallow water. The dose conversion factors for immersion in water and air are given separately in Table B4 for electron and photon radiation.

Immersion in air

The dose conversion factors for air immersion (Table B4) were taken from the calculations by Holford (1989) for electron radiation doses estimated at 70 µm into the body surface of humans, and photon radiation doses at the surface. These calculations assume an air density of 1.189 $kg \cdot m^{-3}$, and a semi-infinite, uniformly contaminated medium with the centroid of the receptor located at a height of 1 m above a plane boundary (Barnard and D'Arcy 1986). As in the case for water immersion, the assumption is conservative, reflecting the maximum dose that could be received by the outer part of the organism.

Immersion in soil and sediments

Many species of fish spend an appreciable amount of time near lake-bottom sediments, plant roots are immersed in soil, and many animals burrow in soil. Also, plants and animals can be covered with a thin layer of soil through various mechanisms. The geometry of these situations is simplified by assuming that organisms can be totally immersed in soil and sediments. This also includes groundshine received by organisms (e.g., trees, large mammals) standing on soil.

The external dose rate is inversely proportional to the density of the medium (Barnard and D'Arcy 1986). This is indicated by the ratios of the electron radiation dose rates for air and water, which differ by about a factor of 1000 (Table B4). The proportionality with density also holds for photon radiation, but this is not apparent in Table B4 because of the differences in the geometry of the media. The density dependence is used to calculate the dose rate caused

Table B4. External dose conversion factors for immersion of plant, mammal, and bird in water and air.

	Dose Conversion Factor ($Gy \cdot a^{-1}$ per $Bq \cdot m^{-3}$)			
	Water		Air	
Radionuclide	Electron	Photon	Electron	Photon
^{14}C	6.51×10^{-12}	0	6.01×10^{-9}	0
^{99}Tc	8.62×10^{-11}	0	7.96×10^{-8}	0
^{129}I	2.91×10^{-12}	1.16×10^{-10}	2.68×10^{-9}	5.46×10^{-8}
^{137}Cs	4.10×10^{-10}	2.41×10^{-9}	3.78×10^{-7}	1.43×10^{-6}

by immersion in soil. Soil densities are usually greater than the density of water so that the use of the water immersion dose conversion factor would be slightly conservative. This conservatism is less than a factor of two, as typical soil bulk densities are of the order of 1500 $kg \cdot m^{-3}$ dry soil (Buckman and Brady 1969). Therefore, it is reasonable to assume that the dose conversion factors for water immersion can also be applied for soil immersion (Table B4). The 0.1-m plane boundary is also reasonable, since most plant roots and animals inhabit the top part of the soil, and the extent of the medium has little effect on the electron radiation dose received. The volume units are converted to mass, using a conservative bulk density of 1500 $kg \cdot m^{-3}$ representative of a sand soil.

Immersion in vegetation

Immersion in vegetation represents the external dose received from contaminated vegetation when an animal lives in a forest or is surrounded by vegetation in its habitat. We do not calculate the external dose from contaminated vegetation to plants because this has already been included in the internal dose conversion factor for plants with the assumption that all internal radiation is absorbed. Therefore, the external dose from vegetation only applies to animals.

We assume that the dose conversion factor for immersion in air is equivalent to that for immersion in vegetation. This assumes that the densities of air and wet vegetation are equal; this is a conservative assumption because vegetation is more dense than air and the dose conversion factors scale inversely with density. Therefore the dose conversion factors for air immersion given in Table B4 can be applied to immersion in vegetation on a volume basis.

Food-chain models often calculate the concentration of radionuclides in vegetation in units of $Bq \cdot kg^{-1}$ wet biomass. Hence, the values in Table B4 must be multiplied by the density of vegetation in units of kg wet biomass$\cdot m^{-3}$ air to be directly applicable to the model output. Higher dose conversion factors will result with higher plant densities. Here we assume a plant yield of 1 $kg \cdot m^{-2}$ (e.g., Zach and Sheppard 1993). We assume a representative plant height of 1 m, giving a total plant density of 1 kg wet biomass$\cdot m^{-3}$ air. This means that the dose conversion factors for air (Table B4), multiplied by unity, are equal to the dose conversion factors for vegetation in units of $Gy \cdot a^{-1}$ per $Bq \cdot kg^{-1}$ wet biomass.

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THE EFFECT OF CHRONIC ENVIRONMENTAL NOISE ON THE RATE OF HYPERTENSION: A META-ANALYSIS

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Critical reviews of noise on human health, performed during the past 15 y have raised questions regarding the potential for noise to result in adverse health impacts. Previous syntheses have been based on critiques of methods used in individual works but have not attempted to provide quantitative evaluations of the collected works. Work described in this paper presents a synthesis of carefully selected investigations from the available literature, including a meta-analysis on selected data, in order to provide some insight into the possibility that chronic ambient noise is related to hypertension as a function of increasing noise levels. Given the large number of persons exposed to environmental noise sources, the strength of association between hypertension and cardiovascular disease, and the derived odds ratios for noise induced hypertension in this paper, noise may be one of the most important environmental factors presently being neglected within the regulatory arena.

INTRODUCTION

Knipschild and Salle (1979) defined noise as "unwanted sound—unwanted because it is annoying and/or harmful." The World Health Organization (WHO 1983) and others (Wu et al. 1987; Anticaglia and Cohen 1970; Andren et al. 1980; Andren et al. 1981) consider noise to be an important environmental and/or occupational variable involved in the pathogenic development of essential hypertension. Although pathogenesis for noise-related hypertension is incompletely understood, it has been hypothesized that vasoconstriction of peripheral blood vessels can occur with exposures to sounds that are of a spectrum and intensity that constitute a damage risk to the middle ear (Manninen 1985; Eggertsen et al. 1987; Manninen 1988; Petiot et al. 1988; Mosskov and Ettema 1977; Ising et al. 1980). It

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is also hypothesized that over a long period of exposure increased resistance resulting from structural lesions subsequently induces arterial hypertension (Eggertsen et al. 1987).

Several animal studies have shown that acute exposure to noise results in an increase in blood pressure (Anticaglia and Cohen 1970; Hudak and Buckley 1961; Medoff and Bongiovanni 1945). Human studies have also noted similar relationships. Manninen (1985), and Petiot et al. (1988) reported increased blood pressure with increased levels of noise. Jonsson and Hansson (1977) identified a relatively small group of male Swedish workers (44 persons) with noise-induced hearing loss. Hearing loss was characterized as auditory impairment of 65 dB(A) or greater at 3000, 4000, or 6000 Hz, and less than 20 dB at other frequencies. When diastolic and systolic blood pressures of the impaired workers were compared to those of a group of workers in the factory without hearing loss, the workers with hearing loss displayed a greater proportion of hypertension than did the control group.

Karagodina et al. (1969) reported an increase in the prevalence of high blood pressure and cardiovascular disease in populations surrounding airports with heavy fly-over. In a study of elementary school children, Cohen et al. (1981) reported higher diastolic and systolic blood pressure values in children attending schools under the flight pattern of an airport, compared to a matched control group in a less noisy school. Herbold et al. (1989) reports that among populations living near streets with high-intensity noise levels males may experience an increased prevalence of high blood pressure. Fouriaud et al. (1984) found a positive correlation between blood pressure and noise among residents of Paris.

Other investigators have found little or no relationship between noise exposure and increased blood pressure (Babisch and Gallacher 1988; Cohen et al. 1980; Gold et al. 1989; Hedstrand et al. 1977; Knipschild and Salle, 1979; Pulles et al. 1990; Talbott et al. 1985; Wu et al. 1988). In an experimental study Cartwright and Thompson (1975) found no significant change in either systolic or diastolic pressures when subjects were acutely exposed to broad-band noise. Takala et al. (1977) measured blood pressure and hearing acuity in a group of male Finnish workers. The investigators identified, through a worksite history of noise exposure, 32 men with noise-induced hearing losses, characterized by deficits of 65 dB or greater at 4000 and 6000 Hz. They compared this group of workers (ages 40-59) with a group of 67 workers from the same factory, but without hearing loss. They found no statistically significant difference between the blood pressures of the two groups of workers.

Much of the research in chronic noise related cardiovascular effects has been carried out on occupational groups (Cavatorta et al. 1987; Manninen and Aro 1979; Talbott et al. 1985), although some work on road noise (Babisch and Ising 1988; Neus et al. 1983) and aircraft noise (Knipschild 1977a; 1977b) has been attempted. Whether the exposure to noise is occupationally or environmentally related may be of less concern since it has been suggested that one should expect no significant difference in noise related effects resulting from exposure to either industrial, aircraft or traffic noise (Mosskov and Ettema 1977).

Critical reviews of noise on human health, performed during the past decade have raised questions regarding the potential for noise to result in adverse health impacts. Thompson (1981) focused on epidemiological data while Kryter (1985) included a variety of laboratory data. Thompson (1981) evaluated 36 English and 47 other language papers that were concerned with the relationship between noise and cardiovascular disease and concluded that "While the epidemiologic evidence in favor of noise as a risk factor for cardiovascular disease, especially hypertension, is not currently strong, the case for noise involvement is so biologically plausible and the disease of such magnitude that the benefits of continued investigation using well designed studies are desirable." Kryter (1985) concluded that the auditory system is neurologically related to the sympathetic nervous system and that through these neural connections, noise may cause autonomic-system responses that occur without conscious thought. Such conclusions argue for a more quantitative method for assisting in the evaluation of the collection of noise-health information.

Work described in this paper presents a synthesis of carefully selected investigations from the available literature, including a meta-analysis on selected data, in order to provide some insight into the possibility that chronic ambient noise is related to hypertension. Previous syntheses have been based on critiques of methods used in individual works but have not attempted to provide quantitative evaluations of the collective works. This paper seeks to remedy this situation and understand what the collective data are suggesting with regard to the potential magnitude of hypertensive response to noise exposure.

MATERIALS AND METHODS

Our data selection was built upon the extensive review by Thompson (1981), who identified a total of 36 English and 47 other language papers. We made extensive use of data bases searching for articles which reported investigations of noise and cardiovascular disease, or some indicator of such, i.e., hypertension; our searches went back to 1980 in order to identify work performed after the review of Thompson (1981). Articles or reports were selected for our meta-analysis on the basis that they had the minimal data required for a meta-analysis: noise level; hypertension based on similar criteria; sex of study subjects; age of study subjects; and number with (or rate of) hypertension. Of the literature which we identified or were identified by Thompson (1981) only, ten articles were found to have the minimum data required; four of these studies concluded no statistically significant effects. Because of the thoroughness of our search and the fact that four of ten studies finally selected concluded no statistically significant effects, we believe that the degree of bias toward positive effects is small.

Characteristically, noise is measured in occupational and environmental settings by collecting frequency-weighted measurements [dB(A)]. Lees and Roberts (1979) have described the decibel A [dB(A)] scale as: an electronically weighted measurement of sound pressure designed to respond to noise in a manner similar to the human ear in terms of subjective loudness, intensity, and damage potential. Because the ear does not respond equally to equal sound pressures at different frequencies, the scale is weighted to take more account of pressures above 1000 Hz than of those below that frequency. It is the accepted scale for measuring ambient industrial noise.

Data on the number of subjects, number with hypertension, age or age group, sex, and levels of exposure were abstracted from each article (Table 1). The data were put in form for a logistic regression analysis as follows. Age ranges were converted to the midpoint of the age interval. Integrated day-night levels (DNL) of noise exposure according to USEPA (1974) were estimated by the formula

$$\mathrm{DNL} = 10*\log_{10}\sum_{i=1}^{4} A_i * \int_{t_{1i}}^{t_{2i}} 10^{\mathrm{dB}(A_i)/10}\,dt - 49.4,$$

where $A_1 = 10$ and dB(A) = 45 for the sleep period from 0000-0700 h, $A_2 = 1$ and dB(A) = 55 for the awake period from 0700-0800 h, $A_3 = 1$ and dB(A) = observed noise level during work from 0800-1600 h, and $A_4 = 10$ and dB(A) = 45 for the sleep period from 2200-2400 h. This formulation reduces to

$$\mathrm{DNL} = 10*\log_{10}\left[8*10^{\mathrm{dB(A)}/10} + 5.1*10^{6}\right] - 13.8,$$

where dB(A) is the average ambient noise level during the work period of 0800-1600 h.

When the noise exposure was given in the Dutch unit B, a conversion to DNL was derived through relating the annoyance level SA = B - 10% shown in Knipschild (1977a) to the DNL levels associated with noise annoyance given in Knipschild and Salle (1979). The regression equation ($R^2 = 99.9\%$, $p < 0.001$) is

$$\mathrm{DNL} = 13.1 + 37.0*\log_{10}\mathrm{B}.$$

The derived data in Table 1 were analyzed using the statistical program BMDPLR (Dixon et al. 1988). This program computes maximum likelihood estimates of parameters of the logistic model. In the logistic model, the predicted proportion of positives in terms of the outcome variable (in this case hypertensives) is assumed to follow the logistic distribution. This yields, in terms of the odds ratio P/(1-P), $\ln(p/(1-P)) = b_0 + b_1 x_1 + b_2 x_2 + \ldots + b_p x_p$. Thus, the logarithm of the odds ratio is expressed as a linear function of independent variables and covariates. Separate analyses were computed by sex within each selected study and for all studies using the dummy variable technique. For the ten studies, nine dummy variables were included to adjust for each study's intercept in the logistic model. Thus, the coefficients for age and DNL are pooled (stratified) across studies. Odds ratios were computed relative to a reference level of B = 20 [dB(A)=61.2] and confidence levels were calculated using the test-based method (Rothman 1986).

Brief reviews of the ten studies selected for this meta-analysis follow.

1. Babisch et al. (1988)

In this cross-sectional study, Babisch et al. (1988) monitored traffic noise exposure and estimated risk for ischemic heart disease in a sample of 2 512 men, aged 45-59 y. Participants completed questionnaires to elicit data on work experience, medical history, personality traits, and chest pain. Each participant was administered a 12-lead electrocardiogram, and blood pressure readings were measured with a random zero sphygmomanometer (R.Z.), and a regular mercury sphygmomanometer. Potential con-

Table 1. Data used for meta-analysis.

	Original Data					Derived Data	
Source	Number	Number with Hypertension	Age Range	Sex	Noise Level	Mean Age	DNL
1.Babisch et al. (1988)	1850	353	45-59	M	51-55[a]	52.0	53.0
	211	45	45-59	M	56-60	52.0	58.0
	318	55	45-59	M	61-65	52.0	63.0
	133	17	45-59	M	66-70	52.0	68.0
2.Brini et al. (1983)	132	5	15-30	M	> 80[b]	22.5	77.7
	85	5	31-40	M	> 80	35.5	77.7
	168	38	> 40	M	> 80	50.0	77.7
	167	15	15-30	M	-[c]	22.5	61.0
	212	27	31-40	M	-	35.5	61.0
	288	51	> 40	M	-	50.0	61.0
	150	17	15-30	M	> 90	22.5	87.7
	142	31	31-40	M	> 90	35.5	87.7
	144	56	> 40	M	> 90	50.0	87.7
3.Idzior-Walus (1987)	303	6	37.3[d]	M	-[c]	37.3	61.0
	481	35	37.3	M	105-116[b]	37.3	105.7
4.Kent et al. (1986)	101	14	31-40	M	90[b]	35.7	85.2
	121	31	41-50	M	90-95	44.8	87.7
	24	6	51-60	M	95	53.2	90.2
5.Knipschild (1977a)	823	11	35-44	M	20-40[e]	39.5	67.8
	523	16	45-54	M	20-40	49.5	67.8
	307	20	55-64	M	20-40	59.5	67.8
	810	15	35-44	F	20-40	39.5	67.8
	654	30	45-54	F	20-40	49.5	67.8
	468	47	55-64	F	20-40	59.5	67.8
	440	14	35-44	M	40-60	39.5	76.0
	381	15	45-54	M	40-60	49.5	76.0
	215	24	55-64	M	40-60	59.5	76.0
	454	9	35-44	F	40-60	39.5	76.0
	452	45	45-54	F	40-60	49.5	76.0
	291	42	55-64	F	40-60	59.5	76.0
6.Knipschild and Salle (1979)	1342	126	40-49	F	55-60[a]	44.5	57.5
	399	35	40-49	F	65-70	44.5	67.5
7.Korotkov et al. (1985)	113	11	34.3	M	65[b]	34.3	61.0
	94	6	34.2	M	93	34.2	88.2
8.Malchaire and Mullier (1979)	495	12	20-29	M	95[b]	24.5	90.2
	325	10	30-39	M	95	34.5	90.2
	210	10	> 40	M	95	50.0	90.2
	148	4	20-29	M	95	24.5	90.2
	196	9	30-39	M	95	34.5	90.2

Table 1. Raw data by source (continued).

	Original Data					Derived Data	
Source	Number	Number with Hypertension	Age Range	Sex	Noise Level	Mean Age	DNL
Malchaire and Mullier (1979) (continued)	237	13	> 40	M	95	50.0	90.2
	187	3	20-29	M	-[c]	24.5	61.0
	165	8	30-39	M	-	34.5	61.0
	148	8	> 40	M	-	50.0	61.0
9.Parvizpoor (1976)	108	0	20-29	M	-[c]	24.5	61.0
	86	1	30-39	M	-	34.5	61.0
	62	4	40-49	M	-	44.5	61.0
	58	5	50-59	M	-	54.5	61.0
	202	2	20-29	M	96[b]	24.5	91.2
	191	14	30-39	M	96	34.5	91.2
	149	18	40-49	M	96	44.5	91.2
	133	36	50-59	M	96	54.5	91.2
10.Wu et al. (1987)	2572	51	36.1[d]	M	< 80[b]	36.1	72.8
	158	12	36.2	M	> 85	36.2	82.7

[a] Day-Night Level.
[b] dB(A).
[c] DNL was computed using 65 dB(A).
[d] Average age of study group.
[e] Noise levels given in Dutch units B as described by Knipschild (1977a).

founders (e.g., age, social class, marital status, employment status, shiftwork, family history of myocardial infarction, type A behavior, body mass index, physical activity, smoking habit, and alcohol consumption) were treated as covariates.

Hourly readings of average sound pressure level were conducted on all streets with local bus service on three consecutive week days. These long-term measurements included continuous day-time traffic flow (all busy roads), as well as single event traffic (side street). Similar measurements were taken at off-main street locations to obtain information on the lowest noise levels.

Short-term measurements were also conducted during representative periods of the day at selected locations. Addresses of study participants were plotted, and average distance from house to road documented. From the values, traffic noise emission levels at 10 m from the center of the road and emission levels at the house facade were calculated for each home.

Noise levels in the sample varied between 51-70 dB(A) and streets were classified in 5-dB(A) categories. Homes with very low traffic volume (5 vehicles/10 min) were grouped in the lowest category. Only 20 % of the study participants resided in areas with noise levels > 60 dB(A), which agrees with other community surveys (Nolle 1985). The traffic noise level ranged between 51 and 70 dB(A). Although the investigators found no association between road traffic noise and the prevalence of ischemic heart disease, they did find a significant relationship between traffic noise exposure and systolic blood pressure.

2. Brini et al. (1983)

In this occupational study, the investigators developed personal histories (e.g., past and present work task, length of employment, smoking history, and exposure to noise) on 1488 male workers. The men were placed into three groups: workers with continuous exposure to noise > 80 dB(A); workers exposed only to sporadic noise of > 90 dB(A); and a comparison group of workers who were not exposed to industrial noise.

Blood pressure on the workers was measured according to WHO criteria, and hypertension was diagnosed when the systolic pressure was 160 mm Hg or greater, and/or the diastolic pressure was 95 mm Hg or greater. Workers with exposure to sporadic noise had statistically significantly more hypertension than either workers with continuous exposure, or with the comparison group; however, workers with continuous exposure were not significantly different than the comparison group. Brini et al. (1983) concluded that hypertension in this study group occurred most frequently among workers exposed to high levels of sporadic noise, rather than among workers exposed over a long time period to low noise levels.

3. Idzior-Walus (1987)

This investigator studied the effects of noise and vibration on a group of 481 sheet metal workers who were exposed to 105-116 dB(A) of noise within a frequency range of 32-2000 Hz. The workers exposure was not shorter than 2 y, with a mean exposure of 15.1 y. The comparison group of workers (303), from the same factory, were selected on the basis of age, sex, place of residence, socioeconomic class, and level of occupational activity approximating that of the exposed group. Physical examinations for both groups included: measurements of height, weight, blood pressure, electrocardiogram, determination of lipid concentration, effort angina, intermittent claudication, smoking habits, and obesity. Hypertension was diagnosed when the systolic pressure was 160 mm Hg or greater, and/or the diastolic pressure was 95 mm Hg or greater.

Study findings indicated that workers exposed to high noise levels experienced statistically significantly more systolic and diastolic hypertension than the comparison group; however, there was a strong association between body weight and blood pressure in both groups.

4. Kent et al. (1986)

In this case-referent study, the investigators explored the relationship between hearing loss (as an indirect indicator of prolonged noise exposure), hypertension, and clinical diagnosis of cardiovascular disease by examining the medical records of 2 250 Air Force aircrew members. The investigators used high-frequency hearing loss, diagnosed with a high probability of being noise-induced, as an indirect indicator of the extent of relevant noise exposure. Average hearing threshold levels in the 3-,4-, and 6-kHz range categorized by age groups were used to determine equivalent 8-h daily occupational noise exposure of an entire flying career. Daily estimates of noise exposure were estimated by age to be: 30-40 y [90 dB(A)]; 41-50 y [90-95 dB(A)]; 51-60 y [95 dB(A)]. Systolic and diastolic blood pressure were recorded for each crew member, and participants were then grouped according to maximum, middle, and minimum hearing loss for analysis. No statistically significant associations were noted between sensorineural hearing loss and hypertension or cardiovascular disease.

5. Knipschild (1977a)

This investigator reported on a community cardiovascular survey of a population living near Schiphol airport (Amsterdam). Approximately 6 000 men and women, ages 35-64 y, were screened for medical treatment for heart disease, angina pectoris, hypertension (systolic > 175 and diastolic > 100 mm Hg), pathological heart shape, electrocardiogram, height, and weight. Aircraft noise is expressed in the Dutch measure B. The community population was divided into two groups who had experienced exposure to variable aircraft noise for a period of 6 y: high aircraft noise (B = 40-60);low aircraft noise (B = 20-40). Persons in areas with more (B > 40) aircraft noise experienced statistically significantly more cardiovascular disease (e.g., pathological heart shape, medical treatment for heart trouble and hypertension) and high blood pressure.

6. Knipschild and Salle (1979)

This population study was restricted to 1342 women 40-49 y of age living in an area characterized by the investigators as quiet [DNL < 62.5 dB(A)], and 339 living in a "noisy" [DNL > 62.5 dB(A)] area. Health end points were hypertension, angina pectoris, ischaemia on E.C.G., and heart shape pathology. The women were identified from an existing cardiovascular screening program and by home address were divided retrospectively into noisy and quiet streets. By measuring daytime (1000-1600 h) noise levels, the investigators determined that the equivalent noise level (Leq) for the noisy streets was 65-70 dB(A), and 55-60 dB(A) for the quiet streets. In both groups, 74% of the women had normal blood pressure, and in both groups, the prevalence rate of hypertension was 9%. From this study, the investigators could not find any indication that persons living in noisy streets run a greater risk of cardiovascular disease.

7. Korotkov et al. (1985)

The investigators examined 207 seamen who were audiologically healthy and ranged in service from 1 y to more than 20 y. The seamen were divided into two groups: deck crew and engine crew. The mean age for both groups was 34 y. The 94 seamen from the engine room were exposed to noise conditions equivalent to 93 dB(A). The 113 deck crewmen were exposed to noise conditions equivalent to 65 dB(A). Findings indicated that exposure to prolonged noise created cardiovascular problems in seamen, primarily hypertension, and that there is an increase in the rate of hypertension as length of service increases, and for those with more than 10 y of service an increase in the rate of hypertension with increased noise levels.

8. Malchaire and Mullier (1979)

In this occupationally-based cross-sectional study, two groups of workers were compared with controls. The first group of 1030 men was composed of car assembly line workers where noise levels were between 92 and 100 dB(A). The second group of 581 men was composed of wire mill workers who were exposed to noise levels between 93 and 97 dB(A). In both industries, the average equivalent noise level was equal to 95 ± 1 dB(A). A control group composed of 500 men who had never been exposed to noise during their working life was selected from one of the two companies. Findings of this study indicate the prevalence of hypertension does not appear to be greater among workers exposed to equivalent noise levels around 95 dB(A) than in the comparison population.

9. Parvizpoor (1976)

Male weavers working in textile mills in the Isfahan area of Iran were selected for study. The 675 men were exposed to an average noise level of 96 dB(A). A comparison group of 314 workers employed in light industry without occupational exposure to noise was selected randomly from the population in the study area. The workers were classified into three groups:

a) Normotensive: Systolic blood pressure below 140 mm Hg and diastolic pressure below 90 mm Hg.

b) Hypertensive: Systolic blood pressure 160 mm Hg or more or diastolic pressure 95 mm Hg or more.

c) Borderline: In between these figures.

Findings suggest a statistically significant ($p < 0.01$) difference between the weavers and the comparison group in the percentage of workers in the normotensive, hypertensive, and borderline categories. The investigator suggests that there is an increase in the prevalence of borderline cases and hypertension the longer a worker is employed. The findings also suggest that textile workers have a greater risk of developing hypertension, and that the difference occurs as early as 39 y of age, and increases with length of employment.

10. Wu et al. (1987)

In this study, a total of 3 748 shipyard workers were screened and workers who were female, had a family history of hypertension, had suffered an elevated blood pressure related disease, had prior documented hypertension, or were exposed to a 80-85 dB(A) noise environment were excluded. The study population remaining included 158 workers whose worksite noise levels exceeded 85 dB(A) (the exposed group), and 2 572 workers working in an environment with noise levels less than 80 dB(A) (the reference group). The prevalence of hypertension in the exposed group was found to be statistically significantly higher than in the reference group.

RESULTS

The logistic regression coefficients overall and by study are shown for each sex in Table 2. Analyses were performed within each study and sex (adjusting for age) and overall for each sex adjusting simultaneously for age and study. Averages over study weighted inversely by the square of the standard error of the estimate were also calculated for each sex. Inspection of the individual regression coefficients in Table 2 provides confidence that no one or two strongly positive or negative studies would dominate the overall logistic regression. After entering the ten studies, age, and DNL into the logistic equation, the goodness-of-fit χ^2 was 97.3 with 32 degrees-of-freedom ($p > 0.001$), and the C. C. Brown goodness-of-fit χ^2 was 0.19 with two degrees-of-freedom ($p = 0.908$). Both of these tests indicate an excellent fit of the model to the data (Rothman 1986). The overall coefficients were used to calculate the increase in the odds of developing hypertension as a function of increasing noise levels above a DNL of 61.5 dB(A) or above B = 20, the Dutch measure of noise exposure (Table 3). The increase in odds of developing hypertension shown in Table 3 are independent of age in the sense that a 50-y old person would have increased odds due to increased DNL

Table 2. Logistic regression coefficients for noise exposure in DNL, adjusted for age and study.

INDIVIDUAL LOGISTIC REGRESSIONS

	Males		Females	
Study	Beta	S.E.	Beta	S.E.
1	-0.018	0.012	-[a]	-
2	0.028	0.006	-	-
3	0.030	0.010	-	-
4	-0.020	0.016	-	-
5	0.068	0.025	0.068	0.018
6	-	-	-0.007	0.020
7	-0.017	0.019	-	-
8	-0.001	0.009	-	-
9	0.042	0.012	-	-
10	0.142	0.034	-	-
Weighted[b] Average:	0.018	0.004	0.034	0.013

OVERALL LOGISTIC REGRESSION

Males		Females	
Beta	S.E.	Beta	S.E.
0.021	0.004	0.031	0.013

[a] Females not investigated in this study.

[b] Each coefficient was weighted inversely to its variance.

compared to a 50-y old person in the lower DNL category. The effect of increasing hypertension with age has been included in the model but the regression coefficients are not shown here.

Since the exposure periods in the occupational studies used were either greater than a minimum of 3 y (most were much longer) or the study population was a stable residential community with exposure levels going back several years, these data can be used to estimate the effects of long-term exposure. One would find the rate for a particular age/sex combination and simply inflate that rate using the odds ratios from Table 3. Of course, confidence limits on such estimates would have to take into account the errors in the underlying rates as well as those in the odds ratios.

DISCUSSION

Noise-produced stress may be an important contributing factor in the development of hypertension in exposed populations. However, as shown in this review, findings reported in the literature represent occupational and community populations and are often contradictory. Babisch et al. (1988) showed a decrease in rate of hypertension at intermediate levels of exposure and a significant increase only between the highest and lowest levels of exposure. The present report found the Babisch et al. (1988) data not to have a significant overall relationship between DNL and hypertension. In a study of merchant seamen, Korotkov et al. (1985) inferred an increase in hypertension with increased length of service at high noise levels, but we found no direct effect at the levels reported, presumably because our analysis did not include length of service. Some authors (Idzior-Walus 1987; Brini et al. 1983; Knipschild 1977a; Knipschild 1977b; Korotokov et al. 1985; Parvizpor 1976; Wu et al. 1987) have suggested that high-intensity noise may elevate blood pressure and lead to the increased prevalence of hy-

Table 3. Odds ratios and 95% confidence intervals for increasing noise levels by sex.

		Male		Female	
B[a]	DNL[b]	OR[c]	95% CI	OR	95% CI
20	61.2	1.00	-	1.00	-
25	64.8	1.08	1.05, 1.11	1.12	1.02, 1.22
30	67.8	1.15	1.09, 1.21	1.22	1.04, 1.44
35	70.2	1.21	1.13, 1.30	1.32	1.05, 1.66
40	72.4	1.26	1.16, 1.38	1.41	1.06, 1.88
45	74.3	1.31	1.19, 1.46	1.50	1.07, 2.09
50	76.0	1.36	1.21, 1.53	1.58	1.08, 2.30
55	77.5	1.41	1.24, 1.60	1.66	1.09, 2.50
60	78.9	1.45	1.26, 1.66	1.73	1.10, 2.71
65	80.2	1.49	1.28, 1.73	1.80	1.11, 2.91

[a] The reference level of B = 20 was chosen following the recommendations of Knipschild (1977b).

[b] Day-Night Noise Level (DNL) takes into account the length of exposure.

[c] OR of 1.00 chosen as equivalent to a worker exposed to less than or equal to B=20 or DNL=61.2 dB(A).

pertension; others (Kent et al. 1986; Knipschild and Salle 1979; Malchaire and Mullier 1979) have argued that prolonged exposure to high-intensity noise was not seen to be significantly related to increased blood pressure. It has also been suggested that adaptation occurs with prolonged exposure to noise at high levels (Catlin 1965; Lees and Roberts 1979).

The equivocal findings cited in this paper may reflect study design considerations as much as the presence or absence of noise-related health effects, since many of the studies were cross-sectional, and could only provide crude estimates of associations between exogenous and endogenous risk factors and hypertension, because of unknown exposure history and other confounding factors. In studies such as these, many confounding factors, e.g., age, body mass index, length of employment, socioeconomic status, marital status, shiftwork, family history of hypertension and heart disease, Type A behavior, physical activity, smoking habits, and alcohol consumption, may play a role in the development of adverse health effects. Although it is virtually impossible to control for all potential confounders, age, which is potentially the most important confounder, was considered in the analysis of all the reviewed studies.

In the United States, hearing loss and increased blood pressure occur with aging in healthy populations (Lasser and Master 1959). Since age is associated with hearing acuity as well as blood pressure in populations that are not specifically exposed to excessive occupational noise (ISO/DIS 1982; Hatwick et al. 1977), it is important to account for age as a confounder in evaluating hearing and cardiovascular disease. In fact, epidemiologic studies are frequently unable to detect subtle effects in populations at very low exposure levels. Consequently, negative studies may be simply reflecting the inability of particular study designs to detect real effects rather than suggesting that effects do not exist.

Cardiovascular disease (CVD) would have been a more attractive endpoint to study than hypertension. However, CVD is a multi-factorial event encompassing quite a few risk factors that are clearly beyond consideration through ecologic research representing most of the available data. Among these other risk factors, hypertension is only one element in a causal network that leads to the disease endpoint (CVD). The study of complex endpoints represents a dilemma for ecologic study and has been discussed at length by others (Morgenstern 1982). Therefore, the use of a continuous measure, hypertension, brings some strength to a quantitative data synthesis. The association of blood pressure levels with risk of CVD has been demonstrated consistently over the past three decades (USDHEW 1979; Tyroler 1986). Such studies, utilizing a broad variety of research designs, have focused on insured individuals, industries and diverse communities (USDHEW 1976; Gordon and Kannel 1972; Pooling Project Research Group 1978; Society of Actuaries 1959; Truett et al. 1976). The risk relationship appears to apply to women as well as to men (Gordon and Kannel 1972). In 1974, the Environmental Protection Agency determined that approximately 20 million Americans were exposed to average levels above 65 dB(A) as a result of urban noise (USEPA 1974). Given the large number of persons exposed to environmental noise sources in excess of 65 dB(A) (e.g., large highways, inner city traffic, airports, etc.), the large proportion of persons susceptible to hypertension, the strength of association between hypertension and CVD, and the derived odds ratios (Table 3) for noise induced hypertension, noise may be one of the most important environmental factors presently being neglected within both the research and regulatory arenas.

Given the recognized difficulties in developing community-based environmental studies, it is probably unrealistic to expect risk ratios of 2.0 or higher in epidemiologic noise research and hypertension and thereby clarify some of the many questions surrounding our present understanding of health responses to environmental noise. As noise and perceived health risks from environmental agents become more of a public concern (Herbold et al. 1989), one option to the dilemma would be a public acceptance of small increases in relative risks associated with particularly sensitive groups within a community population (e.g., the elderly, ill, and very young children) who appear to be more susceptible to the effects of frequent exposure to environmental noise (Petiot et al. 1988). Clearly, this issue is one which should be subject to open public debate with full disclosure by members of the scientific community in terms of the ability to study certain, nearly ubiquitous environmental agents, correctly identify the offending agent(s), and identify efficacious affordable remedial measures.

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REMOVAL EFFICIENCY OF PARTICULATE MATTER BY A RANGE EXHAUST FAN

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The efficiencies of a range exhaust fan in removing particulate combustion products from cooking were evaluated in a first-floor apartment by measuring the size distributions and the number concentrations of the submicrometer aerosols. On average, the particle removal efficiencies of the range hood were in the range of 75%-80%. Without the range hood operating, the number median diameters of making scrambled eggs, frying chicken, cooking soup, and the background conditions were 40 nm, 50 nm, 30 nm, and 70 nm, respectively. While the range hood was on, the number median diameters were found to be approximately 40 nm, regardless of the types of cooking. Regarding the surface area weighted size distributions, the surface median diameters of the four situations mentioned above were 180 nm, 200 nm, 150 nm, and 220 nm with the range hood off, respectively, and 200 nm for most of the conditions while the range hood was on. The volume median diameters in all conditions were almost similar, namely 300-350 nm both with and without the range hood.

INTRODUCTION

Indoor air quality has become an important issue in recent years, because of the occurrence of the "sick building syndrome" and the fact that most people spend more than 80% of their time indoors (NRC 1981). Regarding indoor combustion sources, gas cooking could be considered as one of the important sources because more than 95% of the households use gas stoves in Taiwan.

There have been many investigations of the gaseous emissions from gas cooking, such as nitrogen dioxide emission (Spengler et al. 1983; Goldstein et al. 1988). It was also suggested that some carcinogenic particulate matter might emit from food heating processes, such as polycyclic aromatic hydrocarbons. Some of them are regarded as possible causative agents of human cancers (Clanton et al. 1987). Cooking is a combustion process, which emits highly concentrated smaller particles (smaller than 1 µm) with a subsequent coagulation. From the health aspects, submicrometer aerosol has a larger deposition efficiency in the respiratory tract, especially alveolar region (Phalen et al. 1991; James et al. 1991). Several field measurements demonstrated that cooking had led to particle number concentrations one or two orders of magnitude higher than the background conditions with an average number median diameter of 50 nm (Stoute et al. 1984; Tu and Knutson 1988;

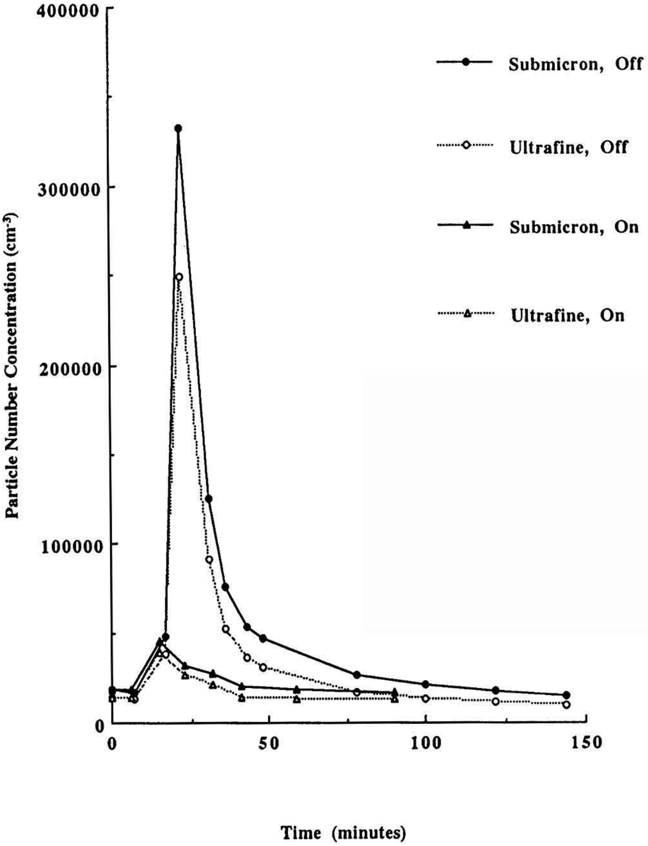

Fig. 1. The number concentrations of the submicrometer and ultrafine aerosols during and after particle generation by scrambling eggs in the kitchen both with (on) and without (off) the fan.

Strong 1988). Therefore, steps to reduce the exposure to airborne emissions from gas cooking becomes an important issue. Generally speaking, air cleaning devices are commonly most effective if installed near the emission sources. For gas stoves, range-exhaust fans are used for providing the vents to carry combustion exhausts to the outside environments. In the U.S., one third of the households have no range exhaust fans and half have vented fans (Nagda et al. 1989). In Taiwan, more than 90% of the households have range hoods above gas stoves. However, little is known concerning the effectiveness of vented fans in decreasing indoor contaminates associated with cooking activities.

This paper addresses the removal efficiency of a range exhaust fan in controlling the particulate emissions of cooking from gas combustion. The field measurements were performed to evaluate the characteristics of submicrometers aerosols (smaller than 1 μm) and ultrafine aerosols (smaller than 0.1 μm) of scrambling eggs, frying chicken, and cooking soup in a kitchen of a first floor apartment both with and without a range exhaust fan. The influences of the range exhaust fan on size distributions and number concentrations of the submicrometer and ultrafine aerosols before, during, and after cooking were evaluated. Furthermore, median diameter (MD), surface median diameter (SMD), and volume median diameter (VMD) with

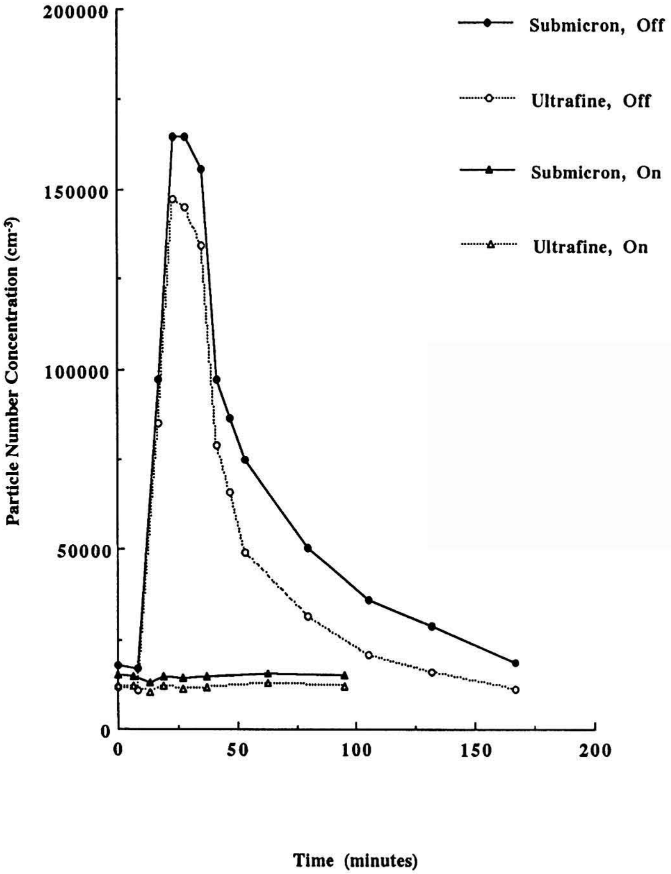

Fig. 2. The number concentrations of the submicrometer and ultrafine aerosols during and after particle generation by frying chicken in the kitchen both with (on) and without (off) the fan.

geometric standard deviation (GSD) for various cooking activities were discussed.

MATERIALS AND METHODS

The field measurements were conducted in a kitchen (5 m × 1.5 m × 3 m) of a first-floor apartment (9 m × 10 m × 3 m) with a living room, two bedrooms, a kitchen, and a bathroom in Taipei in April 1992. The particle sizer is a high resolution electrical mobility aerosol spectrometer, including a differential mobility particle sizer (DMPS TSI 3932) and a condensation particle counter (CNC TSI 3022). This particle detector is capable of measuring the number concentrations of the aerosols within the size range of 0.017-0.886 μm (divided into 33 channels) at the sampling flowrate of 3 Lm^{-1}. The DMPS/CNC instrument was used with a bipolar charger to charge aerosols to a known Boltzman distribution. Then, the aerosols were classified by their ability to traverse an electric field and counted by an optical detector after a supersaturated vapor condense onto particles, causing them to grow into larger droplets. The DMPS/CNC instrument was located 3 m away from the gas stove in the kitchen. In regard to the characteristics of the range exhaust fan, the fan is like a upside-down TSP sampler which is installed 60 cm above the gas stove. Without installing charcoal, a layer of fibre filter is inside the fan for trapping particulate matter.

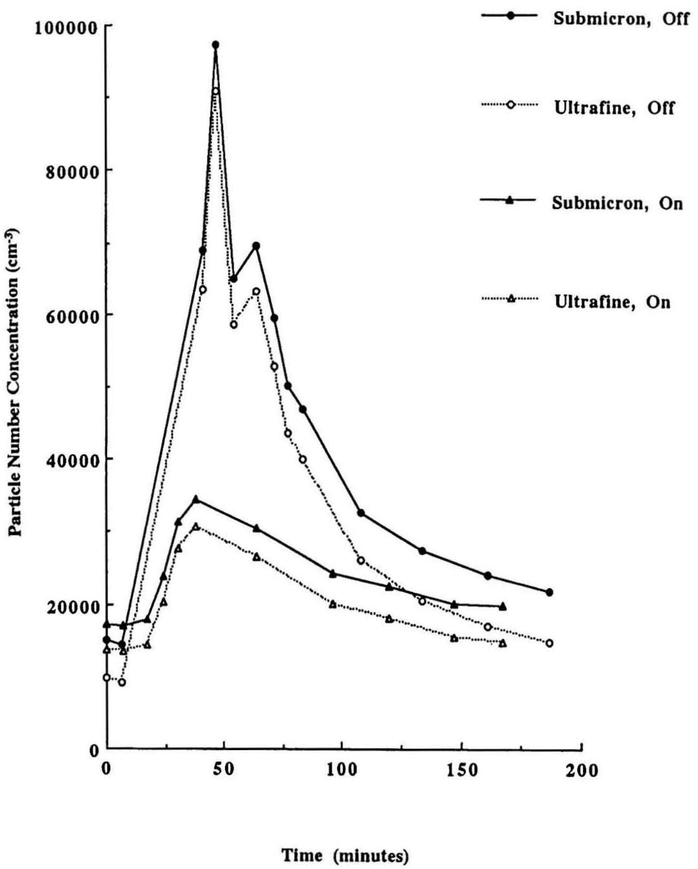

Fig. 3. The number concentrations of the submicrometer and ultrafine aerosols during and after particle generation by cooking soup in the kitchen both with (on) and without (off) the fan.

During all of the field measurements, the doors and windows of the apartment were closed. A 5-min sampling interval was used to measure the submicrometer aerosols. In order to examine the changes of the size distributions and of the number concentrations of submicrometer and ultrafine aerosols before, during, and after the aerosol generations, the time sequences of particle generation and measurement were as follows. Before any particle generation, several sets of the measurements were made as background conditions without gas cooking. The time period of scrambling eggs, frying chicken, and cooking soup was 15 min in order to obtain two or three measurements during these aerosol generation periods. For the cases with the range hood, the hood was turned on as the active aerosol generations started and turned off as the combustion sources ceased in order to simulate the realistic situations. The following measurements had been made for 2 h after the combustion activities ceased for the purpose of evaluating the decay behavior of the generated particles. Furthermore, the decay behavior of the generated aerosols could be evaluated by 5 min after the end of the aerosol generation, 30 min after the end of the aerosol generation, and 60 min after the end of the aerosol generation. Each measurement sequence of the combustion sources was repeated three times, each kind of the particles was produced again, and the time evolution of the particle size distributions was again measured.

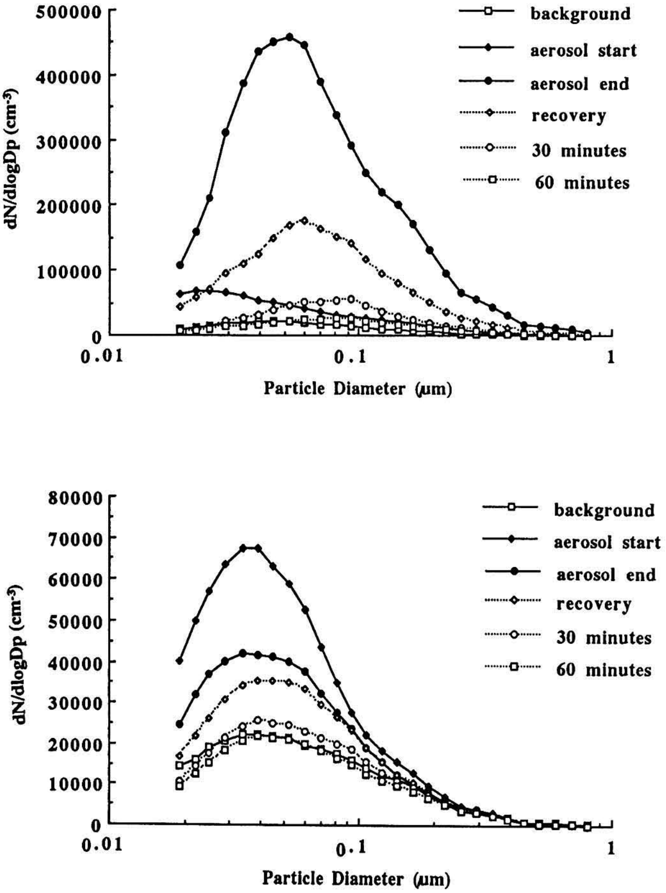

Fig. 4. The number-weighted size distributions of the submicrometer aerosols during and after particle generation by scrambling eggs in the kitchen both with and without the fan.

RESULTS AND DISCUSSION

When the kitchen was not used for cooking (background conditions), the concentration of the ultrafine and submicrometer aerosols ranged from 8400 to 15 000 cm^{-3} (average 13 200 cm^{-3}), and from 12 000 to 20 000 cm^{-3} (average 22 100 cm^{-3}), respectively. In addition, the ultrafine aerosols constituted approximately 60%-75% of the submicrometer aerosols by number. On the average, the MD, SMD, and VMD were 70 nm, 220 nm, and 330 nm, respectively, with an average geometric standard deviation of 2. The median diameters of the background conditions measured in the kitchen were found to be compatible with those observed indoors from other investigations (Stoute et al. 1984; Tu and Knutson 1988; Strong 1988; Owen et al. 1992).

For the evaluation of the range exhaust fan, the particles were produced from scrambling eggs, frying chicken, and cooking soup. The number concentrations, size distributions, surface and volume median diameters of the background conditions (without cooking activities), the situations during cooking, and the recovery conditions (after cooking ceased) were compared to evaluate the particle removal efficiency of the fan. The condensation nuclei counted as a function of time during and after making scrambled eggs, frying chicken, and cooking soup both with and without the range exhaust fan are shown in Figs. 1, 2, and 3, respectively. Moreover, the number-weighted

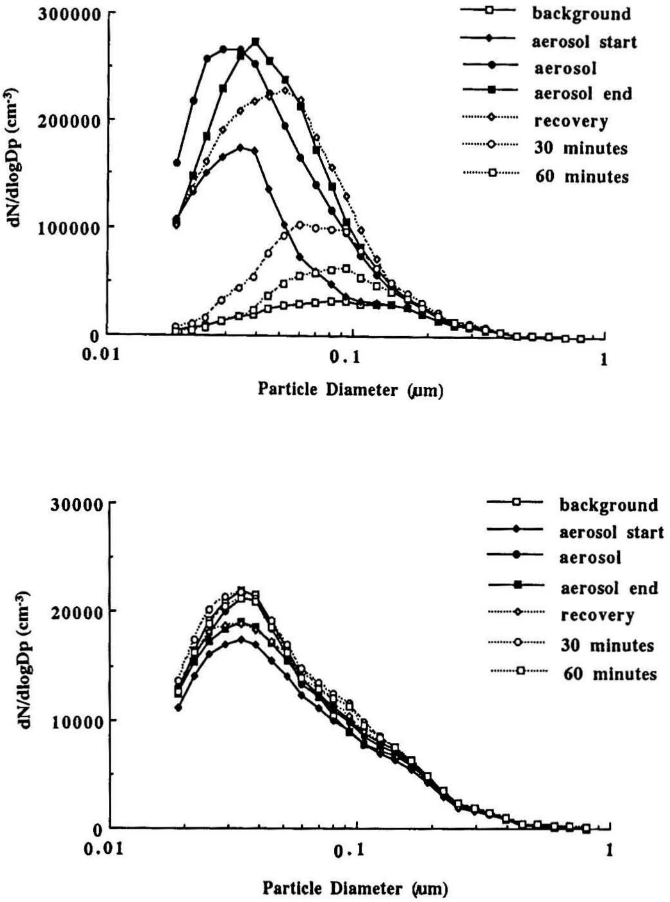

Fig. 5. The number-weighted size distributions of the submicrometer aerosols during and after particle generation by frying chicken in the kitchen both with and without the fan.

particle size distributions of making scrambled eggs, frying chicken, and cooking soup both with and without the range-exhaust fan in the following situations— before (background), during (aerosol start, aerosol, and aerosol end with a 5-min time interval), and after (recovery, 30 min, and 60 min) are presented in Figs. 4, 5, and 6, respectively. The comparisons of the condensation nuclei concentrations, MD, SMD, and VMD with GSD of each case with and without the fan are made in Tables 1, 2, and 3.

In scrambling eggs, the number concentrations of the ultrafine and submicrometer aerosols can reach 91 000 cm^{-3} and 125 000 cm^{-3}. Furthermore, the average number ratio of the ultrafine to submicrometer aerosols was approximately 0.75. During the active aerosol generation, the MD, SMD, and VMD were observed to be 55 nm, 245 nm, and 400 nm, respectively. The results of making scrambled eggs were similar with those observed of frying food without specifically indicating what kind of the cooked food (Tu and Knutson 1988). With the fan on, the number concentrations of the ultrafine and submicrometer aerosols decreased to 21 500 cm^{-3} and 27 200 cm^{-3}, respectively. The particle removal efficiency of the fan was estimated to be 0.80 by the number concentrations of the submicrometer particles. Additionally, the average number concentration ratio of the ultrafine aerosols to submicrometer aerosols was found to be much higher, approximately 0.80. During the active aerosol generation, the MD, SMD, and VMD

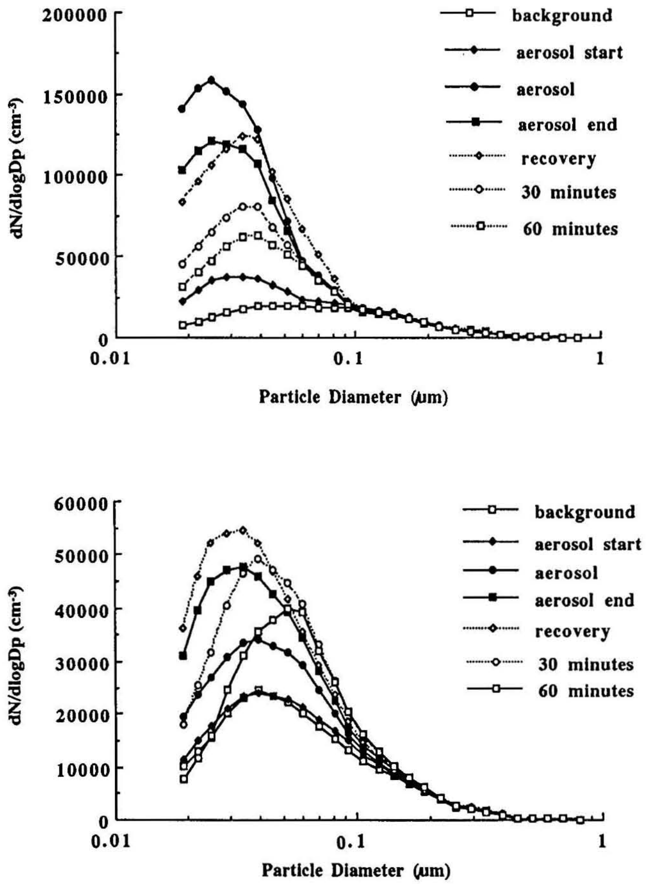

Fig. 6. The number-weighted size distributions of the submicrometer aerosols during and after particle generation by cooking soup in the kitchen both with and without the fan.

were observed to be much smaller because of the shift of the size distributions to the smaller size ranges with the operation of the fan.

Regarding frying chicken, the number concentrations of the submicrometer aerosols ranged from 97 000 cm^{-3} to 165 000 cm^{-3} with an average number ratio of ultrafine to submicrometer aerosols of 0.90. While the aerosols were produced, the MD, SMD, and VMD were found to be 40 nm, 140 nm, and 260 nm, respectively. In addition, the size distributions of frying chicken in this study were similar to those measured with cooking in a kitchen (Stoute et al. 1984). It was recommended that the disappearance of small aerosols, generated from gas combustion, from the particles measured during scrambling eggs and frying chicken might be related to the coagulation effects. The presence of the higher humidity and emitted organic vapors during the processes of cooking tends to induce the produced smaller aerosols to disappearance by coagulation. With the operation of the fan, the reduction of the particle number concentrations was observed to be 90%. The average number ratio of ultrafine to submicrometer aerosols was approximately 0.80, which is smaller than that without the fan. It might indicate that the number reduction of the ultrafine particles was higher than that of the submicrometer ones by the fan. Furthermore, the particle size distributions during and after frying chicken were found to be similar to those of the background conditions while the fan was on.

Table 1. Summary of the measurements of number concentrations of submicrometer (Ct) and ultrafine (Cu) aerosols, MD, SMD, VMD, and GSDs of scrambling eggs with and without the range hood.

	Ct (cm^{-3})	Cu (cm^{-3})	MD (µm)	GSDn	SMD (µm)	GSDs	VMD (µm)	GSDv
Hood Off								
background	17200	13100	0.051	2.059	0.216	2.158	0.352	1.861
aerosol start	48100	38700	0.039	2.171	0.244	2.262	0.404	1.824
aerosol end	33200	24900	0.054	2.016	0.232	2.207	0.385	1.859
recovery	125000	91000	0.061	1.998	0.225	2.175	0.373	1.877
30 min	45000	26000	0.073	1.989	0.245	2.094	0.388	1.820
60 min	23500	15000	0.073	2.025	0.247	2.061	0.383	1.809
Hood On								
background	19000	14400	0.041	1.803	0.148	2.337	0.293	2.115
aerosol start	45500	39200	0.041	1.915	0.170	2.305	0.301	1.997
aerosol end	31700	26300	0.044	1.974	0.184	2.337	0.293	2.115
recovery	27200	21512	0.048	1.987	0.193	2.208	0.329	1.927
30 min	20100	14000	0.051	2.043	0.213	2.175	0.352	1.881
60 min	17200	13000	0.051	2.059	0.216	2.158	0.352	1.861

Table 2. Summary of the measurements of number concentrations of submicrometer (Ct) and ultrafine (Cu) aerosols, MD, SMD, VMD, and GSDs of frying chicken with and without the range hood.

	Ct (cm^{-3})	Cu (cm^{-3})	MD (µm)	GSDn	SMD (µm)	GSDs	VMD (µm)	GSDv
Hood Off								
background	17100	10700	0.081	2.017	0.222	1.916	0.326	1.801
aerosol start	97000	85100	0.035	1.910	0.173	2.350	0.311	1.954
aerosol	165000	147300	0.037	1.847	0.143	2.310	0.269	2.073
aerosol end	165000	145300	0.042	1.807	0.140	2.267	0.264	2.101
recovery	156000	134700	0.045	1.838	0.143	2.200	0.259	2.071
30 min	59800	38000	0.072	1.822	0.189	1.983	0.294	1.885
60 min	41300	26000	0.078	1.849	0.204	1.932	0.308	1.852
Hood On								
background	14700	12100	0.041	2.026	0.192	2.207	0.322	1.904
aerosol start	12800	10300	0.043	2.061	0.203	2.217	0.342	1.896
aerosol	14600	11900	0.041	2.043	0.201	2.240	0.343	1.910
aerosol end	14200	11300	0.044	2.075	0.206	2.207	0.346	1.891
recovery	14600	11600	0.044	2.071	0.206	2.216	0.347	1.894
30 min	15700	12800	0.042	2.041	0.200	2.250	0.345	1.919
60 min	15200	12200	0.043	2.061	0.211	2.263	0.365	1.914

Table 3. Summary of the measurements of number concentrations of submicrometer (Ct) and ultrafine (Cu) aerosols, NMD, SMD, VMD, and GSDs of cooking soup with and without the range hood.

	Ct (cm^{-3})	Cu (cm^{-3})	MD (μm)	GSDn	SMD (μm)	GSDs	VMD (μm)	GSDv
Hood Off								
background	14400	9100	0.071	2.131	0.230	1.980	0.346	1.802
aerosol start	69000	63400	0.032	1.816	0.164	2.585	0.333	2.027
aerosol	97400	91000	0.034	1.745	0.140	2.585	0.304	2.150
aerosol end	65000	58600	0.036	1.835	0.165	2.469	0.322	2.030
recovery	69700	63300	0.037	1.810	0.157	2.486	0.316	2.075
30 min	40900	33900	0.048	1.851	0.178	2.337	0.328	2.015
60 min	28800	23300	0.055	1.847	0.197	2.315	0.335	2.033
Hood On								
background	16900	13500	0.047	1.973	0.186	2.192	0.317	1.942
aerosol start	17900	14200	0.046	1.980	0.183	2.183	0.313	1.952
aerosol	24000	20100	0.044	1.932	0.171	2.249	0.302	1.981
aerosol end	31400	27500	0.039	1.899	0.158	2.322	0.294	2.039
recovery	34600	30500	0.037	1.869	0.153	2.345	0.289	2.054
30 min	30400	25700	0.044	1.830	0.151	2.284	0.283	2.077
60 min	24200	20100	0.051	1.827	0.160	2.194	0.286	1.914

With regard to cooking the vegetable soup, the number concentrations increased to 97 400 cm^{-3}. In particular, the ultrafine aerosols constituted more than 90% of the submicrometer aerosols by number. The MD, SMD, and VMD were found be much smaller than those observed from making eggs and frying chickens. These results demonstrated that the MD was close to those found in the kitchen by a diffusion battery without specifically indicating cooking process or what kind of food was cooked (Strong 1988). From one field investigation (Tu and Knutson 1988), the MD of cooking soup was found to be much smaller, 14 nm, which might be related to the used instruments with the ability to detect smaller particles. With the operation of the range exhaust fan, the particle size distributions were found to shift to the larger size ranges. In addition, the particle number reduction could reach 75%.

CONCLUSIONS

In summary, cooking was found to generate a great number of submicrometer and ultrafine aerosols from gas combustion in the stove. The larger particles could stay airborne longer and would remain in the similar size distributions longer, including scrambling eggs and frying chicken. On the other hand, the smaller particles generated would deposit on the surface (diffusion) and/or coagulate to the larger particles, such as cooking soup. With the fan operating for a short period of time (during the cooking activities, 15 min), the particle removal was found to be very effective, with an average efficiency of approximately 75%. The particle size distributions significantly shifted to the larger size ranges, especially for making eggs and frying chickens. For cooking soup, the influence on the particle size distributions by the fan was not so evident. Therefore, it is suggested that a range exhaust fan could effectively reduce the particulate emission of cooking in the domestic environments.

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INCINERATION FOR RESOURCE RECOVERY IN A CLOSED ECOLOGICAL LIFE SUPPORT SYSTEM

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A functional schematic, including mass and energy balance, of a solid waste processing system for a controlled ecological life support system (CELSS) was developed using Aspen Plus, a commercial computer simulation program. The primary processor in this system is an incinerator for oxidizing organic wastes. The major products derived from the incinerator are carbon dioxide and water, which can be recycled to a crop growth chamber (CGC) for food production. The majority of soluble inorganics are extracted or leached from the inedible biomass before they reach the incinerator so that they can be returned directly to the CGC and reused as nutrients. The heat derived from combustion of organic compounds in the incinerator was used for phase-change water purification. The waste streams treated by the incinerator system conceptualized in this work are inedible biomass from a CGC, human urine (including urinal flush water) and feces, humidity condensate, shower water, and trash. It is estimated that the theoretical minimum surface area required for the radiator to reject the unusable heat output from this system would be 0.72 m^2/person at 298 K.

INTRODUCTION

The high transport-to-orbit cost of $22 000/kg (Moses et al. 1989) associated with current rocket technology dictates the need for extensive recycling and regeneration of human consumables, i.e., water, oxygen, and food, on future long-term space missions. For the short-duration space missions, such as Space Shuttle flights, recycling is uneconomical due to the high cost of transporting the equipment needed for recycling in space. Therefore, the life support system used on short missions is an open loop system. Recycling and food regeneration on long-term missions requires processing of waste streams in order to recover useful materials. This concept of recycling and resource recovery in confined environments has applications in a number of earth-based systems, such as in small remote rural communities in Alaska, isolated communities in deserts and other harsh environments, potential below-ground cities of the future, isolated scientific missions, e.g., the

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South Pole station, and long-duration submarine missions or scientific expeditions. Thus, what has been traditionally treated as "waste" now becomes a "secondary raw material" from which resources can be recovered. For example, the inedible biomass from higher plants can be combusted, and the products carbon dioxide, water, and inorganic nutrients can be fed to crops in a crop growth chamber to produce additional food as well as potable transpired water and oxygen. This type of advanced life support system is referred to as a partially closed system. For the life support system to be completely closed, further processing of solid, liquid, and gaseous streams is necessary. Development of these advanced life support systems will provide a research thrust towards understanding the technology required to enable compliance of communities and institutions with the Federal RCRA-CFR Title 40 (Resource Conservation and Recovery Act).

Methods to process solid wastes and slurries (inedible biomass, food preparation wastes and uneaten food, feces, and trash) are currently under consideration by the National Aeronautics and Space Administration (NASA). These include processes based on physical/chemical or biological principles, as well as combinations of technologies based on these principles. The main physical/chemical methods are thermal processes, such as incineration, wet air oxidation, and supercritical water oxidation (SCWO). Nonthermal processes under investigation by NASA are electrochemical oxidation and/or ultraviolet (UV) radiation. The following brief descriptions of each of these processes are taken mainly from Wydeven (1988). It should be noted that these processes are examples of the technologies available and there is no implicit claim that these are chosen or optimal technologies.

Dry incineration involves the combustion of a concentrated solid feed. Waste feed is concentrated by evaporation to a combustible solids content greater than about 50% by weight before being heated in air or oxygen (O_2) near ambient pressure to a temperature of about 810 K (Labak et al. 1972). Pure O_2 is the preferred oxidizing agent. The end products of dry incineration are biologically sterile and consist of water condensate, inorganic ash, and gases (primarily carbon dioxide, CO_2, and nitrogen, N_2, if air is used instead of pure O_2). A catalytic afterburner may be required when using dry incineration to further the extent of combustion. Dry incineration has these disadvantages: a) incomplete combustion, even with an afterburner; b) product water may require further processing before being reused; and c) an energy-intensive evaporation or predrying step in order to concentrate the combustible material may be required before incineration can be initiated. The ash in the solid product is mainly in the form of oxides, which may eventually be used as a source of inorganic nutrients for growing crops.

Wet oxidation, or the Zimpro Process (Huesler 1971), involves the oxidation of either a dilute or concentrated waste slurry at an elevated pressure and temperature. Combustion takes place in air or O_2 at a pressure of about 14 MPa (2 000 psi) and a temperature range from 470 to 570 K. Wet oxidation, unlike incineration, does not require a predried feedstock. Dilute wastes (~5% solids) can be oxidized using this technique. The primary advantages of wet oxidation for space habitat applications are the recovery of useful water and the reduction of solid wastes to a very small weight and volume of sterile, nondegradable ash (Johnson and Wydeven 1985). Wet oxidation is particularly attractive for space habitats where food crops are grown, since carbon dioxide from combustion of organics and the cations in soluble form are readily available as plant nutrients. Incomplete combustion by wet oxidation may require treatment of the product gas and liquid before they are reused (Johnson and Wydeven 1985). A four-person capacity prototype wet oxidation subsystem for space habitats has been built and tested (Jagow 1972).

Waste destruction by the SCWO process makes use of water in its supercritical state (above 647 K and 22 MPa) as the process medium for carrying out the destruction of organic compounds by oxidation. Water exhibits properties in the supercritical state that makes this process particularly attractive for waste destruction. The following are among the major advantages: 1) Organic materials and oxygen are completely miscible in supercritical water, creating a homogenous medium in which the oxidation process occurs uniformly throughout the solution, and is not mass-transfer limited; 2) A high degree of destruction of organics, including all the microorganisms, is needed to yield a sterile product; and 3) The SCWO process operates at a lower temperature 670-870 K, as compared to 1170-1370 K for incineration. This tends to minimize the production of secondary hazardous compounds, such as dioxins (Esposito 1988). SCWO has some disadvantages: 1) Materials problems, such as corrosion, are encountered when water containing solutes reach temperature/pressure conditions close to the critical values. For example, Bramlette et al. (1990), have noted that the water effluent from SCWO contains chromium. Trivalent chromium (Cr^{3+}) is considered essential for humans and animals at levels of 50-200 μg/d (Jones 1990). Finley et al. (1992) reviewed USEPA's information and showed there was no need for an inhalation reference concentration (RC) for Cr^{3+} due to its virtual nontoxicity and noncarcinogen feature (Langard 1990). Cr^{6+}, however, is a classified carcinogen (Sigmon 1989; Langard 1990; de Flora et al. 1990) and an RC value of approximately 1.2 $\mu g/m^3$ is recommended for Cr^{6+} associated with mist or dust (Finley et al. 1992). Chromium in metallic form produces no toxic or harmful effects to man or laboratory animals (National Research Council 1974; Baruthio 1992). 2) Inorganic salts, either present in the feed or produced during oxidation as a result of side reactions, are normally soluble in water, but tend to precipitate out of solution under supercritical conditions and plug the reactor or accessory equipment (such as valves). 3) Some experts do not consider SCWO to be a mature technology since it has been operated successfully only on a bench-scale (Shaw et al. 1991).

A new electrochemical process combined with UV radiation for oxidizing liquid and solid (slurries) wastes is also being explored by NASA (Lee et al. 1987; Kaba et al. 1989). This process runs at ambient temperature and pressure, requires DC and AC power but no other expendables, and relies on electrochemical and UV-generated powerful oxidants, such as ozone and hydroxyl radicals, to destroy organic compounds. This waste treatment process has not reached the level of development of the thermal processes discussed here.

In this paper, commercially available process simulation software, ASPEN Plus (Aspen Technologies Inc, Cambridge, MA) was used to develop a functional schematic of a waste treatment system based on the process of incineration and for use in space. Processing solids was emphasized, including slurries, even though some liquid streams, such as perspiration, humidity condensate, shower water, urine, and urine flush water are included, since solids form an integral part of heat recovery and the thermal balance and control. Heat recovery for phase-change water purification was emphasized in developing the incineration system functional schematic. Recycle of N_2 is not addressed here, although it is recognized that it plays an important and necessary role in the overall closed-loop life support system.

Incineration was chosen for this design study because it is a well-developed technology that has been used extensively for municipal solid waste processing. In terrestrial applications, incineration is generally used to destroy toxic wastes, recover energy, and reduce the volume of trash that is sent to landfill sites. Although heat and fuel derived from burning refuse is often recovered terrestrially, other products of incineration, i.e., carbon dioxide, water, and minerals are seldom isolated, being permitted to flow into nature's ecosystem. However, in space applications, the high transport-to-orbit cost dictates that most of the heat and mass be recovered and recycled, especially when plants are grown in space for food. It should also be noted that the incinerators currently in use for municipal solid waste treatment are usually designed to handle over 200 tons of waste per day—a much greater capacity than is needed for space, at least for the future. This difference in capacity must be considered when designing a space-based incinerator and trying to relate its design to units currently used for municipal waste treatment.

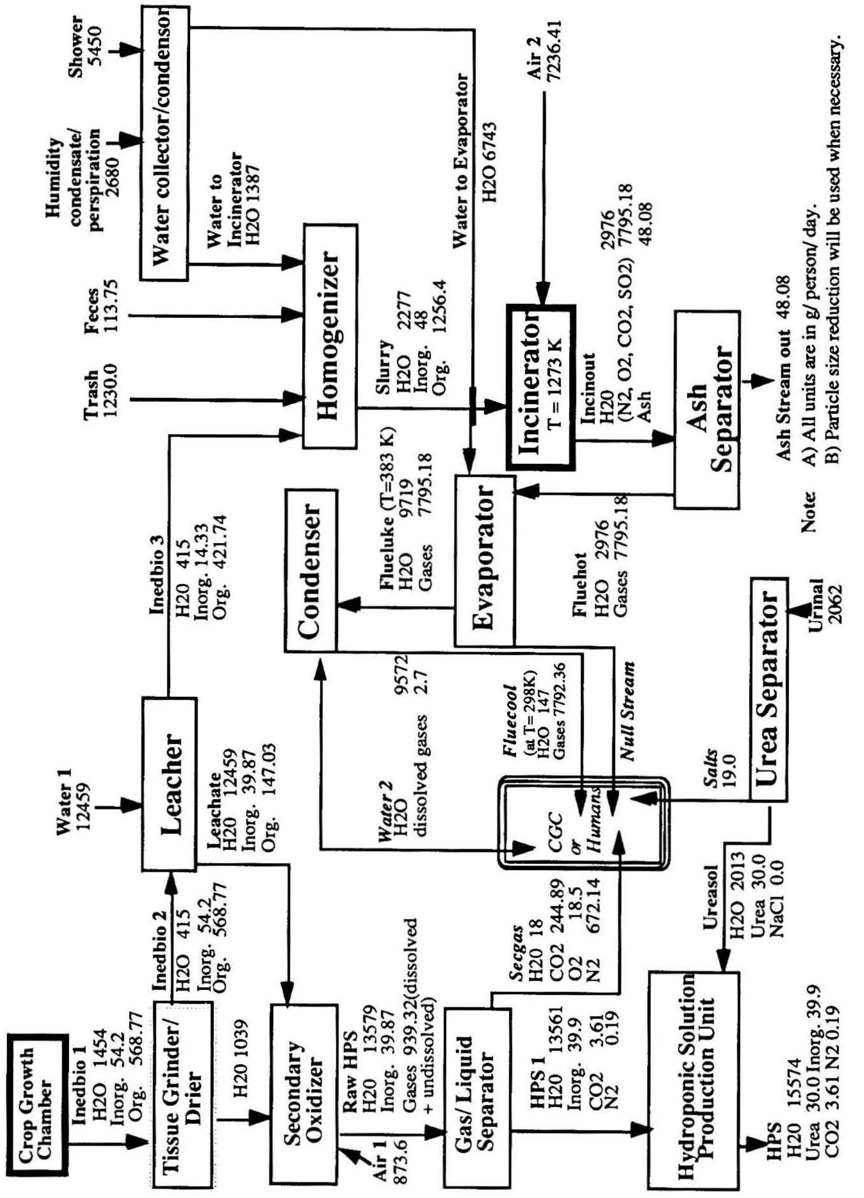
DESCRIPTION OF THE FUNCTIONAL SCHEMATIC FOR INCINERATION

A flow chart showing the material balance and processors of wastes in a CELSS is shown in Fig. 1.

The CGC is the crop-growing unit, and since only certain parts of most crops are normally edible for humans, some inedible biomass will be produced. The inedible biomass from the CGC is shredded and dried in the tissue grinder/drier to remove water. The dried inedible biomass (Inedbio2) is mixed with water and leached to remove the soluble organic and inorganic solutes, using the method of Garland and Mackowiak (1990).

The inedible component (Inedbio3) is mixed with trash (paper and plastic products) and human waste (feces) before being combusted in the incinerator. Humidity condensate, perspiration, respiration, and shower water are all collected in a single stream. A portion of this water is sent directly to the incinerator in order to control its temperature at around 1300 K while the remainder is sent to the evaporator. The products of incineration (Incinout) are sent to an ash separator such as a cyclone followed by a high efficiency particulate arrestor (HEPA) filter to remove particles > 0.3 μm diameter (Ash Separator). The potential for direct supply of the ash to the CGC as a source of inorganic nutrients will be assessed in future studies.

Water from the water collector/condenser is contacted in the evaporator directly with the hot flue gas (Fluehot) from the ash separator. This enables the recovery of energy in the form of heat for purification of water by distillation. Since the available inedible biomass is insufficient to evaporate all the water that needs to be purified, an additional 3.8 MJ/d·person is needed. We have assumed, for the



Note A) All units are in g/ person/ day.
B) Particle size reduction will be used when necessary.

Fig. 1. Mass balance for incineration of wastes in CELSS.

purpose of this study, that the additional energy will be provided from an external source. However, improved evaporator designs, such as vapor compression evaporators (e.g., units with wiped-film multiple effect evaporators, Tleimat 1991) may reduce or eliminate the need to import additional energy for water purification (Corbitt 1989). In the present simulation, all the water in the humidity condensate, shower water, and the perspiration/respiration streams are considered to be pure water for the sake of simplicity, so that all the water is vaporized in the evaporator. However, in an actual operating process, a major fraction of the water delivered to the evaporator will evaporate and a concentrated brine will remain as residue from the evaporator (indicated as Null Stream in Fig. 1).

The moist flue gas leaving the evaporator is sent to a condenser, where it is cooled, and the condensed water collected (Water 2). This stream can be recycled to humans after further treatment if necessary, or used in a CGC. The leachate exiting the leacher can be sent directly to the CGC as a supply of inorganic nutrients or to a secondary oxidation reactor (such as an electrochemical oxidation unit or a bioreactor) for combustion of the organics if the organic carbon level is too high and toxic to plants. The total amount of heat from the secondary oxidizer and the flue gas condenser that needs to be rejected to space is 27.9 MJ/d·person. The theoretical minimum area of 0.72 m^2/person is needed to reject this heat to outer space as calculated using the Stephan-Boltzmann equation.

$$A = Q/(s.e.T^4)$$

where

A = area of radiating surface (cm^2),

Q = heat to be rejected (cal/s),

s = Stephan-Boltzmann constant (5.67×10^{-12} $cal/cm^2\cdot s\cdot K^4$),

e = emissivity (assumed to be 1), and

T = temperature of radiating surface (K).

However, the actual surface area to reject the heat is likely to be larger than this. Two major factors likely to influence the size are the emissivity of the radiating surface and the design of the radiator. The present design of the radiator for Space Station Freedom is a moderate-temperature radiator at the nominal heat-load of 49 kW, with an entry temperature of 287.5 K and exit temperature of 237.5 K (Andish and Ewert 1992). Based on this design, the Stephan-Boltzmann equation calculates a 28% larger surface area (0.93 m^2/person) to reject 27.9 MJ/d·person of heat. The product from the secondary oxidation unit (RawHPS) is separated into liquid (HPS1) and gaseous (Secgas) streams in a gas-liquid separator. Urine and the urine flush water from a urinal are treated in a hypothetical unit (Urea Separator) which separates the salt (sodium chloride) from urea and water. Sodium separation from urine is required to keep its concentration in the hydroponic solution below the toxic level for plants. A modified electrodialysis process might eventually be used to accomplish this separation. The sodium chloride can be recycled to humans. The urea solution (Ureasol) is mixed with HPS1, and after further pH and conductivity adjustments and/or inorganic nutrient supplementation, this adjusted solution is sent to the CGC. Thus, a portion of the inorganic matter contained in the biomass, along with all the urea and any other macro- and micro-nutrients found in urine, such as potassium, are recycled to the CGC. The gaseous product from the secondary oxidizer (Secgas) along with the cooled dry flue gas (Fluecool) is sent to the CGC.

DESCRIPTION OF THE PROCESS SIMULATION USING ASPEN PLUS

A simple material and energy balance model of the waste processing flow-sheet described above using the ASPEN Plus process simulator was developed. ASPEN Plus and Pro/II (Simulation Sciences, Fullerton, CA) are some of the commercial process simulators available. These are functionally very similar, and can be used interchangeably for most process simulations. Our choice of ASPEN Plus was based on our familiarity with this software and our ready access to it.

The material balance model is presented in Fig. 1. The values of the feed streams used in the simulation, along with the calculated values, are also shown in the units of g/d·person. In process simulation, specification of a large number of different values is necessary in order to completely define the system. The required inputs can be classified as:

1) specification of input streams,
2) specification of property values of nonconventional components, and
3) specification of the design and operating parameters for the process units.

Many different sources were used to obtain the required inputs. When the needed information was not readily available, we made reasonable assumptions to approximate the values of the inputs. The following sections discuss the methods and assumptions used to arrive at the various input values.

Specification of input streams

A number of solid and liquid waste streams is treated in the simulated process. These are inedible biomass from the CGC, human feces and urine, along with urine flush water, trash, respiration and perspiration water, humidity condensate, and shower water. In addition to these streams, water for leaching the inorganic material from the inedible biomass and air for combustion of the organic material sent to the incinerator are also provided and specified. The following describes how the values of these streams were chosen.

The amount of the inedible biomass produced per gram of edible biomass is specific to the plant. Thus, this number depends mainly on the type of foods consumed. For the purpose of this study, the recommended daily consumption of different food to provide the "modest diet" was used (Hoff et al. 1982; Table 1). The corresponding amounts of inedible biomass calculated from known values of harvest indices are also listed. The total amount of inedible biomass specified in the simulation is the sum of the individual biomass values from the modest diet. Following Glover's (1991) report, the assumption is made that the moisture content of the unprocessed, original inedible biomass is 700 g/kg. Thus, the inedible biomass fed to the system will contain 1454 g water/d·person.

The inedible biomass contains inorganic and organic components. A fraction of this inorganic and organic matter is readily soluble upon leaching with water. Of the remaining inorganic materials in the residue, a further fraction becomes leachable from the ash after processing by incineration.

Table 2 was developed using the published data of Salisbury and Ross (1985), Garland and Mackowiak (1990), and Dreschel et al. (1991). The inorganic elemental value of 87 g/kg of wheat straw was considered to be representative of the inorganic fraction of total inedible biomass. The C, H, O, N, and S distribution of the organic fraction of the inedible biomass was calculated from the data of Salisbury and Ross (1985). Estimation of the elemental distribution in the soluble and insoluble fractions from a leaching process was calculated using data of Garland and Mackowiak (1990). The gross chemical compositions for the two fractions were computed from the above information (Table 2). Pending similar measurements on other crops, we have assumed the same elemental distribution for wheat straw as being representative of the inedible biomass for other crops in the modest diet.

Table 1. Amount of wet inedible biomass derived from the components of a "modest diet" (Hoff et al. 1982).

Crop	Edible biomass g/d.person	Inedible biomass g/d.person	Harvest Index	Reference
Soybean	180	334	35%	Bubenheim 1991
Dry Bean	190	190	50%	Scully and Wallace 1990
Peanut	72	216	25%	Wade 1989
Wheat	405	439	48%	Bubenheim 1990
Rice	390	476	45%	Wade 1989
Potato	600	141	81%	Bubenheim 1991
Carrot	4.8	0.3	95%	Glover 1991
Chard	5.6	0.3	85%	Glover 1991
Cabbage	145	36	80%	Glover 1991
Tomato	200	244	45%	Wade 1989
Total	2192.4	2076.6		

Table 2. Distribution of inorganic and organic material in the dried inedible biomass into soluble and insoluble components.

Component	Raw Wheat residue	Insoluble fraction	Soluble fraction
Total Mass, g	1000	700	300
Inorganic matter, g	87	23	64
Carbon, g	421	312	109
Hydrogen, g	56	41.5	14.5
Nitrogen, g	14	10.5	3.5
Sulfur, g	1	1	0.0
Oxygen, g	421	312	109

Gross Chemical Formulae:

Insoluble Wheat Residue: $C\,H_{1.59}\,N_{0.029}\,S_{0.0013}\,O_{0.75}$

Solubilized Residue: $C\,H_{1.63}\,N_{0.027}\,O_{0.75}$

Table 3. Selected values for solid and liquid waste generation in space (Wydeven and Golub 1990; 1991).

a) Production of trash per person-day = 1230 g/day
water = 385 g/day
ash = 30 g/day
cellulose = 815 g/day

b) Production of feces per person-day = 113.75 g/day
water = 90.25 g/day
ash = 3.75 g/day
cellulose = 3.75 g/day
lipids = 3.75 g/day
protein = 12.25 g/day

Note: The non-combustible portion of feces is assumed to be ash.

c) Production of urine per person-day = 1568 g/day
water = 1519 g/day
combustible solids = 30 g/day
noncombustible solids = 19 g/day

Note: Urea and sodium chloride are assumed to be representative of the combustible and non-combustible dissolved solids in urine, respectively.

d) Production of:
humidity condensate = 520 g/day
perspiration/respiration water = 2160 g/day
urinal flush water = 494 g/day
shower water = 5450 g/day

Trash constitutes the second major solid waste. The amount and composition of trash is taken from Wydeven and Golub (1990, 1991). We have denoted the inorganic portion of the trash by ash and the organic (assumed to be completely combustible) portion by cellulose (Table 3).

For this simulation, the average of the feces values reported by Wydeven and Golub (1990, 1991) was used (Table 3). The fecal composition was calculated by assuming all fecal matter is made up of ash, cellulose, lipids, and protein. This assumption is consistent with the analyses given by Wydeven and Golub (1990, 1991). The following elemental compositions are assumed for the organics in feces (Cason 1956):

cellulose: $(C_6H_{10}O_5)$ n
lipids: $C_{51}H_{92}O_6$
protein: (C_3H_5NO) n

The production rates and composition of the liquid streams, urine, urine flush water, perspiration and respiration water, humidity condensate, and shower water are all based on Wydeven and Golub (1990). As mentioned in Table 3, urea and sodium chloride are assumed to be representative of the dissolved solids in urine. Further, all the liquid waste streams except urine are assumed to be pure water for the purpose of the simulation, since the solids content of these streams is too small to affect the heat and material balances. The composition of these streams will have to be considered in the detailed process and equipment design, because a purge stream containing concentrated solutions of these dissolved solids will have to be removed from the evaporator and sent to the incinerator to prevent accumulation of these solids in the evaporator. This concentrated stream, as mentioned previously, is denoted as Null Stream in the flow sheet to stress the fact that such a stream will exist in an actual system. Also, note that the urine flush water and urine are added and treated in combination. This is to reflect the fact that these two exist as a common waste stream.

Fresh water is needed to dissolve the soluble organic and inorganic portions of the inedible biomass. Since the fractions of the respective amounts dissolved are based on Garland and Makowiak (1990), the same ratio of fresh water to dry inedible biomass, 1 kg water per 50 g of dry inedible biomass, was used.

Finally, the amounts of air necessary to combust the organic components in each stream sent to the incinerator and the secondary oxidation unit were calculated, and the air flow rates were set at about 10% higher than needed. The exact amount of excess air that will be needed to ensure near-complete combustion is a complex function of the incinerator geometry and design, nature of the combustibles, residence time in the specific incinerator, and the incinerator temperature, which in turn is determined in part by the amount of excess air used. The determination of the amount of excess air needed for any operating incinerator has to be computed during actual operation, based on a number of measurements, such as the chemical analysis of the flue gas and incinerator temperature. Once this information is experimentally obtained, the new air flow rates will be incorporated into our model.

Specification of the property values of nonconventional components

In order to obtain correct material balance, a number of nonconventional components were created and used in this simulation. They are inorganic matter, ash, minerals, cellulose, protein, lipids, and soluble and insoluble organic matter. The chemical compositions of these have already been discussed in the previous section. In this section their physical/chemical properties are defined.

Since incineration was chosen as the treatment method in this simulation, the most important property values are those needed to calculate the heats of reaction. It is more convenient to input heats of formation than heats of reaction into ASPEN Plus. Therefore, the various heats of combustion were obtained first, and the heats of formation were calculated to be consistent with the heats of reaction. This approach was followed for all the combustibles. The values of the heats of combustion (lower or net heating values) for the nonconventional components are given in Table 4. The heats of combustion of various agricultural residues are given by Domalsky et al. (1986). Here, a representative value of 17004 J/g was chosen.

The composition of the feces in terms of ash, cellulose, protein, and lipids has already been specified in the previous section. Since the values of the heats of combustion of these constitutive components are known reasonably well (Lange 1956), the heat of combustion of the dry feces can be calculated, as shown in Table 4.

It was assumed that little or no chemical transformation of inorganic matter takes place. Hence, the chemical composition of ash, minerals, and inorganic matter is not important. Likewise, the heat of formation of these components is similarly unimportant.

The specific heats for the conventional components are already in the ASPEN Plus database. Those of the nonconventional components are based on literature values for the corresponding components, given by Avallone and Baumeister (1986), Lange (1956), Weast (1970), and Green (1984).

Table 4. Heats of combustion of nonconventional components.

a. Heats of combustion (assumed to be lower heating values) of the constituents of inedible biomass and feces at 298 K, based on Lange (1956), are:

cellulose	= 17556 J/g
lipids	= 38874 J/g
protein	= 24244 J/g

The calculated heat of combustion of feces (on dry basis, assumed to be lower heating values) at 298 K is 21644 J/g.

b. The representative value of the heat of combustion (lower heating value at 298 K) of the inedible biomass is taken to be 17004 J/g (Domalsky et al. 1986).

c. Feces has a higher lipid content than inedible plant biomass, hence the higher heat of combustion of feces.

Specification of the design and operating parameters for the process units

The most important units in the simulation of the resource recovery process described here are the incinerator and the secondary oxidizer, both of which oxidize organics to carbon dioxide and water. Equilibrium constants for oxidation reactions are usually high (>10^{20}). Therefore, complete conversion in both these reactors was assumed and specified. Note that it is not necessary to specify the type of secondary oxidizer (i.e., whether it is electrochemical, biochemical, UV-ozone, UV-peroxide, or any other low temperature reactor) for this assumption to be valid.

The conversion of carbon and hydrogen in the organic matter is straightforward. Any oxygen chemically combined with the reactant organic molecule along with externally supplied oxygen is used to form carbon dioxide and water. It was assumed that the chemically bound nitrogen in proteins is converted into molecular nitrogen. Other chemical pathways, such as the ones leading to ammonia or nitrogen oxides, are possible, but these products were ignored due to the lack of experimental information.

Following the discussion in Avallone and Baumeister (1986), 1273 K was chosen as the operating temperature of the incinerator. The amount of water sent to the incinerator from the water collector/condenser is automatically adjusted by the simulator to maintain this temperature. We have assumed that this temperature is sufficient to obtain complete conversion of the organics to carbon dioxide and water. This temperature can be easily changed to reflect operating experience from small scale incinerators specially designed and built for this project, when available. The incinerator is assumed to operate adiabatically with no material losses and complete oxidation of the combustibles.

The hot flue gas from the incinerator flows to the ash separation unit, where the solid ash particles are separated from the gas. For the sake of simplicity complete separation of ash and the flue gas in this unit was assumed. Other equipment may be needed in addition to the ones mentioned, but since this has little impact on the heat and mass balance of the process, it was not considered further.

Gas phase heat transfer is usually slow. Therefore, to avoid large heat exchangers in the process it was chosen to inject the waste water directly into the hot flue gas. This operation cools the flue gas and evaporates the water at the same time. The warm flue gas is further cooled in a condenser to condense out the water, and to lower the flue gas temperature to room temperature. The condensed water may be recycled to the CGC, used for leaching the inedible biomass, or used by humans after appropriate processing, if necessary.

The unit Urea Separator is intended to separate salt from urea. The separated urea will be utilized in the CGC. A complete separation of dry sodium chloride from the aqueous urea solution can be seen. As discussed later, the function performed by this unit is essential to the success of the process scheme given here, and will have to be developed. For the purpose of mass and energy balance, the simple and idealized unit is sufficient.

KEY TECHNICAL UNCERTAINTIES IN THE USE OF INCINERATION FOR A CELSS

For any long duration human space mission, the health and nutrition of the crew must be considered paramount. A number of different diets has been proposed for astronauts to meet their nutritional requirements (Hoff et al. 1982). A modest vegetarian diet (Table 1) was used for developing our incineration-based functional schematic. For any given diet, one can calculate the amount of food to be consumed by the humans on board. Literature on the ratio of the edible to inedible biomass often includes a very broad range for all the crops included in the diet. Various reasons account for this broad range, such as, differences in food processing technology, variations in growth conditions/cultural practices of the crop, and sociocultural practices of humans. For example, the fraction of edible mass in lettuce is reported as 0.90 by Dreschel (1991), 0.80 by Glover (1991), and 0.85 by Wade (1989), and these discrepancies appear to be related to the growing conditions. In hydroponically grown lettuce, *Lactuca sativa* cv Waldmann's Green, in greenhouse conditions, we observed that 85% of the total plant fresh weight is leafy material and constitutes the edible biomass. The recently built crop growth research chamber (CGRC) prototype used for plant growth performance at NASA-Ames Research Center has well defined environmental parameters and controls (Wagenbach and Bubenheim 1991). This growth chamber will enable better control of shoot/root partitioning of carbohydrates, nutrient uptake by plants and will provide an accurate measure of edible/inedible biomass ratios of the candidate CELSS crops.

The chemical compositions and heating values of the corresponding inedible biomass for the variety of crops, such as those required for a modest diet, needs to be measured accurately in order to perform the correct mass and energy balance. Experimentation to study the amount of water in the edible and inedible biomass, when grown under CGRC conditions, will be conducted as a further study. These values are not critical to terrestrial operations since the atmosphere provides a large sink for the evaporated water, and the large fresh water supply provides a large source of water. However, the closed system under consideration for use in space lacks the large water source and sink buffers, and the amount previously considered lost must now be accounted for accurately in order to operate the closed system. The water remaining in the inedible biomass after squeezing ("bound water") must also be measured for similar reasons.

The chemical characteristics of the ash left over after combustion of the biomass and other solids are very important from the point of view of incinerator operation and mineral recycle. There is a considerable amount of literature on the chemical characteristics of the edible components of plant food. However, the authors found no available literature on the chemical characteristics of inedible components of plant foods. The softening point of the ash may determine how one designs and operates the incinerator (either well below the softening point or well above it, as in the case of slagging incinerators). The chemical characteristics of the ash will influence the chemical or biological processing scheme for recycling the minerals from the ash to the CGC. Further, the particle size distribution of the ash will influence the gas throughputs and the selection and sizing of the downstream ash separation equipment.

The stoichiometry of the combustion reactions for hydrocarbons and carbohydrates is relatively simple, since carbon dioxide and water are the only products of combustion. However, combustion of proteins found in human feces and unused food is not that simple. Even though it was assumed in the simulation that all the nitrogen in the protein exits the incinerator as molecular nitrogen, other reactions giving rise to nitrogen oxides are quite possible. Certain accepted assumptions (Hoff et al. 1982), such as general protein chemical formula ($C = 0.53$; $H = 0.07$; $N = 0.16$; $O = 0.23$; and $S = 0.01$), are utilized and can be used in computing the nitrogen mass balance.

This simulation has used the average values for the amounts and composition of human waste, as reported by Wydeven and Golub (1990). These values may or may not be consistent with the modest diet suggested by Hoff et al. (1982). Mass and chemical composition of human wastes as specifically related to the human diet provided would be useful in the design of any waste processor.

SOME REMAINING ISSUES

In this simulation, the recycle of the major chemical elements, namely, carbon, hydrogen, and oxygen was accounted for. Another plant macronutrient, nitrogen, is only partially accounted for through the recycle of urea. Nitrogen recovery and recycle in a form suitable for use by plants as a nutrient or fertilizer is a complex problem and needs further work. Recovery and recycle of other plant macro- and micronutrients, such as phosphorous, potassium, calcium, iron, etc. have also not been considered in this simulation study.

Intimately linked with the problem of nitrogen recycle is the problem of urine treatment. Urine comprises a number of chemicals (Wydeven and Golub 1990), including urea (and related compounds, such as uric acid), salts (such as sodium and potassium chloride), and dissolved organics (such as phenols and citric acid). Urea and other organic compounds that can be readily utilized by plants can be recycled directly to the CGC. However, the other dissolved organics may need to be removed from the aqueous solution containing urea to maintain a high level of oxygen tension in the hydroponic solution for efficient crop production. For example, a 50% drop in the oxygen tension of the hydroponic solution reduced growth of barley *Hordeum vulgare* cv Hispont by 57% over a 7-day period (Wignarajah et al. 1976). The dissolved inorganic materials can also be sent to the CGC with the exception of sodium, which must be largely removed and could be recycled to humans. Thus, we may need a process (or a set of processes) to remove the nonnitrogen containing organics and sodium salts from the urine and urine flush water due to their toxicity to plants.

A small fraction (<0.01%) of the nutrients, mainly micronutrients such as copper and zinc, necessary for plants and humans will end up in the ash product from the incinerator. Recommended Dietary Allowance (RDA) requirements of 4-5 mg copper (Cu) and 30-40 mg zinc (Zn) per adult human (Scott 1986) and 0.02 Cu and 0.05-0.25 Zn (in $\mathrm{mg \cdot L^{-1}}$) for plant nutrient solutions (Salisbury and Ross 1985) will be required. These may be recycled as in a closed system or supplied from storage as in open systems due to the small mass.

CONCLUSIONS

A simple conceptual scheme based on incineration for processing solid wastes and slurries in a CELSS for use in space was developed. This model takes into account recycling the major elemental constituents of waste, carbon, hydrogen, and oxygen, for which a mass balance was developed. It does not evaluate the other macro- and micronutrients, e.g., nitrogen, potassium, and phosphorus. Whenever possible, inorganic nutrients are leached from inedible biomass before reaching the incinerator to prevent them from being converted to ash. Heat from the incinerator was used for phase change purification of water from other streams found in a CELSS. This authors' investigation of the solid waste treatment in a CELSS showed important gaps in the quantitative understanding of the problem. Research, both experimental and theoretical, is currently in progress to substantiate the authors' assumptions and provide experimental data on hitherto unknown parameters of crop production in controlled systems. The future findings will be used for the development of a more robust process design for waste treatment and recycle in space.

APPENDIX TO ACRONYMS USED IN TEXT AND FIG. 1.

Inedbio 1 = Wet inedible biomass

Inedbio 2 = Oven-dried inedible biomass

Inedbio 3 = Inedible biomass after leaching in water

Incinout = Gases and solids leaving incinerator

Fluehot = Hot gases and water vapor leaving incinerator after ash separation

Water 1 = Water used to leach inedible biomass

Water 2 = Water from condensor

Raw HPS = Solution for potential hydroponic solution before any processing and including dissolved gases

HPS 1 = Hydroponic solution after gas separation

HPS = Final processed hydroponic solution

Secgas = Gaseous mixture generated by secondary oxidization

Ureasol = Urine solution after removal of sodium chloride

Flueluke = Water vapor and gases released after evaporator and incineration

Fluecool = Water vapor and gases emerging from the condensor after complete cooling

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EFFECTS OF ROOT AND FOLIAR TREATMENTS WITH LEAD, CADMIUM, AND COPPER ON THE UPTAKE DISTRIBUTION AND GROWTH OF RADISH PLANTS

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The effects of treatment of radish plants with cadmium, lead, and copper were studied. Both root treatment and foliar treatment were used. All three elements were found to inhibit the growth of radish plants. Cadmium and lead were greater growth inhibitors than copper on the plant. Effects of cadmium and copper were greater on the growth of shoots, while the effect of lead was greater on the growth of roots. Foliar treatment was more harmful to plant growth than root treatment. The uptake of metal ions and the distribution of this uptake in the roots and shoots of treated plants were determined. Cadmium and copper uptake by plant was concentrated mostly in the shoots, while the uptake of lead was concentrated more in the roots of treated radish plants. The amount of metal uptake increased with the increase in metal ion used in treatment of plants. The amount of uptake was higher in foliar-treated plants than in root-treated plants. Concentration of cadmium and lead exceeded the maximum allowed limit in foods in most cases; concentration of copper exceeded the maximum allowed limit in food only in one sample. The percentage of metal ions taken up by plants from the total amount of metal ions added during treatment was very small. This percentage was comparatively higher in the case of foliar treatment than in the case of root treatment. It was also higher from solutions having low concentrations of metal ions than from solutions having high concentrations of metal ions.

INTRODUCTION

Uptake of toxic heavy metals by plants from soil and from the atmosphere has been considered a serious problem with serious implications to human health. Even before the plant itself exhibits any phytotoxic symptoms, plant tissue accumulation of heavy metals might reach levels considered hazardous to the consumer (CAST 1976; 1980). Presence of toxic heavy metals has been proven also to inhibit the growth of plants.

The elements lead and cadmium are known to be very toxic to humans, animals, and plants (Jones et al. 1972; Friberg et al. 1974). Their toxicities are especially dangerous because of the cumulative nature of these elements. Copper is an essential and beneficial element in human metabolism and small amounts of copper are not generally regarded as toxic (Zajic 1971); nevertheless, copper has been found to be very harmful to the growth of some types of plant. For example, root treatment with a 1 μg/mL copper solution resulted in a complete inhibition of the growth of cabbage heads (Hara et al. 1979).

Metals in plant tissues may have two principle origins: absorption from soil and deposition from the atmosphere. Soils naturally contain lead, ~15 mg/kg and cadmium, ~ 4.5 mg/kg (Brooks 1978). Soils become enriched with metal ions through agricultural practices, and this increases the amount of metals absorbed through roots. For example, sewage sludge application to soils has been reported as a serious source of contamination with lead, cadmium, and copper affecting the growth and the uptake of plants from soil (Chang et al. 1982; Beckett et al. 1983; Jackson et al. 1991).

The main sources of lead in the atmosphere are the combustion of lead-additive gasoline, coal combustion, sludge incineration, burning or attrition of lead painted surfaces, and industrial processes (Smith 1984). Atmospheric cadmium sources are primarily smelting and electroplating of metals, motor oil, and motor vehicle tires (Lagerwerff and Specht 1970). Copper is found in sulfide deposits. It is usually present in small quantities in zinc concentrates and in smelters and can be carried long distances by air and water (Brooks 1978).

Uptake of metals by plants is affected by several factors including the type of metal, concentration of metal, the type of plant, plant species, plant age, type of soil, pH of soil, organic matter content of soil, redox potential of soil, cation exchange capacity of soil, surface area and texture of soil particles, the presence and concentration of foreign ions, growth rate, and growth conditions.

The uptake of cadmium on radish plants was reported to be concentrated in the shoots of radish plants (Lagerwerff 1971; John 1972; Khan et al. 1983), but concentration in both plant parts was significantly increased by the cadmium application to soil (John 1972). On the other hand, lead was found to be concentrated more in the roots of radish plants than in the shoots (Khan et al. 1983). Studying thirty types of soils, John et al. (1972) found that cadmium was concentrated in the shoots of radish plants and in the roots of lettuce plants. The uptake of cadmium was found by these authors to be affected by soil properties such as soil pH, organic matter content, and the presence of foreign ions such as iron and manganese. The uptake of lead, cadmium, and copper by oat plants (Bjerre and Schierup 1985a) had been greatly effected by the organic matter content of the soil. For all metals studied (including lead and copper) except cadmium, the total uptake was lowest from the organic soil; cadmium uptake was lowest from sandy soil (Bjerre and Schierup 1985a). Copper and lead were suggested to bind to organics and oxides in soil, but cadmium was bound to inorganics and organics (Bjerre and Schierup 1985b).

Using five types of soil, Hardiman et al. (1984a; 1984b) reported that most of lead, cadmium, and copper was retained in the roots of bush bean plants, and the presence of these in soil caused a reduction in the yield of the plants. Correlations between metal uptake and the concentration of metal in soil were suggested (Hardiman et al. 1984a; 1984b). Such correlation has been also suggested for the uptake of cadmium by vegetables (Algeria et al. 1991). However the lead content of soil was not the main factor influencing the lead content of vegetables.

Cadmium was found to be, on molar basis, twenty times more a growth inhibitor than lead on radish plants (Khan and Frankland 1983). This difference in effect was attributed to the difference in mobilities of cadmium and lead within the soil-plant system. Thus while the movement of lead was restricted by the barrier effect of roots (Khan and Frankland 1983; Jones and Clement 1972), the movement of cadmium was not restricted because of its high mobility. On the other hand, the root-barrier effect in the ryegrass-soil system was suggested to be able to restrict the movement of cadmium and reduce its uptake (Jarvis and Jones 1978). Mobilities of cadmium, lead, and copper were higher from sandy soil into oat plants than from organic soil. Cadmium was more mobile than lead and copper in all types of soil (Bjerre and Schierup 1985b).

The uptake of lead, cadmium, and copper was proved to be dependent on the pH of soil (John et al. 1972; Miller et al.1976), texture and surface area of soil particles (John et al. 1972; Hardiman et al. 1984a), age of plant and growth rate (Jarvis and Jones 1978), and the varieties of plant species (John and Van Laerhoven 1976; John 1977).

Atmospheric pollution with metals, particularly lead, has been reported to have great effect on plants. Forty percent of the lead in tops of radish plants grown near a highway was reported to come from the atmospheric pollution (Lagerwerff 1971). Elevated lead content was found in leafy vegetables grown near heavy traffic (Preer et al. 1980). Cadmium levels were not distinctly higher in vegetables grown in polluted gardens in cities than in vegetables grown in unpolluted gardens in rural areas (Preer et al. 1980; Hibben et al. 1984). Radish tops and lettuce leaves accumulated lead from the atmosphere more than other vegetables including spinach, swiss chard, cabbage, beet, onion, and carrots (Hibben et al. 1984). Both lead and cadmium concentrations in soil and only the lead concentration in vegetation fell off rapidly with increasing distance from high traffic roads (Flores and Castellon 1982). Foliar treatment of broad beans, carrots, and marrow plants was more effective on plant growth than root treatment of plants with lead or cadmium (Salim et al. 1992a; 1992b; 1992c).

In the present paper, we studied the uptake of three growth-inhibitor metals by plants using radish plants under conditions very close to the conditions used by local farmers. The objective was to show to the public and to the decision-makers the risk of irrigating this commonly planted vegetable in our area with polluted sewage water. Radish plants were chosen because of several reasons: (1) they are commonly eaten by local inhabitants in Nablus especially during the month of fasting (Ramadan); (2) a large portion of the radishes sold in the market comes from farms irrigated with polluted sewage water by local farmers around the city of Nablus; (3) it is a plant with distinct roots and shoots and thus it is suitable for studying the distribution of metals in plant tissues; and (4) most of the reported studies in the literature were confined to studying the effect of either root-treatment or foliar-treatment of radishes with one or two metal ions at a time. We aimed to evaluate the elements cadmium, lead, and copper using two types of treatment (root and foliar treatments).

EXPERIMENTAL

Soil

The soil used in this study was provided by a local nursery and consisted of brown soil:sand, 2:1. Details of the physical and chemical characteristics of the soil used were similar to those given in a previous study (Salim et al. 1992a).

Plant

This study was carried out on radish plants (*Raphnus sativus L.*) which are commonly planted by farmers around Nablus. Seeds of radish were planted in plastic pots containing 3.5 kg of well-mixed soil (3 seeds in each pot). After the appearance of the first true leaves, only the best-looking plant was left in each pot and allowed to grow under greenhouse conditions. The plants were irrigated twice a week with 200 mL tap water free from lead, cadmium, or copper. (The concentrations of these elements were below the detection limits of FAAS, i.e. < 0.03 mg/L Cu, < 0.01 mg/L Cd, < 0.05 mg/L Pb). This tap water was replaced by a nutrient solution (lg/L) once every two weeks. The nutrient used was composed of 20% NH_4NO_3, 20% P_2O_5, 20% K_2O, 0.015% Zn, 0.011% Cu, 0.007% Mo, 0.1% Fe, and 0.05% Mn.

Treatment with metal ions

After two weeks of transplanting the seedlings, the plants were treated with various concentrations of cadmium, lead, or copper. Three plants were treated with each concentration, either for root treatment or foliar treatment. Root treated plants were irrigated with 200 mL of the required ion concentration every week for the remaining period of growth which lasted 12 weeks. Foliar-treated plants were sprayed with 50 mL of the required metal ion concentration every week for 12 weeks. A plastic sheet was used to prevent the sprayed mist from reaching the soil in the case of foliar treatment.

Chemical analysis of plants

The roots and shoots of the completely grown radish plants were taken in plastic bags. They were then cleaned thoroughly with distilled water and dried in an oven at 90°C. The average weight of dry untreated plants was 13.75g (average fresh weight = 30.10 g). Average weight of dry treated plants ranged from 13.42-0.50 g (average fresh weight = 23.31-0.15 g). The relative standard deviation of weight allowed was 15%. Weights with higher standard deviations were excluded. This exclusion occurred with ≈ 10% of samples. The dry plants were ground and ashed in a furnace at 550°C for six hours and kept in labelled plastic bags ready for chemical analysis.

A certain weight of the ash of each sample was treated with 2 mL of concentrated HNO_3 and digested under pressure for 10 h at 170°C. After that, the volume was made up to 15 mL with distilled water and all samples were analysed for cadmium, lead, or copper. The analytical method used was the graphite furnace atomic absorption spectrometry using a Perkin-Elmer Spectrometer Model 5100 equipped with a HGA-7700 Professional Computer. The heating programs were as follows:

	Cadmium		Lead		Copper	
Step 1	120°C	30s	130°C	15s	120°C	20s
Step 2	700°C	30s	300°C	20s	900°C	20s
Step 3	1800°C	4s	2100°C	4s	2300°C	6s
Step 4	2500°C	2s	2400°C	1s	2600°C	3s

The AAS computer was programmed to do analyses and calibrations in this sequence: blank, sample, standard S1, standard S2, and standard S3. The standards used were provided ready by the Ecology Department, University of Bielefeld, with concentrations of 2, 3 and 6 µg/L for cadmium and 60, 80, and 100 µg/L for lead and copper. The calibration process was automatically repeated every ten readings, and all readings were corrected for the blank. Three batches of each sample were analysed, and the averages of two or three readings of these (with relative standard deviation <10%) were reported in the results of this work. A matrix modifier of palladium nitrate was applied for the analysis of samples for cadmium.

RESULTS AND DISCUSSION

Effects on plant growth

The effects of treatment of radish plants with metal ions by both root treatment and foliar treatment on the dry weight of plant (whole plant, roots, and shoots) are given in Tables 1-3 for the treatment with cadmium, lead, and copper, respectively.

Results of Table 1 showed a substantial weight reduction in all plants treated with cadmium. This reduction in weight increased generally with the increase of the cadmium concentration in solutions used for treatment. The effect of foliar treatment with cadmium (considering the total amounts of cadmium added through the whole period of growth) was distinctly higher on the growth of roots and shoots of the treated plants than the effect of root treatment. Growth inhibition was generally somewhat more on shoots than on roots in both types of treatment. The results of Table 2 showed a substantial reduction of dry weight by either root treatment or foliar treatment of plants with lead. This reduction in weight increased with the increase of lead concentration in solutions used in both types of treatment. The effect of foliar treatment on growth was higher than the effect of root treatment. Root growth was affected more than shoot growth.

Table 1. Dry weights of plants treated with cadmium.

Cd - concent. mg/L	Roots		Shoots	
	dry weight g/plant	% reduction in weight	dry weight g/plant	% reduction in weight
Root-treatment (200mLx12 times)				
0.0	6.898	0.0	6.854	0.0
0.4	6.612	4.1	6.812	0.6
1.1	4.750	31.1	3.892	43.2
1.8	3.504	49.2	2.356	65.6
Foliar-treatment (50 mL x 12 times)				
0.0	6.898	0.0	6.854	0.0
0.4	3.863	44.0	4.448	35.1
1.1	2.023	70.6	3.008	56.1
3.6	3.540	48.6	1.312	65.0
10.9	2.376	65.5	0.932	86.4

Cd - concent. mg/L	Whole Plant	
	dry weight g/Plant	% reduction in weight
Root-treatment (200mLx12 times)		
0.0	13.752	0.0
0.4	13.424	2.3
1.1	8.642	37.1
1.8	5.860	57.4
Foliar-treatment (50 mL x 12 times)		
0.0	13.752	0.0
0.4	8.311	39.5
1.1	5.031	63.4
3.6	4.852	64.7
10.9	3.308	75.9

Table 2. Dry weights of plants treated with lead.

Pb - concentration (mg/L)	Roots		Shoots	
	dry weight g/plant	% reduction in weight	dry weight g/plant	% reduction in weight
Root- treatment (200mL x 12 times)				
0.0	6.898	0.0	6.854	0.0
0.6	3.192	53.7	2.550	62.9
3.1	2.293	66.7	2.320	66.1
6.3	1.953	71.6	2.056	70.0
12.5	1.212	82.4	1.098	83.9
Foliar-treatment (50mL x 12 times)				
0.0	6.898	0.0	6.854	0.0
3.1	0.0	100	3.333	51.4
9.0	0.0	100	2.722	60.2
18.8	0.0	100	0.503	92.6

Pb - concentration (mg/L)	Whole Plant	
	dry weight g/Plant	% reduction in weight
Root-treatment (200mL x 12 times)		
0.0	13.752	0.0
0.6	5.742	58.2
3.1	4.613	66.4
6.3	4.009	70.9
12.5	2.310	83.2
Foliar-treatment (50 mL x 12 times)		
0.0	13.752	0.0
3.1	3.333	75.7
9.0	2.722	80.2
18.8	0.503	96.3

The results in Table 3 showed that treatment of radishes with copper retarded their growth, but the effect of concentration of copper in solutions used for treatment was in many cases not obvious. The effect of treatment with copper was more obvious on the shoots rather than on the roots of treated plants and was higher in case of foliar treatment than in case of root treatment.

Comparison between the effects of cadmium, lead, and copper on the growth of radish plants

Consulting the results of Tables 1-3 to compare the effects of similar concentrations of the elements Cd, Pb, and Cu on the growth of radish plants and also consulting the results of Table 4, which shows the concentrations of metal ions causing 50% weight reduction, enabled us to compare the inhibition ability of the three elements on the growth of radish plants. This comparison revealed the following:

(1) The effect of the three elements as growth inhibitors could generally by arranged in the decreasing order: Lead > Cadmium > Copper.

(2) Foliar treatment of plants with metal ions was more effective on plant growth than root treatment using the same amount of metal ions. This might be due to the barrier effect of roots restricting the translocation of metal ions from soil (in case of root treatment) into the plant (Bjerre and Schierup 1985b; John 1977; Jarvis and Jones 1977; Hardiman et al. 1984b) and to the effect of adsorption of metal ions on soil (Bjerre and Schierup 1985b; John 1977; Petrozelli and Guidi 1976; Jarvis 1981; Hendrickson et al. 1981).

Table 3. Dry weights of plants treated with copper.

Cu - concentration (mg/L)	Roots		Shoots		Whole Plant	
	dry weight g/plant	% reduction in weight	dry weight g/plant	% reduction in weight	dry weight g/Plant	% reduction in weight
Root-treatment (200mL x 12 times)						
0.0	6.898	0.0	6.854	0.0	13.752	0.0
0.3	3.908	43.3	2.070	69.7	5.978	56.5
2.5	4.166	39.6	2.912	57.5	7.078	48.5
3.8	4.816	30.1	3.333	51.3	8.149	40.7
7.5	5.074	26.4	4.727	31.0	9.801	28.7
Foliar-treatment (50 mL x 12 times)						
0.0	6.898	0.0	6.854	0.0	13.752	0.0
2.5	3.635	47.3	3.700	46.0	7.335	46.7
3.8	2.702	75.3	2.332	65.9	5.034	70.6
5.0	2.309	66.5	2.100	53.4	4.409	67.0
7.5	2.196	68.1	3.191	59.2	5.387	60.0

Table 4. Concentrations causing 50% weight reduction (mg/L).

Part of plant	Cadmium		Lead		Copper	
	Root Treatment	Foliar Treatment	Root-Treatment	Foliar Treament	Root-Treatment	Foliar Treatment
Roots	1.8	1.0	0.6	very low	---	2.7
Shoots	1.1	0.9	0.6	---	3.5	2.8
Whole plant	1.5	0.8	0.6	0.5	---	2.6

(3) Cadmium effect as growth inhibitor was more obvious on shoots than on roots of treated plants. The growth-inhibition effect of either lead or copper was almost the same on roots and on shoots of the treated plants. This might be due to the higher mobility of cadmium ions in plant compared to the mobilities of lead or copper (Bjerre and Schierup 1985a; Page et al. 1972).

Effect of metal addition on its concentration in plant

The results of Tables 5-7 show the concentration of metal ions in radish plants treated with cadmium, lead, and copper, respectively.

The results of these tables indicated that the metal concentration in plants increased with the increase of the concentration of that metal in solutions used in treatment of plant. Cadmium and copper were more concentrated in the shoots, but lead was more concentrated in the roots of treated plants. The concentration of each element in foliar-treated plants was higher than that in root-treated plants when similar amounts of metal ions had been used for treatment.

The uptakes of cadmium, lead, and copper by plants per unit concentration of metal ion in solutions used for root treatment of plants (µg/g per mg/L) are included in Tables 5, 6, and 7 for Cd, Pb, and Cu, respectively. The results showed a general trend of decrease in this uptake with the increase of concentration of metal ions in solutions used in root treatment (with the exception of the roots of plants irrigated with cadmium which showed an increase in the uptake with the increase of metal ion concentration). The uptake of cadmium and copper per unit concentration of metal ions used for foliar treatment of plants increased with the increase of metal ion concentration in solutions used for treatment. The uptake of lead per unit concentration of lead ions in solutions used for foliar treatment of plants did not show a regular trend. Comparing the results of Tables

Table 5. Concentration of cadmium (µg/g in dry plants) and uptake (µg/g in dry plants per mg/L in solution) in treated radish plants.

Cd-Concentration mg/L	Roots		Shoots		Whole plant	
	µg/g dry plant	µg/g per mg/L	µg/g dry plant	µg/g per mg/L	µg/g dry plant	µg/g per mg/L
Root-treatment (200mL x 12 times)						
0.0	0.021	---	0.019	---	0.020	---
0.4	0.030	0.023	1.212	2.983	0.705	1.713
1.1	0.199	0.162	2.184	1.968	1.093	0.979
1.8	0.567	0.303	3.792	2.096	1.693	0.929
Foliar-treatment (50mL x 12 times)						
0.0	0.021	---	0.019	---	0.020	---
0.4	0.117	0.240	0.275	0.640	0.202	0.455
1.1	0.774	0.685	1.257	1.142	1.063	0.948
3.6	2.407	0.663	7.816	2.166	3.870	1.069
10.9	10.892	0.997	18.822	1.725	13.108	1.201

5-7 with the maximum allowed concentration of cadmium (i.e., 1 µg/g, Brooks 1984), lead (i.e., 2 µg/g, Marr et al. 1983), and copper (i.e., 20 µg/g, Marr et al. 1983) indicated that plants treated with solutions having concentrations > 1 mg/L of cadmium or lead became a health hazard to humans. Only solutions having concentrations of copper > 7.5 mg/L resulted in making the roots of the foliar-treated radishes a human health hazard. These concentrations were extremely higher than the average concentrations of these elements in sewage as reported in nearby countries which were 0.01 mg/L Cd, 0.1 mg/L Pb, and 0.05 mg/L Cu (Hardiman et al. 1984a; El-Nennah and El-Kobbia 1983). However, because most of the metal ions added during treatment of plants were retained in soil (as shown later in this work, Table 11, and in concordance with other authors, Bjerre and Schierup 1985a; John 1977), continuous irrigation of soil with polluted sewage water saturates the soil with harmful elements. This later reflects itself on harming the growth of future plants and increases the concentrations of toxic elements in these plants.

Effect of treatment on the total content of metal in plants

The metal contents in treated radish plants are shown in Tables 8, 9, and 10 for cadmium, lead, and copper, respectively.

The results of these tables indicated a general trend of increase in the metal ion content in the various plant parts with the increase of metal ions in solutions used for treatment of plants by either root or foliar treatment.

The results of Tables 8-10 indicated also that the main part of cadmium and copper content was found in the shoots of the treated plants, while most of the lead content was found in the roots of the treated plants.

Table 6. Concentration of lead (µg/g in dry plants) and uptake (µg/g in dry plants per mg/L in solution) in treated radish plants.

Pb-Concentration mg/L	Roots		Shoots	
	µg/g dry plant	µg/g per mg/L	µg/g dry plant	µg/g per mg/L
Root-treatment (200mL x 12 times)				
0.0	0.188	---	0.355	---
0.6	0.836	1.080	3.307	4.920
3.1	18.811	6.007	10.127	3.152
6.3	22.121	3.481	3.089	0.434
12.5	40.281	3.207	3.031	0.214
Foliar-treatment (50mL x12 times)				
0.0	0.188	---	0.355	---
3.1	NO ROOT	---	7.435	0.284
9.0	NO ROOT	---	7.971	0.846
18.8	NO ROOT	---	40.324	2.126

Pb-Concentration mg/L	Whole plant	
	µg/g dry plant	µg/g per mg/L
Root-treatment		
0.0	0.271	---
0.6	1.934	2.772
3.1	14.443	4.572
6.3	12.361	1.919
12.5	22.566	1.784
Foliar-treatment		
0.0	0.271	---
3.1	7.435	2.311
9.0	7.971	0.856
18.8	40.324	2.130

Table 7. Concentration of copper (µg/g in dry plants) and uptake (µg/g in dry plants per mg/L in solution) in treated radish plants.

Cu-Concentration mg/L	Roots µg/g dry plant	Roots µg/g per mg/L	Shoots µg/g dry plant	Shoots µg/g per mg/L
Root-treatment (200mL x 12 times)				
0.0	0.131	---	0.094	---
0.3	0.879	2.493	1.564	4.900
2.5	1.802	0.668	3.879	1.514
3.8	2.568	0.641	7.666	1.993
7.5	3.479	0.446	7.567	0.996
Foliar-treatment (50 mL x 12 times)				
0.0	0.131	---	0.094	---
2.5	0.547	0.166	1.076	0.393
3.8	0.756	0.164	3.857	0.990
5.0	8.372	1.648	4.611	0.903
7.5	24.695	3.275	9.236	1.219

Cu-Concentration mg/L	Whole plant µg/g dry plant	Whole plant µg/g per mg/L
Root-treatment		
0.0	0.113	---
0.3	1.116	3.343
2.5	2.656	1.017
3.8	4.653	1.195
7.5	5.451	0.712
Foliar-treatment		
0.0	0.113	---
2.5	0.814	0.280
3.8	2.192	0.547
5.0	6.581	1.294
7.5	15.537	2.057

Table 8. Total cadmium content in radish plants treated with cadmium.

Cd-Concent. (mg/L)	Roots µg	Roots % from plant	Shoots µg	Shoots % from plant	Whole plant µg
Root-treatment (200mL x 12 times)					
0.0	0.144	52.9	0.128	47.1	0.272
0.4	0.200	2.4	8.259	97.6	8.459
1.1	0.944	10.0	8.501	90.0	9.444
1.8	1.988	18.2	8.935	81.8	10.923
Foliar-treatment (50 mL x 12 times)					
0.0	0.144	52.9	0.128	47.1	0.272
0.4	0.452	26.9	1.224	72.7	1.676
1.1	1.566	29.1	3.781	70.7	5.347
3.6	8.521	45.3	10.255	54.6	18.776
10.9	25.880	59.5	17.542	40.4	43.360

Table 9. Total lead content in radish plants treated with lead.

Pb-Concent. (mg/L)	Roots		Shoots		Whole plant
	µg	% from plant	µg	% from plant	µg
Root treatment (200mL x 12 times)					
0.0	1.299	34.8	2.432	65.1	3.731
0.6	2.670	24.0	8.434	76.0	11.104
3.1	43.133	64.7	23.494	35.3	66.627
6.3	43.202	87.2	6.352	12.8	49.554
12.5	48.821	93.6	3.328	6.4	52.128
Foliar-treatment (50 mL x 12 times)					
0.0	1.299	34.8	2.432	65.1	3.731
3.1	NO ROOT	---	24.780	100	54.780
9.0	NO ROOT	---	21.698	100	21.698
18.8	NO ROOT	---	20.283	100	20.283

Table 10. Total copper content in radish plants treated with copper.

Cu-Concent. (mg/L)	Roots		Shoots		Whole plant
	µg	% from plant	µg	% from plant	µg
Root-treatment (200mL x 12 times)					
0.0	0.905	58.3	0.646	41.6	1.551
0.3	3.434	51.4	3.237	48.5	6.671
2.5	7.506	39.8	11.296	60.0	18.802
3.8	12.369	32.6	25.551	67.4	37.920
7.5	17.653	32.8	35.770	66.9	53.423
Foliar-treatment (50 mL x 12 times)					
0.0	0.905	58.3	0.646	41.6	1.551
2.5	1.990	33.3	3.982	66.6	5.972
3.8	2.042	18.4	8.995	81.4	11.037
5.0	19.331	66.6	9.683	33.3	29.014
7.5	54.230	64.7	29.472	35.3	83.700

Metal uptake by plant from the total amount of metal ions added during plant treatment

The results of Table 11 show the percentage of metal uptake by treated radish plants from the total amount of cadmium, lead, or copper added during root or foliar treatment of plants. These results indicated that only a very small part of metal ions added during treatment was taken up by the plants. The main part of the metal ions added was presumably retained by soil.

The results of Table 11 also indicated that the fraction of metal uptake by treated plants was higher in case of foliar treatment than in the case of root treatment. This fraction was also higher from solutions having low concentrations of metal ions than from solutions having higher concentrations of metal ions.

Table 11. Metal uptake from the total amount of metal added during treatment.

Metal Conc. mg/L	Percentage			
	Cadmium		Lead	
	Root-treatment	foliar-treatment	Root-treatment	Foliar-treatment
0.4	0.85	0.59	---	---
0.6	---	---	0.51	---
1.1	0.35	0.77	---	---
1.8	0.25	---	---	---
3.1	---	---	0.85	2.74
3.6	---	0.86	---	---
6.3	---	---	0.30	---
9.0	---	---	---	0.33
10.9	---	0.66	---	---
12.5	---	---	0.16	---
18.8	---	---	---	0.15

Metal Conc. mg/L	Copper	
	Root-treatment	Foliar treatment
0.3	0.71	---
2.5	0.29	0.30
3.8	0.40	0.42
5.0	---	0.92
7.5	0.29	1.83

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ARSENIC FORMS IN MINE-POLLUTED SEDIMENTS OF MOIRA LAKE, ONTARIO

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The sediments of Moira Lake, Ontario, have accumulated large quantities of arsenic and toxic metals since the 1830's when mining began in its drainage basin. Despite the fact that the mine activities ceased in 1961, leachates from the abandoned mine wastes still deliver large quantities (about 3.5 $Mg.y^{-1}$) of arsenic to the lake. The As concentrations at the top of the sediments average about 545 $\mu g.g^{-1}$, with maximal concentrations of about 1000 $\mu g.g^{-1}$ occurring at depths of 23-27 cm. Approximately 56% of the As in the sediments is bound to the iron and manganese oxides. Observed changes in the profiles of As bound to the different chemical fractions suggest that some of the oxide-bound As is being converted to the residual phases. In view of the dominant form of As in the sediments, changes in the Eh or pH may trigger the release of large quantities of As to the overlying water.

INTRODUCTION

Moira Lake has been contaminated with arsenic (As) since the 1830's when mining and mineral processing began in its drainage basin. By 1900, gold was mined, milled, and smelted at Deloro; and the As wastes in the ore found a market as pesticides. In 1914, the first cobalt produced commercially in the world was manufactured at Deloro, and As was an important byproduct (Bowles 1982). The plant at Deloro closed down in 1961, due to the slumping demand for cobalt and arsenic, but large amounts of refining slag, calcium arsenite, arsenic trioxide, ferric hydroxide tailings, and other miscellaneous tailings and chemical wastes remained on the site. The effects on the surface waters remained so severe that in 1979 the Ontario Ministry of the Environment began treating the metal-rich leachate that was draining into the river from abandoned mine wastes. The treatment removes about 15 tons (Mg) of As per year (Azcue 1992). In spite of this remedial measure, approximately 3.5 Mg of As, most probably from the waste pits and mine tailings at Deloro, are still reaching Moira Lake each year (Azcue 1992).

High concentrations of As in polluted sediments of lakes have also been reported in many places. The sediments of the Great Slave Lake in Canada, which receive wastes from gold mining, contain over 2 800 µg.g^{-1} As (Mudroch et al. 1989). Union Lake in USA, close to an As manufacturing plant, show As concentrations of up to 2 290 µg.g^{-1} (Faust et al. 1983). Lake sediments from the mining area of Sudbury (Canada) have been found to contain up to 650 µg.g^{-1} (Nriagu 1983; Palmer et al. 1989). Analysis of Lake Lansing sediments (Michigan), affected by herbicides applications, found As concentrations of 265 µg.g^{-1} (Siami et al. 1987).

Sediments used to be considered a final sink for the arsenic pollution being loaded into lakes. However, several studies (Aggett and Kriegman 1988; Belzile and Tessier 1990; Camacho-Ibar et al. 1992) suggest that the As are not necessarily fixed permanently by the sediments, and that many physicochemical reactions can alter the mobility of the deposited As. After the sediment is deposited, changes in the redox conditions can alter the mobility and bioavailability of the As reservoir. Regeneration of As from sediments is of concern in view of the well-known toxicity of As to the aquatic biota.

This report uses a five-step sequential extraction procedure to evaluate the potential retention and mobility of As pollution in Moira Lake sediments. It is possible that, even if the river loadings are stopped, enough As will be released from the large reservoir in the sediments to maintain the As in the water column at high levels for a long time.

MATERIAL AND METHODS

Moira Lake, located in eastern Ontario (44°30'N, 77°27'W), is the first major enlargement in the Moira River (approximately 100 km) which discharges into the Bay of Quinte on the northern shore of Lake Ontario (Fig. 1). Moira Lake is a shallow lake (mean depth 4.4 m) divided by a constriction into two separate basins, west (215 ha or 2.15 km^2) and east (615 ha or 6.15 km^2).

The sediment cores were collected by divers from the eastern (EC) and western (WB) basins using Plexiglas tubes of 9-cm diameter. The tubes were tightly closed with Nylon stoppers to minimize perturbation of the sediment during transport to shore. All cores were sectioned in the following sequence using a hydraulic extruder: every 1 cm from 1 to 10 cm; and every 2 cm from 10 to 30 cm. All the cores were approximately 30 to 40 cm long; with a deposition rate of 0.25 cm.y^{-1} (Cornett et al. 1992), the cores represent material deposited during the past 140 y. The sediment fractions were kept in sealed plastic bags at 4°C during transport to the laboratory where they were frozen until analysis.

Water content (oven dried at 40°C) and carbon content (total and organic) were determined for all the fractions of the sediment cores. The total and organic carbon were determined with a Carbon Determinator Leco, model CR-12. Density (g.cm^{-3}) of the sediment samples were determined with a Multivolume Pycnometer 1305.

Arsenic in different fractions (exchangeable, bound to carbonates, bound to iron and manganese oxides, bound to sulfide or organic matter, and residual), was determined in the sediment cores based on the sequential extraction procedure of Tessier et al. (1979), with only slight modifications (Azcue 1992). The following extractants were employed: magnesium chloride (1M) for the exchangeable fraction; sodium acetate (1M) for the carbonate fraction; $NH_2OH.HCl$ (0.04M) for the oxide fraction; and $NHO_3+H_2O_2$ (0.02M) for the organic fraction. Wet sediments were used instead of dry samples to avoid possible chemical changes and interactions expected mainly from readily oxidizable species such as Fe(II) and Mn(II).

Extractions were performed with approximately 8 g of wet samples in centrifuge tubes. Following each extraction, the mixtures were centrifuged and the supernatants decanted. Total and residual fractions were placed in a Teflon beaker, with 6 mL of aqua regia and 1.5 mL of HF, for acid digestion in microwave oven. The samples were treated by the following microwave program: a) 3 min. at 30 psi, b) 5 min. at 50 psi, c) 5 min. at 100 psi, and d) 5 min. at 130 psi. After the microwave digestion, the samples were evaporated to dryness at about 80 to 90°C in a fumehood, and leached with HCl for atomic absorption determination. Total As, Fe, and Mn were determined in the sediment samples by atomic absorption spectrometry involving direct aspiration of the aqueous solution into an air-acetylene flame.

RESULTS AND DISCUSSION

The profiles of water and carbon contents in the sediments for both basins are presented in Fig. 2. The sediments have a high water content, with negligible intrastation variability. Although at the sediment-water interface in both stations, the carbon contents average approximately 20%, the sediment from the west basin has a higher carbon content. The difference can be explained by the higher inputs of detrital material from the Moira River in the west basin of the lake. The dry density of sediments (g.cm^{-3}) varies between 2.0 and 2.4, averaging 2.0 at station WB and 2.2 at station EC. The physico-chemical characteristics of Moira Lake are summarized in Table 1.

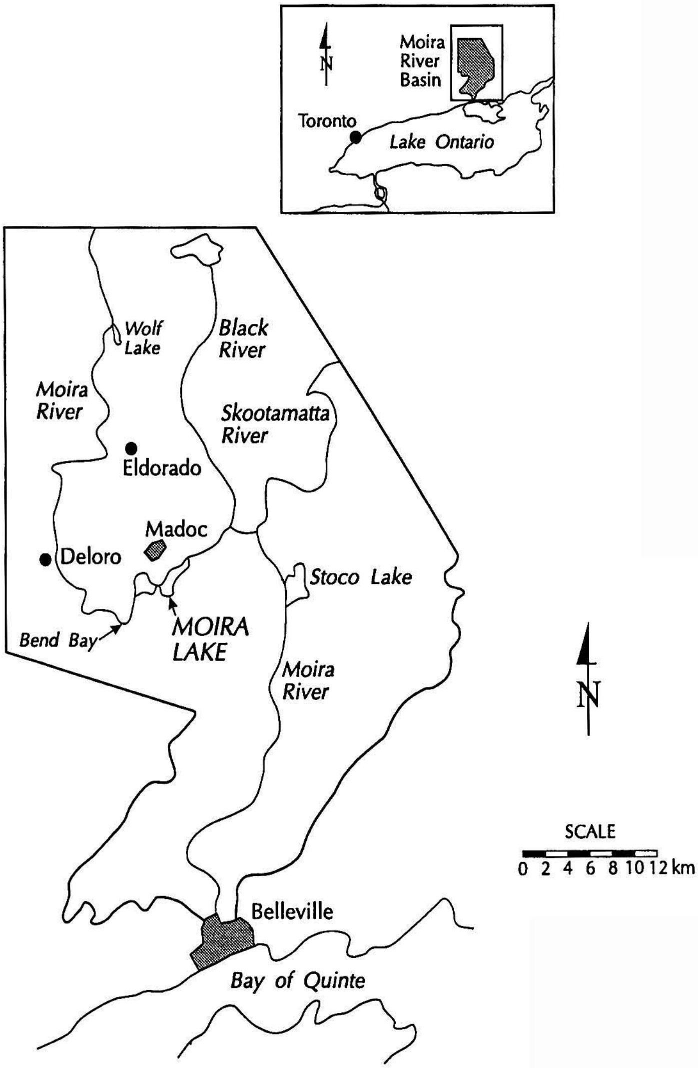


Fig. 1. Study area.

Sediments represent a significant repository of As in Moira Lake, with concentrations in solid phase being about 10^4 times higher than in overlaying waters. High total As concentrations are found in the sediment cores which show an increase with depth and maximal values of about 1000 $\mu g.g^{-1}$ at depths of 23 to 27 cm (Fig. 3). These values contrast with typical background levels of 1 to 5 $\mu g.g^{-1}$ for unpolluted lakes (Allan and Ball 1990; Pershagem 1983). The lower As concentrations in the upper sections of the sediments coincide with the decline of the mining activities and the final shut-down in 1961. However, the very high As concentrations found at the top of the sediments (450 $\mu g.g^{-1}$ in WB and 640 $\mu g.g^{-1}$ in EC) indicate continuing inputs of As pollution to the system, most probably from the abandoned mine tailings at Deloro. The average As concentration for station EC is 723 $\mu g.g^{-1}$ and is slightly higher than 623 $\mu g.g^{-1}$ found in station WB. Further transport and resuspension of the fine-

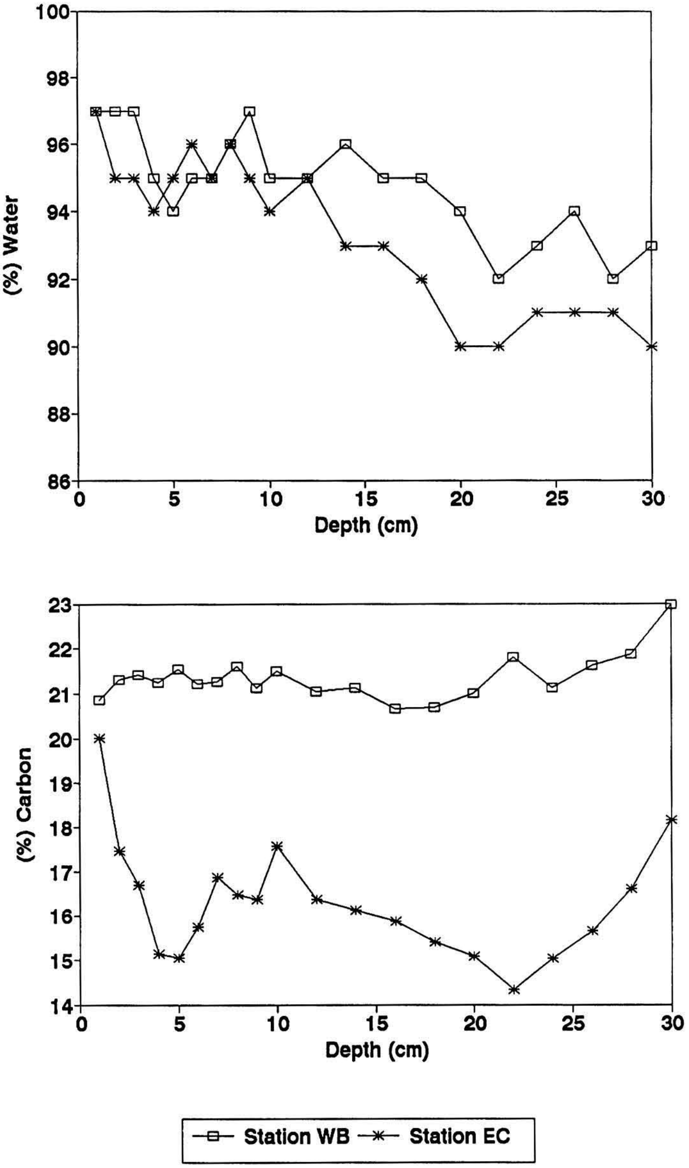


Fig. 2. Water and carbon content of the sediments from Moira Lake.

grained size particles can explain the higher As concentrations in sediments and suspended particles of the east basin.

The profiles for total Fe and Mn in the sediment cores are shown in Fig. 3. The average total Fe concentrations are 45×10^3 $\mu g.g^{-1}$ and 50.5×10^3 $\mu g.g^{-1}$ for stations WB and EC, respectively. The lack of any deep peak in the Fe concentration in the sediments, in contrast to the maximum As concentrations observed at approximately 20-cm depth, probably reflect the fact that mining wastes do not control the accumulation of Fe in the sediments.

Table 1. Physico-chemical characteristics of Moira Lake.

	Lake Average	s.d.
Surface area (ha)	830	---
Water volume (x10^4 m^3)	987	---
Mean depth (m)	5	---
Water residence time (years)	0.34	---
pH	8	0.3
Summer temperature (C)	25	---
DOC (mg.L^{-1})	11.8	---
Conductivity (μmho.cm^{-1})	286	40
Total alkalinity (mg.L^{-1})	133	18
Total phosphorus (μg.L^{-1})	37	57
Nitrogen (kjedahl μg.L^{-1})	531	126
TDS	167	84
Chlorophyll a (μg.L^{-1})	10.3	4.7
Dissolved arsenic (μg.L^{-1})	56	17
Particulate arsenic (μg.g^{-1})	864	277
Bottom sediments (μg.g^{-1})	673	71

Total Mn in sediments shows a very similar trend in both basins, with peaks at the sediment-water interface (Fig. 3). Manganese concentration in the top centimeters at station EC reaches 5 691 µg.g^{-1}. The near-surface enrichments of the Mn indicate diagenetic precipitation at the oxic interface. The fact that the vertical movement of Mn in sediments is more pronounced than that of Fe, reflects the higher sensitivity of Mn to changes in the redox conditions. The accumulation of Fe and Mn are less influenced by the mine wastes compared to As. Since the total As concentration is <3% of the (Fe+Mn) concentrations in these sediments (Fig. 3), a significant correlation should not be expected between the levels of As and (Fe+Mn).

The five geochemical fractions used in this study have widely been adopted in the investigation of the accumulation and possible mobilization of trace metals in sediments (Moore et al. 1988; Nirel and Morel 1990). The sequential extraction data for As in sediments of Moira Lake, like the results of any other sequential extraction procedure, unavoidably suffer from a certain lack of selectivity (Tessier et al. 1979). Consequently, the observed distributions should be regarded as operationally defined by the methods of extraction. However, even after considering these limitations, when compared with information obtained by the analysis of total sediments, the advantage of sequential extraction is considerable.

Variations of the concentrations of the different fractions of As with depth are shown in Figs. 4 and 5. The first extraction, the exchangeable fraction, should remove the weakly bound As by anion-desorption and dissolution of oxidic coatings. Despite the fact

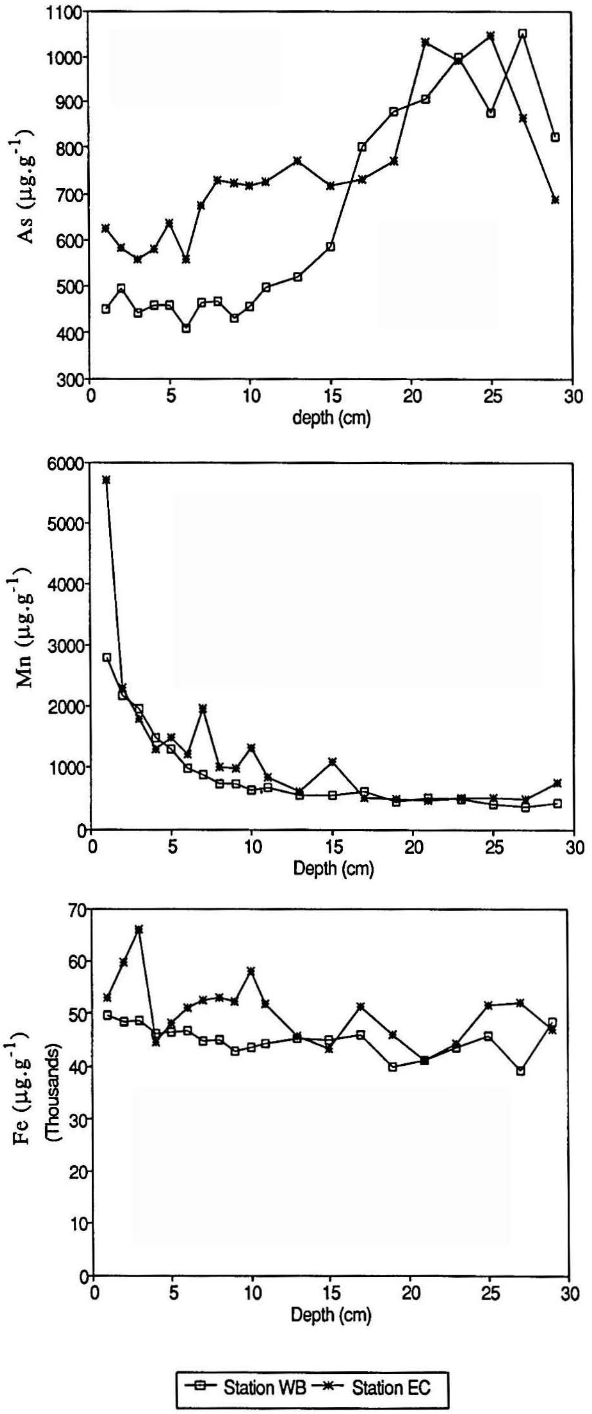


Fig. 3. Profiles of total arsenic, iron, and manganese in Moira Lake sediments.

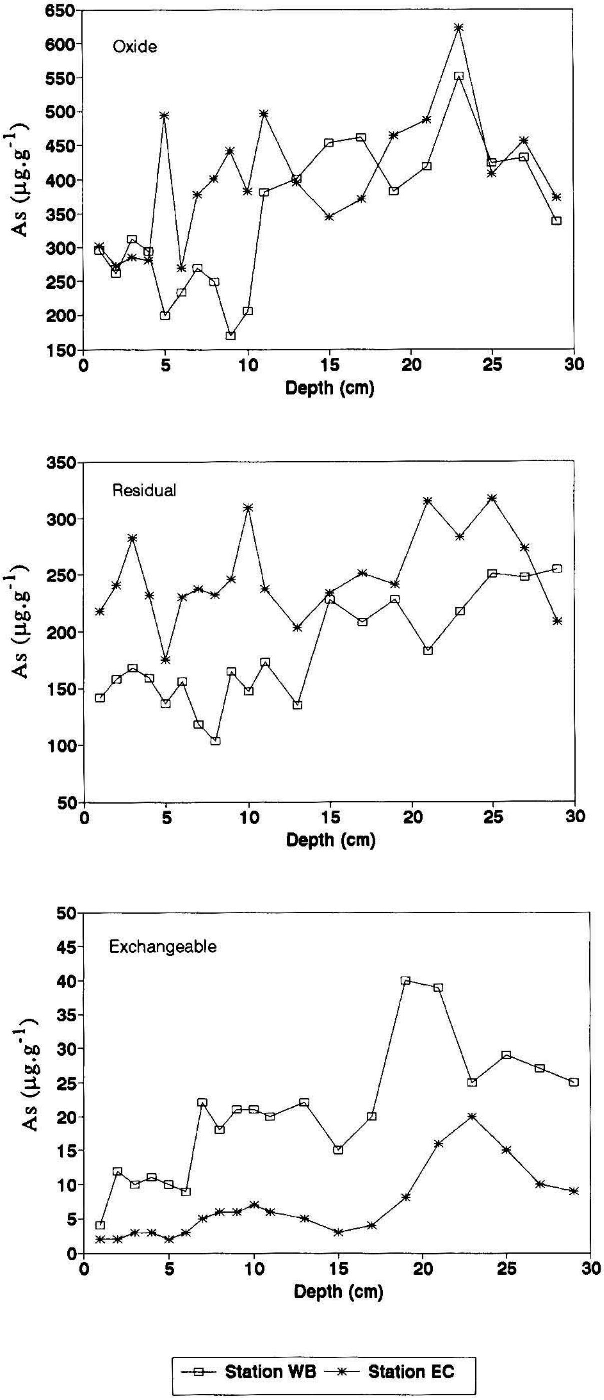
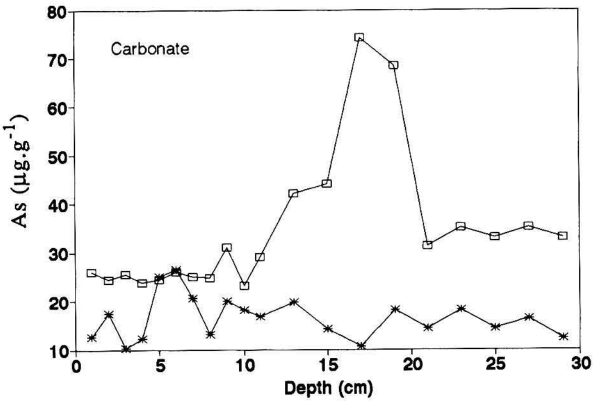


Fig. 4. Concentration of arsenic in the different chemical fractions of the sediment of Moira Lake.



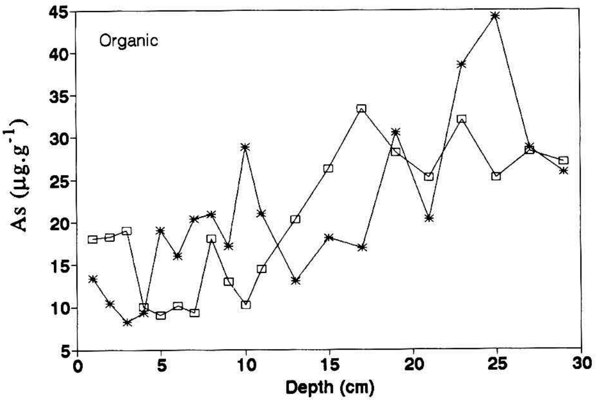


Fig. 4. Continued.

that this fraction represents less than 4% of the total As in the sediments from both stations (Table 2), it can not be ignored because it still averages 5 $\mu g.g^{-1}$ in the top centimeters of the sediments and it is believed to be the most available form biologically. The essentially anionic chemistry of As, and the cationic specificity of the magnesium chloride extraction, support the low values obtained for this fraction (Fig. 4).

The second extraction should remove As bound to carbonates (Fig. 4). This fraction comprises 5.8% of the total As in station WB and 2.4% in station EC, equivalent to weight concentrations of 34 $\mu g.g^{-1}$ and 16.5 $\mu g.g^{-1}$ at station WB and EC, respectively. These results are in agreement with the suggestions of previous studies that the carbonate in the sediment is relatively irrelevant in the chemistry of As (Kersten 1988; Moore et al. 1988; Oscarson et al. 1981). However, it should be noted that the carbonate fraction as defined by the extraction method used is very susceptible of phase changes and matrix effects (Nirel and Morel 1990).

The amounts of As associated with the Fe and Mn oxide fraction at both stations are shown in Fig. 4 and represent approximately 56% of the total As in both stations (Table 2). This fraction clearly is the dominant form of As in the sediments. In station EC, the amount of As extracted in this fraction changed very little from the water-sediment interface to the bottom of the core, with an average concentration of 396 $\mu g.g^{-1}$. At station WB, the As concentration in the top 10 cm was 249 $\mu g.g^{-1}$, compared with 424 $\mu g.g^{-1}$ in the deeper sections of the core. The station WB, where the Moira River enters the lake,

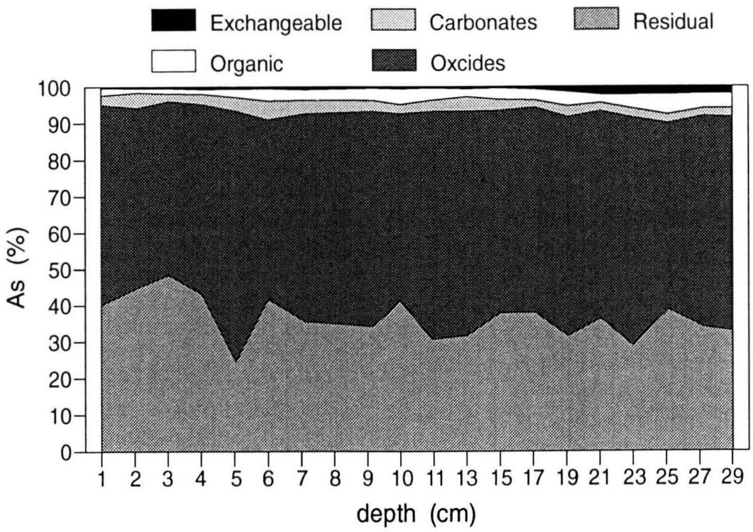


Fig. 5. Profile of arsenic percentages in sediment fractions of Moira Lake.

presumably reflects the As input source functions more closely than the station EC. In fact, the difference in the profiles in the two basins suggest extensive mobility and redistribution of As in sediments at station EC.

The organic/sulfide fraction, shown in Fig. 4, constitutes about 3% of the total As in the sediments of both stations. In the top 3 cm, the As concentration is higher in the core from station WB (18.6 $\mu g.g^{-1}$), decreases to an average of 10 $\mu g.g^{-1}$ at a depth of 10 cm, then increases significantly in deeper sections. The same trend of increasing As concentrations with depth can also be observed from the sediment cores of station EC. The observed profiles for this fraction can be explained in terms of high inputs of detrital sulfidic phases by the river (surface enrichment) and progressive diagenetic formation of arsenic sulfides in older sediments (Manning and Ash 1979).

Table 2. Percentages of total arsenic in the different chemical fractions of the sediment cores at stations WB and EC.

	Station WB		Station EC	
Fraction	Avg.	(Range)	Avg.	(Range)
Exchangeable	3.4	(0.8-5.6)	0.9	(0.3-2.0)
Carbonate	5.8	(4.1-9.3)	2.4	(1.6-4.8)
Organic	3.3	(2.0-4.4)	3.0	(1.4-5.5)
Oxide	56.7	(42.5-64.6)	57.1	(48.4-69.1)
Residual	30.8	(21.8-41.2)	36.6	(24.5-48.0)

No correlation can be observed between the organically associated As fraction and the carbon content of the sediments in Moira Lake (compare Figs. 2 and 4). This is not surprising since As does not bind strongly to organic ligands in sediments and soils (Kersten 1988). The distribution of As, thus, differs from the partitioning of other elements in sediments with high organic carbon concentrations. For instance, Cornett et al. (1989) showed that the highest concentration of Ni in Moira Lake sediments was contained in the organic fraction. It should also be noted that the interpretation of the organic fraction in sequential chemical extraction experiments is very difficult because pyrite is not easily oxidizable, but rather extractable by strong acid digestion in the last residual step (Horowitz et al. 1990; Kersten 1988).

The As contained in the residual fraction of the sediments is shown in Fig. 4. The average As concentration in this fraction at station EC is 248 $\mu g.g^{-1}$, with little variation with depth. In the top 10 cm of station WB, the average As concentration is 145 $\mu g.g^{-1}$, while the deepest fractions of the core average 230 $\mu g.g^{-1}$. This fraction constitutes 31% (WB) and 37% (EC) of the total As on the average (Table 2). This fraction is generally believed to reflect the lithogenous As in sediments (Sager et al. 1990). If so, the river must be loading large quantities of arsenic-rich detrital material into the lake. The higher concentration of the residual fraction in the station EC also suggest that some of the pollutant As is being converted to the residual phases, for example, by the replacement of silica by As in the clay minerals.

The data clearly suggest that the inputs from the mines have changed the forms of As in the sediments. In premining times, one would expect the As to occur primarily in the residual and sulfide fractions. The fractional distribution of As in such sediments would be in the order residual ≥ sulfide > oxide > exchangeable > carbonate. With increased flux of dissolved As pollution into the lake, scavenging by seston becomes a major route for the delivery of As to the sediments. This is reflected in the observed predominance of the oxide fraction in the polluted sediments. The fractional distribution sequence is then changed to oxide > residual > sulfide > exchangeable > carbonate. The fact that this sequence is being maintained in Moira Lake sediments indicates that the abandoned mines still control the As cycle in the lake. The forms of As and their distribution sequence in Moira Lake are generally consistent with observations in other polluted sediments. For example, Moore et al. (1988) found that As is largely present in the organic fraction in the deeper sediments of Clark River, Western Montana, but occurs mostly in the oxide phase in the overlying contaminated sediments.

Figure 5 shows the historical changes in the combined (EC+WB) percentages of As bound to different chemical fractions in Moira Lake sediments. Two features are particularly noteworthy: a) the concentration of residual As in the polluted sediments is high, and b) there are significant incursions of the oxide fraction into the field for residual fraction. The two features suggest that some of the oxide-bound As is being converted to the residual phases. The oxide and residual fractions make up over 90% of the As in the sediments and changes in the relative proportions of the exchangeable, carbonate, or organic fractions to the two dominant fractions have been small.

Since the pollutant As is dominantly associated with the oxide fraction, changes in the Eh or pH of the sediments can trigger a regeneration of the As reservoir in the sediments. Elimination of As loadings to the lake, thus, may not guarantee a drastic reduction in the As levels in the water column. It is, however, encouraging that lake processes do result in the conversion of the oxide-bound As to the less mobile residual forms. An understanding of the conversion processes should be useful in developing proper remediation measures for Moira Lake and other As-contaminated bodies of water.

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NEW PATENTS

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33998

APPARATUS AND PROCESS FOR PRODUCING AN ORGANIC PRODUCT FROM SEWAGE SLUDGE

Quentin Hampton

A completely integrated and automated apparatus by which liquid sewage sludge from any sewage or waste treatment plant may be processed into a completely dry, pelletized and sterilized product of an organic nature containing nutrients valuable for the support of plant life. The apparatus involves one completely integrated and automated unit together with a control center by means of which electric circuits program each component of the apparatus to automatically regulate the operation of each component, so that no labor or other manpower is required in the operation, except for observation, lubrication, maintenance and repair of the various motors and machineries involved.

331104

COMBINED BURNER NOZZLE, NOZZLE-SUPPORTING HEAT EXCHANGE BLOCK, AND CONTROL VALVE SUBASSEMBLY UNIT FOR A WASTE OIL BURNER

Glenn Bender assigned to Shennandoah Manufacturing Co Inc

The ornamental design for a combined burner nozzle, nozzle-supporting heat exchange block, and control valve subassembly unit for a waste oil burner, as shown.

5129110

SELECTABLE TOILET-WATER-LEVEL FLUSHING SYSTEM

Robert A Richter

A selectable toilet-water-level flushing system (10) that allows a toilet user to selectively control the quantity of water that is used for a toilet flush. The quantity of water used depends on whether liquid or solid waste is to be flushed. For liquid waste, only a partial flush is necessary; for solid waste, a full-flush is used. The system (10) functions by performing a simple modification to the toilet flush valve (12). The modification consists of inserting into the valve opening a weight (16) that causes the normally buoyant valve to become non-buoyant. Since the valve is non-buoyant, the lifting of the valve from the valve seat (36) is totally controlled by the toilet flush handle (38) which, in turn, is controlled by the user. Typically, for a partial flush the handle (38) is temporarily held in its depressed position for two seconds while for a full flush, it is held for four seconds. Over a period of time, by using partial flushes a large savings of fresh water can be realized.

5129335

FLUID WASTE BURNER SYSTEM

Eddy Lauwers, Kalmthout, Belgium assigned to Union Carbide Industrial Gases Technology Corporation

A process for controlling the temperature and flame front in a liquid waste incinerator comprising: dispersing fluid wastes into the flame of at least one oxygen/fuel burner to incinerate the waste in and around the flame, wherein flame energy is regulated by adjusting the fuel to the low heating value waste ratio to control the flame front and temperature in said incinerator. The flue gas resulting from burning the waste may be used to heat, possibly concentrate partially and/or evaporate (if liquid is present) the fluid waste prior to dispersing it into the flame.

5131192

DUST ARRESTER FOR A SANDING MACHINE

Mau-Nan Cheng, ,tuohtmlaK

A dust arrester for a sanding machine includes a hollow workbench and a tubular filter unit which is axially rotatable inside the hollow workbench. A suction unit draws polluted air into the workbench to be filtered by the filter unit. A blowing unit is disposed inside the filter unit and generates a downwardly oriented air stream to blow dust particles collected by the filter unit into a removable dust receiving bin inside the workbench. The dust arrester is simple in construction, has a relatively low cost, and can effectively control air pollution.

5131934

APPARATUS FOR REMOVING HAZARDOUS PARTICULATE AND FIBROUS MATERIALS

Manhar A Patel assigned to Union Carbide Chemicals & Plastics Technology Corporation

A glove bag assembly comprising a glove bag adapted to be optionally sealed horizontally to create an upper and a lower portion; a valve assembly connected at its inlet to said lower portion via a conduit and at its outlet to a waste container; and vacuum-generating means communicating with splitter valve means, whereby the amount of vacuum applied to the entire assembly can be controlled.

5132227

MONITORING FORMALDEHYDE

Thomas J Kelly assigned to Batelle Memorial Institute

Methods and apparatus for monitoring formaldehyde vapor in a gas, comprising directing the gas into contact with an aqueous acidic solution that can dissolve the vapor and thus collect it therein, separating the gas from the solution, reacting the solution with a reagent to form from the collected formaldehyde a derivative that can be excited by radiation at a wavelength in the range of about 230 to 300 (typically 254) nanometers to fluoresce at a substantially different wavelength, irradiating the solution at a wavelength in said range for excitation, and measuring the intensity of the resulting fluorescence. Typically the fluorescence is measured at a wavelength in the range of about 450 to 550 nanometers and the irradiation and the measurement of fluorescence are carried out by means comprising conventional fluorometric means.

5132663

VEHICLE SAFETY SYSTEM AND METHOD FOR MONITORING TOXIC AND COMBUSTIBLE FUELS

Wolfgan Strobl, Klaus Pehr, Eichst Federal Republic Of Germana assigned to Bayerische Motoren Werke Aktiengesellschaft

A vehicle and method for detecting the formation of ignitable mixtures in the closed spaces of the vehicle has at least one signal-generating sensor mounted in the closed spaces of the vehicle at a point at which, because of the physical characteristics of the fuel and because of the spatial conditions, harmful substances and/or gases collect first. The signals generated by the at least one sensor are processed in an electronic circuit which, as a function of the measured harmful-substance or gas concentration, actuated movable vehicle parts for closing and opening certain vehicle spaces.

5133089

WATER CLOSET FLUSHING APPARATUS

Osamu Tsutsui, Atsuo Makita, Hirofum Takeuchi, Shinji Shibata, Noboru Shinbara, Chigasaki, Japan assigned to Toto Ltd

In a water closet flushing apparatus of the type in which the flushing water from a flushing water supply source is fed through different flushing water feed lines to a bowl portion and a trap discharge passage defined adjacent to the bottom portion of the bowl portion, a water jet injector is provided so as to inject the flushing water jet toward the trap discharge passage, an opening-closing valve is disposed in each of different feed lines, and the operation of the opening-closing valve is controlled by a control unit. The flushing water is flushed into the bowl portion so as to clean the same while the jet of flushing water is injected into the trap discharge passage to cause the same to act as a siphon, whereby waste matter is discharged.

5133374

APPARATUS AND METHOD FOR PURGING MEDICAL INSTRUMENTS AND DISPOSING OF INFECTIOUS WASTE

Kevin W Druding, William Merkle

An apparatus for transmitting infections medical waste to a sewer without personnel exposure employing a closed container having a waste tube and a suction tube extending thereinto. The waste is transmitted from an endoscope or other source into the container and the container is drained to a sewer under control of a vacuum applied to the inside of the container. The automated container drainage affords virtually unlimited container volume for improved cleaning of instrument internal channels.

5133962

METHOD OF CONTROLLING COLEOPTERAN INSECTS WITH BACILLUS THURINGIENSIS

August J Sick, Thomas E Gilroy assigned to Mycogen Corporation

A novel B.t. toxin gene encoding a protein toxic to coleopteran insects has been cloned from a novel coleopteran-active B. thuringiensis microbe. The DNA encoding the B.t. toxin can be used to transform various prokaryotic and eukaryotic microbes to express the B.t. toxin. These recombinant microbes can be used to control coleopteran insects in various environments.

5134266

MOBILE DEICING APPARATUS

Dennis L Peppard

Mobile apparatus is described for melting accumulated ice from surfaces such as aircraft, spacecraft, rocket assemblies, etc. The apparatus includes a heating source for heating air, a compressor, an elongated boom with a discharge head for discharging heated air, and controls for controlling the position of the boom. The apparatus avoids the need for chemicals and accordingly reduces pollution problems.

5134946

NEUTRALIZER FOR TOXIC AND NUCLEAR WASTE

Gary N Poovey

A method and apparatus are disclosed wherein toxic and nuclear waste are pumped in a metered fashion or introduced through a sealing door into a plasma region. The plasma region is generated in a sealed chamber by a radio frequency plasma torch. In the plasma region the toxic waste is atomized and ionized. The recombining of the atomized and ionized molecules is managed in the sealed reaction chamber to yield environmentally neutral products. Encapsulation material that is either introduced into the process chamber with the waste or is resident in the process chamber encapsulates radioactive or heavy metal atoms in a glassy stone like material. This encapsulating renders the atoms environmentally neutral. The flow of material in and out of the reaction chamber are regulated carefully. The radio frequency power level is also carefully controlled. These controls insure the neutrality of the recombining products. The fluids exiting the chamber are filtered before release, to insure environmental neutrality.

5135361

PUMPING STATION IN A WATER FLOW SYSTEM

Thomas Dion assigned to Gotherman William

A water flow system for collecting and discharging waste water, storm water and the like includes a water pumping station into which water is delivered through an inflow main and from which water is pumped through a water discharge main. The pumping station has a water collection well, a pair of water pumps and a conduit arrangement by which the suction side of each pump is communicated with the well and the pressure side of each pump is communicated with the discharge main. A secondary conduit also communicates the pressure side of one pump with the suction side of the other pump. A control system is operative to actuate one of the pumps for normal pumping conditions and to actuate both pumps during periods of heavy water inflow to the station, the secondary conduit providing serial flow of water through the pumps under such conditions to substantially increase the water outflow rate from the pumping station in comparison to conventional parallel combined operation of the pumps.

5135387

NITROGEN OXIDE CONTROL USING INTERNALLY RECIRCULATED FLUE GAS

Michael J Martin, William C Gibson, Lee Massey assigned to IT-McGill Environmental Systems Inc; Tulsa Heaters Inc

An improved process and apparatus for reducing NOx content of flue gas effluent from a furnace, the improvement comprising a burner assembly having a burner and flue gas recirculating system for collecting and passing internally recirculating flue gas into a combustion zone for reaction with a combustion flame. The burner preferably has a plurality of fuel dispensing nozzles peripherally disposed about the combustion zone to aspirate collected internally recirculating flue gas into the combustion zone, and has a plurality of fluid driven eductors to drive further amounts of collected internally recirculating flue gas into the combustion zone.

5135656

PROCESS FOR REMOVING WATER SOLUBLE ORGANIC COMPOUNDS FROM PRODUCED WATER

C Mitchel Means, Michael Braden assigned to Nalco Chemical Company

A process for the removal of water soluble organic compounds from produced water is provided. The process allows for the removal of water soluble organic compounds by passing the produced water through a column of adsorbing resin which is capable of removing the soluble organic compounds from the water and providing an environmentally acceptable effluent. The removal of polllutants from the produced water is monitored continuously by a fluorescence detector. The process further allows for the generation of the adsorbing resin by regenerating the resin with a solvent capable of eluting accumulated soluble organic compounds from the column followed by treatment of the resin with steam to remove residual eluting solvent. The process further allows for the treatment of the eluting solvent and soluble organic compound admixture in a manner to allow reuse of the solvent and to allow recovery of the soluble organic compound or to allow direct injection of the soluble organic compound admixture into the oil stream. Thus, the invention provides a process for removal and recovery of water soluble organic compounds from produced water which creates no environmentally hazardous waste streams.

5135721

STERILIZATION AND COATING APPARATUS

Daniel Richard assigned to Net/Tech International Inc

A sterilization apparatus comprises a housing provided with an opening through which an object may be inserted, and an ultraviolet radiation generator at least partially inside the housing for irradiating with bacteriocidal radiation an object inserted into the housing through the opening. A liquid spraying mechanism or gas injection mechanism is disposed at least partially inside the housing for applying to the inserted object a sterilizing agent. A coating or cover forming mechanism is also provided at least partially inside the housing for forming on the inserted object a protective covering. A control unit controls the activation of the radiation generator, the sterilizing mechanism and the coating mechanism.

5136111

CONTROLLED CATALYTIC AND THERMAL SEQUENTIAL PYROLYSIS AND HYDROLYSIS OF PHENOLIC RESIN CONTAINING WASTE STREAMS TO SEQUENTIALLY RECOVER MONOMERS AND CHEMICALS

Helena Chum, Robert J Evans assigned to MRI Ventures Inc

A process of using fast pyrolysis in a carrier gas to convert a waste phenolic resin containing feedstreams in a manner such that pyrolysis of said resins and a given high value monomeric constituent occurs prior to pyrolyses of the resins in other monomeric components therein comprising: selecting a first temperature program range to cause pyrolysis of said resin and a given high value monomeric constituent prior to a temperature range that causes pyrolysis of other monomeric components; selecting, if desired, a catalyst and a support and treating said feedstreams with said catalyst to effect acid or basic catalyzed reaction pathways to maximize yield or enhance separation of said high value monomeric constituent in said first temperature program range to utilize reactive gases such as oxygen and steam in the pyrolysis process to drive the production of specific products; differentially heating said feedstreams at a heat rate within the first temperature program range to provide differential pyrolysis for selective recovery of optimum quantity of said high value monomeric constituent prior to pyrolysis of other monomeric components therein; separating said high value monomeric constituent; selecting a second higher temperature program range to cause pyrolysis of a different high value monomeric constituent of said phenolic resins waste and differentially heating said feedstreams at said higher temperature program range to cause pyrolysis of said different high value monomeric constituent; and separating said different high value monomeric constituent.

5152232

INCINERATOR APPARATUS

James P Crawford

An incinerator apparatus has a primary incinerator chamber which has a secondary incinerator chamber coupled thereto by a passageway. The primary incinerator chamber has a primary air input into the incinerator chamber and the secondary air chamber has a secondary air input thereinto having a plurality of air input lines with each line having an electric motor control valve, such as a damper motor controlling a damper valve controlling the flow through one of the input lines. A plurality of ultraviolet flame detector ports open into the side of the secondary incinerator chamber, each being spaced a predetermined distance from each other and each having a ultraviolet flame detector positioned therein for sensing the ultraviolet radiation and the flame adjacent the detector in the secondary incinerator chamber. Each ultraviolet flame detector is operatively coupled through electronic controls which includes relays to actuate each of the plurality of electric damper motors to open and close the damper valve responsive to the ultraviolet flame detector signal thereby the secondary air flow is controlled by a flame detector reading the flame position at a plurality of points in the secondary incinerator chamber. One air blower can direct the air to the primary chamber and to the secondary chamber through a plurality of ports into each chamber with the secondary air being increased or decreased responsive to the length of the flame in the secondary chamber to thereby maintain the temperature within a predetermined range within the secondary chamber to ensure complete combustion of the incinerated product.

5152966

APPARATUS FOR PRODUCING A CONTROLLED ATMOSPHERE

Elman Roe, William R Ash, Terry Campbell, Steve Forney assigned to Nicap Inc

An apparatus for producing a controlled atmosphere in an area by providing for the removal of oxygen, carbon dioxide, water droplets and ethylene from a gas stream. The apparatus includes two compressors to increase the pressure of the gases present which are then separated by diffusion across at least two membranes.

5153563

FIRE SENSING SYSTEM, PROCESS FOR SENSING FIRE AND ENVIRONMENT MONITOR

Haruhisa Goto, Kazunari Naya, Hideo Segawa, Hiroomi Sato, Keiichi Miyamoto, Toda, Japan assigned to Nippon Mining Co Ltd; Kajima Corporati

A fire sensing system, a process for sensing a fire and an environment monitor are disclosed. The system includes infrared sensors with sensing wavelength bands sensing an infrared radiation from an infrared source. One of the sensing wavelength bands is a CO2-molecular resonance radiation wavelength band. The system determines whether a disastrous fire occurs or not on the basis of outputs of the sensors and a change in a ratio of the outputs. The process computes the temperature of the infrared source from a ratio of outputs of infrared sensors with at least two sensing wavelength bands of an infrared radiation from a monitored area, produces the intensity of infrared radiation of either of the bands from the computed temperature and computes a heating area from the intensity and the output of a corresponding infrared sensor. The process determines the progress of a fire. The monitor produces a control signal to an air conditioner or room heater-and-cooler from outputs of sensors and an output of a thermometer.

5154235

METHOD FOR CONTROLLING AND SUPPRESSING FIRES USING DEALGINATED, DEWATERED KELP WASTE

John Renaker, Donald A Magley, Michael Bustamante assigned to Damcosur S A De C V

A method is described for the control or suppression of a fire in which one applies to the fire a suppressant material which contains dealginated, partially dewatered kelp. Other components, such as perlite, may also be present. The suppressant material will have a water content no greater than about 25%, preferably about 5%-10%. It is used in the form of particulates and applied to the surface of a fire to suppress or extinguish the fire. It is particularly applicable to fighting fires in remote or inaccessible locations; large area fires, such as pools of burning oil; or fires where use of conventional water fire fighting methods are either dangerous or insufficient. The material may be molded into various shapes adapted to be used as fire barriers in vehicles and building walls.

5154466

PNEUMATIC SOIL REMOVAL TOOL

John Neuhaus assigned to The United States of America as represented by the United States Department of Energy

A soil removal tool is provided for removing radioactive soil, rock and other debris from the bottom of an excavation, while permitting the operator to be located outside of a containment for that excavation. The tool includes a fixed jaw, secured to one end of an elongate pipe, which cooperates with a movable jaw pivotably mounted on the pipe. Movement of the movable jaw is controlled by a pneumatic cylinder mounted on the pipe. The actuator rod of the pneumatic cylinder is connected to a collar which is slidably mounted on the pipe and forms part of the pivotable mounting assembly for the movable jaw. Air is supplied to the pneumatic cylinder through a handle connected to the pipe, under the control of an actuator valve mounted on the handle, to provide movement of the movable jaw.

5154734

POLLUTION CONTROL SYSTEM AND METHOD OF USING SAME

Shui-Chow Yung assigned to Calvert Environmental Inc

A pollution control apparatus, which monitors the amount of contaminants being removed from treated gas, and which adjusts parameters to maintain the contaminant removal amount within a preselected, desired range having maximum and minimum limits. A computing microprocessor, causes one or more parameters to be adjusted, thereby increasing or decreasing contaminant removal in order to maintain the level of removal within the preselected range.

5155047

METHOD AND APPARATUS FOR MEASURING AND CONTROLLING EFFICIENCY OF A COMBUSTION

Mario Cioni, Gennaro De Michele, Mirella Musci, Franco Curcio, Pisa, Italy assigned to ENEL - Ente Nazionale per l'Energia Elettrica

A method and an apparatus for measuring and controlling the efficiency of a combustion whereby, ash samples are drawn at predetermined time intervals from a region of a combustion plant, each drawn sample is set in an exhausted reaction cell, combustion reaction gas is introduced under controlled pressure, a superficial layer of the sample is heated to the carbon combustion temperature by a CO2 laser beam, the reaction gas is drawn from the cell and the amount of carbon dioxide produced by the carbon combustion is measured in a calibrated detector. The amount of unburnt carbon contained in the ashes is determined based on a preceding calibration carried out on ashes of known carbon content.

5155364

SOLID-LIQUID REVERSIBLE SCINTILLATOR AND METHOD OF USING THE SAME

Haruo Fujii, Tokyo, Japan assigned to Packard Instrument B V

The present invention is a scintillator which emits light in response to radiation. The scintillator is capable of being reversibly changed between solid and liquid phases, whichever is desired, by temperature control. The scintillator comprises a fluorescent substance for converting radiation energy into light energy; a solvent which transfers radiation energy to the fluorescent substance and dissolves and diffuses the fluorescent substance and a radioactive substance acting as an object of measurement to thereby homogenize them; and a fixing substance which enables the solvent, the fluorescent substance and the radioactive substance to be fixed in a solid state and also liquified upon heating, the fixing substance being capable of phase change reversibility.

5156722

DECONTAMINATION OF RADIOACTIVE METALS

Thomas S Snyder, William R Gass, Samuel A Worcester, Laura J Ayers assigned to Westinghouse Electric Corp

Two alternate, mutually exclusive, methods of removing radio contaminants from metal are taught based respectively on electrowinning or electrorefining of the base metal. The alternative using electrorefining controls the anolyte oxidation potential to selectively reduce the technetium in the metallic feedstock solution from Tc(VII) to Tc(IV) forcing it to report to the anodic slimes preventing it from reporting to the cathodic metal product. This method eliminates the need for peripheral decontamination processes such as solvent extraction and/or ion exchange to remove the technetium prior to nickel electrorefining. The other alternative method combines solvent extraction with electrowinning. By oxidizing technetium to the heptavalent state and by using mixtures of tri-n-octyalphosphine oxide and di-2-ethyl phosphoric acid in aliphatic hydrocarbon carriers to extract the radio contaminants prior to electrowinning, the background metal may be recovered for beneficial reuse. Electrowinning may further polish the decontamination extraction process to remove residual actinides in solution while winning a radio- chemical free metal product. These methods are particularly useful for the decontamination of nickel by radio contaminants such as technetium and actinides.

5156926

SYSTEM FOR GENERATING ELECTRIC ENERGY FROM FUELS HAVING ELECTROCHEMICALLY ACTING FUEL CELLS

Joseph Lemoine, Friedrichshafen, Federal Republic Of Germany assigned to MTU Friedrichshafen GmbH

The invention relates to a system for generating electric energy from fuels by means of electrochemically acting fuel cells. In order to achieve an operation of a system which is efficient and not harmful to the environment, heat exchangers and at least one gas washing unit are coupled to the fuel cells. The heat exchanger is contructed such that the heat quantities occurring during the process are reutilized for the operation of the fuel cells. The gas washing unit is used for the precipitation and recovery of residual fuel components contained in the fuel waste gas and of expensive catalyst gas which are recycled to the fuel cells. An additional gas washing unit and additional precipitating unit are controlled by a microprocessor to increase the efficiency of the system while energy is generated in a manner which leaves practically no residues and is not harmful to the environment.

5157795

DUAL FLUSH VALVE FOR WATER CLOSETS

John P Pasquin

A dual flush valve assembly for use in the water storage reservoir of a conventional toilet is disclosed. The assembly includes a valve, a guide track, a pair of slider members, slideably mounted in the guide track and individually connected to the valve and an actuation assembly adapted for controlling the displacement of those slider members. The valve is adapted for effecting a discharge of a first quantity of water, and a second quantity of water. The action of the valve is controlled by the actuation assembly effecting a displacement of one or more of the slider members. The first quantity of water is measureably smaller than the second quantity of water. The invention provides a means whereby the user may select the quantity of water discharged in a flush cycle according to the type of waste materials being disposed of.

5158024

COMBUSTION CONTROL APPARATUS FOR A COAL-FIRED FURNACE

Shinji Tanaka, Tatsuy Miyatake, Kazuyoshi Yamamoto, Yuichi Miyamoto, Tokyo, Japan assigned to Kawasaki Jukogyo Kabushiki Kaisha

This invention relates to a combustion control apparatus for a powdered coal-fired furnace that monitors noxious substances contained within the burning waste gases, unburned substances within the ash and the power data of a pulverizing mill in order to operate the combustion furnace safely and efficiently. The combustion control apparatus infers from the current states or data optimal control amounts that will maintain within the minimum allowable ranges the noxious nitrogen oxides and the in-ash unburned substances that affect the combustion efficiency- and thereby controls the combustion furnace with good stability. The combustion control apparatus qualitatively evaluates as fuzzy quantities the density data of the nitrogen oxides contained within the exhaust gases of the unburned substances contained within the ash, and the power data of the pulverizing mill. Based upon the evaluation results a fuzzy inference is formed so as to determine the optimum control amount of the two-stage combustion air ratio for minimizing the nitrogen oxides and also the optimum control amount for the fine/coarse gain separator so as to extract powdered coal of a grain size most effective for minimizing the unburned substances within the ash.

5159885

PROCESS FOR INCINERATING SOLID WASTES AND A PROCESS FOR TREATING SOLID WASTES AND A PROCESS FOR TREATING GASES GENERATED THROUGH INCINERATION OF THESE WASTES

Nobuyasu Hasebe, Nobukatsu Hasebe, Nishiogikita, Suginamiku, Tokyo, Japan

The present invention relates to a process for incinerating burnable wastes, such as plastics, and to the treatment of the gases generated by such incineration. The waste materials are buried in a landfill, combustion is initiated with an explosion which simultaneously creates a combustion chamber as well as initiating incineration. A fuel and an oxidizing gas are supplied to the combustion chamber and conduits are provided for discharging the gases formed during the incineration process. The angle of introduction of the fuel and/or fuel and air mixture controls the direction of the incineration process. Landfill gases can be fed into the fuel conduit pipe for utilization as a combustion fuel. In addition, when using a liquid fuel, good results have been achieved by combining a suspension of a carbonate or bicarbonate in the fuel which serves to reduce chloride gases such as phosgene which are generated during the decomposition of plastics such as polyvinylchloride. Incineration gases are let into the treatment apparatus for conversion into non-toxic gases which are subsequently catalytically treated to remove environmentally harmful substances.

5160069

INTEGRATED POWER UNIT COMBUSTION APPARATUS AND METHOD

Reinhard M Klaass, Bert Minshall, Francis J Suriano, William Caan assigned to Allied-Signal Inc

The invention relates to secondary power system apparatus and method for use aboard aircraft in place of conventional auxiliary power units (APU's) and emergency power units (EPU's). The invention integrated power unit (IPU) performs the function of both an APU and an EPU, while avoiding the use of hazardous monofuels. The IPU includes a turbine engine operable on pressurized ambient air, or on pressurized stored air, along with jet engine fuel. The structure of a combustion chamber for the engine which is able to use pressurized air from two separate sources; of a control able to selectively operate the engine as an EPU, as an APU, and to effect operating transition from EPU to APU; and of a complete secondary power system with the IPU are all disclosed.

5160438

METHOD AND MEANS OF SAMPLING LARGE REGIONS OF LIQUID FOR POLLUTION OR BIOLOGICAL ACTIVITY USING BUBBLES

Richard M Detsch assigned to The United States of American as represented by the Secretary of the Navy

A unique bubble production system and method for sampling and cleaning large regions of dirty or polluted bodies of water, or for otherwise sampling them for other biological activity. This is achieved by the use of millions to trillions of tiny chemical coated particles which are usually dispersed in air by suitable means to effect predetermined patterns of the particles and resultant bubble region as they descend in the water. The particular character of the particles and their selected dispersal mode assure the homogeneous generation of large concentrations of millions to trillions of bubbles throughout a predetermined volume of the water body so as to generate a planned and controlled bubble spectra for a selected applicational purpose. A bubble spectrum is a plot of the number of bubbles per volume as a function of bubble diameter.

5160517

SYSTEM FOR PURIFYING AIR IN A ROOM

Richard E Hicks, Richard R Fenner

A system for indoor pollution control that purifies ambient air in a room. The air-purification components can be housed, for example, in an item of ordinary furniture such as a chair. This allows large components capable of high purification rates to be used, but without the large space requirements hitherto normally required with previously known high-rate systems. In addition, the air flow is directed so that a localized spatial zone can be preferentially purified without the need for physical enclosures. The system can be used to prevent dispersion of harmful substances such as pathogens or tobacco smoke that originate from a source, and can also create a microenvironment of purified air.

5160604

TOXIC SUBSTANCE-DETECTING SYSTEM WITH FIXED MICROORGANISM MEMBRANE FOR WATER QUALITY-MONITORING

Eiichi Nakamura, Hiroaki Tanaka, Yoshihar Tanaka, Takashi Iitake, Hirosh Hoshikawa, Ibaraki, Japan assigned to Fuji Electric Co Ltd; Public Works Research Institu

A toxic substance-detecting device detects toxic substances in water by use of a microorganism sensor to ascertain the safety of affluents flowing into sewage-treating processes, environmental waters such as rivers, and waters flowing into water purification plants and a water quality-monitoring system employing a detecting device. The device includes a fixed micro-organism membrane and apparatus for circulating a buffer solution of micro-organism substrate and nutrient to one side of the membranne and solutions of water to be examined, standard and cleaning water to the other side.

5161958

VALVE DEVICE FOR AUTOMATIC CIRCULATION IN A WASTE WATER PUMP STATION

Folke Landquist, Balsta, Sweden assigned to ITT Flygt AB

The pressure side of a submersible pump unit is provided with a valve device which during certain periods of operation opens a connection between the submersible pump and the pump station to obtain the necessary circulation of the waste water in the station. The opening and closing of the valve device is effected by a ball which is controlled by the submersible pump pressure.

5161966

METHOD AND APPARATUS FOR BURNING A POLLUTANTS CONTAINED IN A CARRIER FLOW

Herbert Obermueller, Linsengericht, Federal Republic Of Germany assigned to H Krantz GmbH & Co

In a method and apparatus for cleaning a gas flow that carries oxidizable pollutants in varying concentrations, the temperature within the combustion apparatus is maintained substantially constant by admixing controllable proportions of the gas to be cleaned and/or fresh air to the combustion flow. However, admixing prior to introducing the gas to be cleaned into the combustion flow is avoided by performing the admixing at a location near the exit end of a flue gas mixing pipe. This mixing location permits maintaining the combustion chamber temperature constant or at its rated level while simultaneously keeping the temperature of the flow control device at acceptable levels. The flue gas mixing pipe is arranged downstream and coaxially with a burner so that the admixing takes place after the combustion or carrier flow has already passed the burner at the entrance to the combustion chamber.

5163829

COMPACT REGENERATIVE INCINERATOR

Henry Wildenberg assigned to Thermo Electron Wisconsin Inc

A compact regenerative incinerator for incinerating an effluent includes a single vessel with two compartments separated by a partition. Each compartment includes an opening and a combustion chamber, and these are separated by a thermal storage medium. The incinerator also has a bypass system, which includes a bypass opening in the vessel and a bypass thermal storage medium separating the opening from the combustion chambers. Valving, which includes one or more flushed control valves, directs the effluent to flow into one of the compartment openings and directs the products of incineration to flow out of the other. The valving is also adapted to direct the effluent into the bypass opening while reversing the flow direction in the incinerator. A controller monitors effluent concentration, its temperature and that of the products of incineration, as well as rates of temperature change, and uses the resulting information to reverse the flow direction at times which optimize efficacy for differing levels of delivery of effluent. A purging system recirculates a portion of the products of incineration during purging, and pressure is regulated so that the purging occurs within a set period of time.

5163981

METHOD AND APPARATUS FOR CONTROLLING DISCHARGE OF POLLUTANTS FROM NATURAL GAS DEHYDRATORS

Michael S Choi assigned to Conoco Inc

A glycol dehydrator for removing water from produced natural gas includes a conduit for conveying uncondensed hydrocarbons from a reboiler overhead condenser to an auxiliary burner in the reboiler firetube by natural draft from the firetube flue stack.

5165902

METHOD AND APPARATUS FOR REDUCING NITROGEN DIOXIDE EMISSIONS IN A DRY SODIUM SCRUBBING PROCESS USING HUMIDIFICATION

Steven Bortz, John W Podlenski assigned to Research Cottrell Inc

A method and apparatus for reducing nitrogen dioxide (NO2) emissions in a dry sodium scrubbing process without significantly reducing sulfur dioxide (SO2) and nitrogen oxides (NOx) removal efficiencies. A sodium additive is injected into a flue gas duct carrying flue gas from a combustor to a particulate collection device to remove sulfur dioxide and nitrogen oxides from the flue gas. The flue gas is humidified by introducing water into the flue gas duct at a point upstream of the sodium additive introduction point. Through control of the moisture content of the flue gas and the temperature in the particulate collection device, the amount of NO2 emissions is reduced to a value below that which causes the creation of a brown plume emanating from the gas stack.

5168265

PERSONAL ELECTROMAGNETIC RADIATION MONITOR

Edward E Aslan assigned to Narda Microwave Corp

A personal electromagnetic radiation monitor includes an electromagnetic radiation sensor, a conductive shield spaced apart from the sensor and a backing of graduated lossy material. The electromagnetic radiation sensor includes thin film resistive thermocouples. The backing of graduated lossy material is interposed between the radiation sensor and the conductive shield. The layer is progressively more conductive through its thickness from the side which faces the sensor to the side which faces the conductive shield.

5170064

INFRARED-BASED GAS DETECTOR USING A CAVITY HAVING ELLIPTICAL REFLECTING SURFACE

Philip T Howe, Pinawa, Canada assigned to Atomic Energy of Canada Limited

A nondispersive gas analyzer for use in monitoring the concentration of one or more gases, comprises a body having a cavity having an elliptical reflecting surface, defining a first focus and a second focus, for transmitting radiation between the focuses, a chamber (2) for holding a sample gas to be analyzed, one of the focuses being located within the sample chamber, a chamber (4) for holding an inert gas and a chamber (3) for holding an analyte gas, a radiation source (24) disposed at one of the focuses, and a radiation detector (26, 27) associated with each of the inert and analyte gas chambers for detecting the radiation passing through the sample gas and the inert gas and the radiation passing through the sample gas and the analyte gas located at the other of the focuses.

5170702

BALING PRESS FOR MAKING HIGHLY COMPRESSED BOUND BALES OF WASTE MATERIAL

Hermann Schwelling, D 7777 Salem 2, Federal Republic Of Germany

A baling press for automatically and mechanically placing and binding one or more binding wires around highly compressed bales of waste material. The baling press includes for each binding plane a separate feeding station, cutting station and twisting station on the opposite side of the pressing shaft. The feeding elements are not mechanically or positively connected to each other. Rather, the feeding elements are all connected to the same pulse generator for carrying out the control of the feeding elements.

5171406

FLUIDIZED BED SELECTIVE PYROLYSIS OF COAL

Jer Y Shang, Chang Y Cha, Norman W Merriam assigned to Western Research Institute

The present invention discloses a process for the pyrolysis of coal which comprises the effective utilization of two zonal inclined fluidized beds, where said zones can be selectively controlled as to temperature and heating rate. The first zonal inclined fluidized bed serves as a dryer for crushed coal and additionally is controlled to selectively pyrolyze said coal producing substantially carbon dioxide for recycle use. The second zonal inclined fluidized bed further pyrolyzes the coal to gaseous, liquid and char products under controlled temperature and heating rate zones designed to economically integrate the product mix. The gas and liquid products are recovered from the gaseous effluent stream while the char which remains can be further treated or utilized in a subsequent process step.

5171446

POLLUTANT EMISSION CONTROL SYSTEM

Hsin-Der Shen, ,2 melaS 7777 D

A pollutant emission control system including a centrifugal separator having blades capable of causing sufficient centrifugal force to remove large pollutant particles, and a pressurized deposit container including an annular container with cleaning fluid serving as a vaporizing passageway, permitting gaseous pollutants to mix with a liquid cleaning agent by means of turbulence and Henry's law generated in said annual container with the result that polluted particles deposited in the cleaning liquid, and liquid membranes having a porous sponge body with a high density of pockets capable of further filtering the pollutant particles in the vaporized emission, and, finally a demisting device with a humidity/odor removing system having an activated carbon sponge bag used to further remove fine pollutant and odorous particles.

5171517

METHOD FOR MONITORING CORROSION ON A MEMBER IN A NUCLEAR REACTOR CORE

Harvey D Solomon, Gerald M Gordon assigned to General Electric Company

An apparatus and method for monitoring corrosion to members within the core of a nuclear reactor, particularly fuel rod cladding. A sensor means is submerged inside the core of a nuclear reactor near the member or fuel rods. The sensor means is comprised of a generally cylindrical section having an outer surface that is subject to corrosion and radiation, and has a cross-sectional area A1. The sensor means additionally has a reference section subjected to radiation but not to corrosion, and having a cross-sectional area A2. At least one pair of first probes, separated by a length L1, is placed in electrical contact with the cylindrical section. At least one pair of second probes separated by a length L2, is placed in electrical contact with the reference section. A current is passed throughout the sensor means to produce a potential gradient in the cylindrical section and reference section. The change in potential in the reference section, and the cylindrical section is measured and used to calculate the subsequent cross-sectional area in the cylindrical section between the first probes. Preferably, the cylindrical section and reference section are made from the same material as the member.

5171547

RECOVERY OF CHROMIUM IN HIGH PURITY STATE FROM WASTE MATERIALS OF ETCHING OPERATIONS

Ranko Crnojevich, Andrew B Case, Felix D Rando, John D Sweeney assigned to Amax Inc

The present invention is directed to a method for treating a sludge containing substantial amounts of chromium, aluminum, calcium, iron, and phosphorous. The method comprises forming a slurry of the sludge; reacting the slurry with an acid to dissolve substantially all the aluminum and chromium and provide a solids residue comprising mostly calcium sulfate; separating the chromium/aluminum-containing solution from the solids residue; raising the pH of the chromium/aluminum solution to precipitate chromium as chromium hydroxide; and separating the chromium hydroxide from the remaining aluminum-containing solution. The chromium hydroxide is then enriched with an alkali or earth alkali compound and calcined in an oxidizing atmosphere to convert the chromium to a chromate. The calcine is leached in an aqueous medium at a controlled pH to yield a high concentration, high purity chromate solution suitable for producing metallic chromium or a variety of chromium chemicals.

5171553

CATALYTIC DECOMPOSITION OF N2O

Yuejin Li, John N Armor assigned to Air Products and Chemicals Inc

The invention describes a highly efficient catalytic pollution control process for removing N2O from gaseous mixtures. The catalytic process, which is substantially unaffected by the presence of oxygen, comprises contacting an N2O-containing gaseous mixture with a catalyst comprising a crystalline zeolite which, at least in part, is composed of five membered rings having a structure type selected from the group consisting of BETA, MOR, MFI, MEL and FER wherein the crystalline zeolite has been at least partially ion-exchanged with a metal selected from the group consisting of copper, cobalt, rhodium, iridium, ruthenium and palladium under conditions sufficient to convert the N2O into gaseous nitrogen and gaseous oxygen.

5171694

METHOD FOR MONITORING AQUEOUS CARBON DIOXIDE

Dennis J Connolly assigned to The Babcock & Wilcox Company

An apparatus and method for the measurement of low levels of carbon dioxide in a sample employing membrane separation and ion-exchange technology. The difference in acid strength of carbonic acid and other acids is exploited by first treating the sample with a weak base in a membrane separator and then with a strong base in the membrane separator. In this manner, the carbonic acid is distinguished from the stronger acids. By converting carbonic acid to sodium carbonate, the conductivity level is enhanced facilitating more precise measurements.

5185007

SUCTION DRAINAGE INFECTION CONTROL SYSTEM

James F Middaugh, Peter Bryant, Richard W Grabenkort, Timothy Oswald, Edward S Tripp assigned to Abbott Laboratories

A suction drainage control system wherein waste-treating material is released into a sealed chamber. The chamber comprises of a cover with a flexible liner sealed to and suspended therefrom. A normally closed reservoir is provided on an underside of the cover for storing the waste-treating material therewithin as long as the reservoir remains closed. An externally operated actuator is provided on the cover for opening the reservoir to release the waste-treating material into the sealed chamber.

5185122

GAMMA RAY FLUX MEASUREMENT SYSTEM

Heinz F Poppendiek, John A Lundin assigned to Geoscience Ltd

Gamma radiation leaving the surface of a radioactive materials storage vessel is measured and monitored using a plurality of gamma ray absorbing calorimeters. The gamma ray energy absorbed is converted into heat and such heat is measured or indicated for the purpose of monitoring expected radioactive decay processes of the stored radioactive materials. Material leakage or removal from storage is detected and defined by deviations from the normal expected decay in gamma radiation. Such deviation or lack of deviation, as the case may be, provide the desired accountability of the radioactive materials. Since there can be several bands of gamma ray radiation, both flux and its energy level may be determined by using different gamma absorbing materials in the calorimeters selected for the known possible energy levels of the decaying radioactive material. From n simultaneous heat balance equations one for each calorimeter having a different absorbing material, it is possible to measure the energy level of the gamma radiation flux at each calorimeter.

5185129

OZONE MONITORS

Petros Koutrakis, Jack M Wolfson assigned to President and Fellows of Harvard College

An ozone monitor including an ozone reactive surface, held within a container, which is adapted to specifically react with ozone. The surface is also adapted to fail to react with nitrogen dioxide in an amount which affects ozone quantitation by more than 20% when the nitrogen dioxide is provided at a concentration of 76 ppb and ozone is provided at a concentration of 30 ppb within a test gas.

5185305

CATALYST SYSTEM FOR TREATING THE EXHAUST FROM A LEAN-BURN GASOLINE-FUELED ENGINE

Somasundaram Subramanian, Mohinder S Chattha assigned to Ford Motor Company

A catalyst system for converting NOx, CO, and HC contained in the exhaust gas from a gasoline-fueled engine controlled to operate under lean-burn conditions (R=0.03-0.9) such that the a ratio of NOx to HC in the exhaust gas in in the range of 1/3 to 3/1 (i.e., minimum C3H6 of 250 ppm and NOx of 200-400 ppm). The system comprises a first stage catalyst containing a transition metal-exchanged zeolite (i.e., Cu-

ZSM5), and a three-way catalyst for treating the effluent from said first stage catalyst. The second stage catalyst consists of a high surface area alumina support impregnated with an intimate mixture of 0.5-20% lanthana, 0.2-30% palladium, and advantageously an outer washcoat TiO2. A method of treating the exhaust gas from a fossil-fueled engine comprising operating the engine under lean-burn conditions while controlling the emission ratio of NOx/hydrocarbon to be in the range of 1/3 to 3/1; exposing the exhaust gas to a first stage catalyst comprising a copper ion-exchanged ZSM5 zeolite having at least 3% by weight copper; and exposing the effluent from said first stage catalyst to a second stage catalyst comprising an alumina support impregnated with an intimate mixture of 0.5-20% lanthana and 2-30% palladium.

5186146

COMBUSTION EVALUATION APPARATUS AND COMBUSTION CONTROLLER

Kenichi Sohma, Tugihir Yukitake, Shigeru Azuhata, Norio Arashi, Hiroatsu Tokuda, Nakamachi, Japan assigned to Hitachi Ltd

A combustion/evaluation apparatus having a sampling member for sampling light emitted from flame in an internal combustion engine, optical fibers for separating the light sampled by the sampling member into at least two lights, optical filters for selectively transmitting lights having different wavelengths by being provided in optical paths for the separated lights, photoelectric conversion elements for respectively converting optical signals transmitted through the optical filters into electrical signals, and a calculation/evaluation unit for calculating an air ratio and a temperature for evaluation of the combustion condition of the flame by using a ratio of outputs from the photoelectric conversion elements, and for evaluating the combustion condition on the basis of the air ratio and the temperature. Preferably, the air ratio is calculated based on the ratio of an electrical signal output from the photoelectric conversion element obtained from the optical signal from CH radicals and an electrical signal output from the photoelectric conversion element obtained from the optical signal from C2 radicals, and the temperature is calculated from the ratio of electrical signal outputs from said photoelectric conversion elements based on an optical signal obtained from thermal radiation having wavelengths including none of the wavelengths of an optical signal obtained from radical emission.

5190725

CHEMICAL TREATMENT OF AN INFECTIOUS WASTE

Robert S Meijer, John P Frain assigned to Winfield Industries

An infectious waste, a solid chlorite salt, a solid acid and a preheated aqueous solvent are mixed in a treatment volume. At least a portion of the chlorite salt and acid is dissolved in the preheated aqueous solvent incident to mixing and is reacted to form a treatment solution containing a chlorine dioxide disinfectant and a byproduct acid salt. The infectious waste is contacted with the chlorine dioxide in the treatment solution which attacks and destroys the infectious constituents of the waste, thereby decontaminating the waste. Upon dewatering, the decontaminated waste is suitable for landfilling. Process control is exercised by controlling the temperature of the aqueous solvent. A solvent temperature is selected which optimizes both the chlorine dioxide concentration in the treatment solution and the reactivity of the chlorine dioxide with the infectious constituents. Continuous monitoring of the chlorine dioxide concentration in the treatment solution enables adjustment of the solvent preheat temperature to optimal values in accordance with the dynamics of the treatment system.

5192667

METHOD FOR EVALUATING ANTI-FOULING PAINTS

Arthur V Stiffey assigned to The United States of America as represented by the Secretary of the Navy

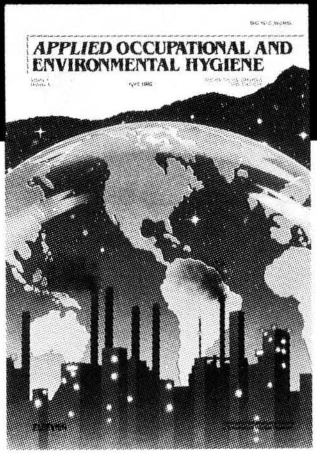
A method of evaluating marine paints for their ability to inhibit growth and attachment of organisms to ship bottoms, to find chemicals toxic to marine fouling organisms and to permit rapid formulation of superior anti-fouling paints, using a bioluminescent microbiological assay. The bottoms of test vials are coated with a paint solution, the paint dried, and identical aliquots of an assay medium containing Pyrocystis lunula cells are added to the tests vials and to identical (but unpainted) control vials. After a preselected settling time, the vials are agitated and their light outputs measured and compared. Any dimuition of light in the test vials, relative to the control vials, in an indication of the anti-fouling characteristics of the paints being tested.

5192865

ATMOSPHERIC PRESSURE AFTERGLOW IONIZATION SYSTEM AND METHOD OF USE, FOR MASS SPECTROMETER SAMPLE ANALYSIS SYSTEMS

Jianzhong Zhu assigned to Cetac Technologies Inc

An system and method for use for analyzing samples in mass spectrometers using afterglow metastable species at atmospheric pressure to controllably dissociate, fragment and ionize sample is disclosed. Metastable species are created at atmospheric pressure by application of adjustable intensity and/or frequency electrical energy in one portion of a modular electric discharge chamber, then are caused to interact with sample in a distally located portion of the electric discharge chamber, termed the afterglow portion, to produce ionized sample molecules and ionized sample fragments etc. The system and method can be used with any source of sample but a preferred embodiment utilizes an ultrasonic nebulizer to nebulize sample solutions, such as conventional liquid chromatography system effluents, into sample solution droplets, followed by desolvation thereof to provide nebulized sample particles, prior to sample entry to the afterglow portion of an electric discharge chamber. Ionization of sample occures as a result of interaction with energy released by relaxing metastable species. Operation at atmospheric pressure reduces operational, contamination and maintenance problems and allows easy introduction of sample in a liquid form.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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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