AIRBORNE LEVELS OF MINERAL FIBRES IN THE NON-OCCUPATIONAL ENVIRONMENT

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INTRODUCTION

A wide variety of potential sources of asbestos and other fibres exist that may contribute to non-occupational exposures. Table 1 lists some of the potential sources for asbestos. Virtually all currently manufactured products containing asbestos incorporate the fibre into a matrix from which release is difficult. However, during past years, the incorporation of asbestos into highly friable material provides current sources for exposure. The most important of these materials are in commercial and public buildings and, to a lesser extent, in private dwellings. The greatest potential for release of fibres from these materials occurs during building maintenance and renovation activities. To the extent that such activities are identified and procedures are established to prevent fibre release, non-occupational exposures can be minimized.

MEASUREMENT OF ENVIRONMENTAL ASBESTOS CONCENTRATIONS

Analytical techniques

Asbestos air concentrations encountered in buildings and in the general environment are virtually always below the limit of sensitivity of optical microscopy of from 0.001 to 0.01 fibres >5 um/ml. The ineffectiveness of optical

microscopy below this level results from the presence of non-asbestos inorganic or organic fibres that cannot be distinguished from the asbestos minerals with phase contrast or polarizing light microscopy. Concentrations below 0.01 f/ml may largely consist of such non-asbestos fibres. An exception to the limitation is the analysis of amosite fibres, where their size, density and configuration allow most non-asbestos fibres to be rejected from consideration, with a concomitant reduction in the limit of sensitivity. However, if confounding fibres, such as gypsum, are present, special precautions must be taken. Additionally, the practical resolution of the optical microscope precludes observation of fibres <0.3-0.4 um in diameter.

Recommended methods of analyses specify transmission electron microscopy to enumerate and size asbestos fibres (Samudra et al., 1977; Burdett, 1984; Yamate et al., 1984). Samples for such analysis are usually collected either on a Nuclepore^{R} (polycarbonate) filter with a pore size of 0.4 um or less or on a Millipore^{R} (cellulose ester) filter with a pore size of 0.8 um or less. Samples collected on Nuclepore^{R} filters are prepared for direct analysis by carbon coating the filter to entrap the collected particles. A segment of the coated filter is then mounted on an electron microscope grid, which is placed on a filter paper saturated with chloroform, the vapors of which dissolve the filter material. Special precautions must be exercised during and following sample collection to assure that fibres are not lost from the filter prior to reaching the analysis laboratory. The fibres on Millipore^{R} filters can also be directly transferred to electron microscope grids. In this case, an initial treatment with acetone vapors serves to partially collapse the filter. The filter is then partially etched in a low temperature asher to expose fibres within the filter matrix and coated with carbon to entrap the fibres as above (Burdett and Rood, 1983). After coating, the remainder of the filter is dissolved with acetone. Without the etching step, as much as 90% of the fibres on an 0.8 um filter can be lost in the dissolution process. The loss is greater for the thinner fibres and lower losses occur with smaller pore size filters.

An alternative to the above direct analyses is to prepare samples by ashing a portion of the filter in a low temperature oxygen furnace. This removes the membrane filter material and all organic material collected in the sample. The residue is recovered in a liquid phase, dispersed by ultrasonification, and filtered on an Nuclepore^{R} filter. Here, one can select the amount of material to be

filtered to achieve the desired material loading. The refiltered material is coated with carbon and mounted on a grid as above. Earlier electron microscopic analysis utilized a rub-out technique in which the ashed residue was dispersed by grinding in a nitrocellulose film on a microscope slide and a portion of the film was then mounted on an electron microscope grid for scanning (Nicholson and Pundsack, 1973). A disadvantage of the indirect method is that fibres are broken apart by the dispersal techniques with a concomitant increase in the number of smaller fibres. However, light ultrasonic treatment does not break apart most fibres >5 um (Sebastien, 1985). In contrast, physical grinding or prolonged ultrasonic treatment is likely to significantly alter the number of both the short and the long fibres. This, however, results in a more uniform distribution of the asbestos material allowing greater precision in the measured concentrations, but all information on size distribution is lost.

The grids prepared by either direct or indirect methods can be scanned at both high and low magnification to identify all asbestos fibres within the scanned area. Chrysotile asbestos is identified on the basis of its morphology in the electron microscope and amphiboles are identified by their selected area electron diffraction patterns, supplemented by energy-dispersive X-ray analysis. Both scanning and transmissions electron microscopic techniques can be utilized. However, SEM analysis usually identifies only fibres thicker than 0.2 um, because of contrast limitations, while TEM can visualize fibres of all sizes. Both SEM and TEM analysis can identify most fibres, particularly the larger ones, but the X-ray or electron diffraction patterns of some fibres may not be completely clear. Fibre concentrations in fibres per unit of volume are calculated based on sample volume and filter area counted. Mass concentrations are reported using fibre volume and density relationships. Mass concentrations can be converted into equivalent optical fibre concentrations using data from parallel analysis of samples by phase contrast microscopy and transmission electron microscopy. The approximate relationship is 3 nanograms/m^3 (ng/m^3) are equivalent to 0.1 f >5 um(optical)/ml. The uncertainty in this relationship, resulting from differing fibre size distributions, is about a factor of five (USEPA, 1986a).

A disadvantage of the direct transfer processes is the crucial requirements for filter loading. Too little material requires excessive scanning time or results in

low fibre counts of high statistical uncertainty; too much material results in obscuration of fibres by other debris and support film breakage during electron microscopic analysis. The obscuration effect can be substantial for both short and long fibres. Results of parallel analyses by Chatfield (1985a) using direct and indirect preparations indicated that in eight samples the mass was 12 times greater (geometric mean), the number of fibres of all sizes was 6 times greater (geometric mean) and the number of fibres greater than 5 um was 2.5 times greater (arithmetic mean) when indirect techniques were utilized. The increases in mass and the numbers of long and short fibres cannot be explained by fibre breakup, but are likely due to obscuration effects in the direct preparations.

Analytical Perspectives

Measurements of ambient air contaminants should satisfy two criteria for sensitivity. They should be able to measure the higher of: (1) typical ambient air concentrations or (2) levels commensurate with lifetime risks of the order of 10^{-6}. The latter criterion follows from the levels at which U. S. environmental regulatory agencies typically act to control exposures when the potential number of population cancer deaths/yr exceeds 1. Figure 1, adapted from Travis et al. (1987), shows the history of U. S. environmental regulatory action. Of 23 regulatory decisions by U. S. agencies (EPA, FDA, CPSC) where the population risk\yr exceeded 1, exposure reduction was mandated in 15. An additional five positive actions were taken for risks greater than those depicted in the figure. The eight circumstances considered for which regulation has not yet mandated were for exposures to formaldehyde, aflatoxin, saccharin and polycylic organic matter. Risks with fewer than 1 potential cancer death/yr in the U. S. population or where the individual risk was less than 10^{-6} were typically not regulated. In the case of asbestos, ambient background concentrations are of the order of 1 ng/m^3 or 0.1 f >5 um/l. Four estimates of lifetime risk from such exposures are shown in Table 2. As these are all well above an individual risk level of 10^{-6}, most even above 10^{-5}, any widespread source of population asbestos exposure is of regulatory concern. Thus, analytical procedures should be utilized that would, at least, quantify ambient background exposures equivalent to about 0.1 f >5 um/l. This places a substantial burden on the analyst. At typical loadings of 0.5 m^3 of air/cm^2 of filter, a concentration of 0.1 f/l yields an average deposition density of

1 f/200 grid squares. Since at least four fibres should be counted to establish a meaningful concentration value, the scanning requirements of counting fibres greater than 5 um at typical ambient air concentrations are overwhelming.

A problem with any of the ambient asbestos air measurement methods is that none of the variables used to measure asbestos concentrations corresponds to a measure of increased cancer risk. The least meaningful measure is the concentration of fibres of all sizes. In many circumstances such values reflect the presence of a vast number of tiny single chrysotile fibrils. Ubiquitous 1 um long-0.04 um diameter fibrils have substantially less carcinogenic potential than fibres ten times longer and thicker. Because all estimates of risk in the occupational circumstances are associated with measures of exposure in terms of fibres >5 um, the enumeration of such fibres is a useful component of any environmental asbestos evaluation. It should be recognized, however, that even perfect enumeration of fibres >5 um does not directly relate to carcinogenic risk. This is because the carcinogenicity of fibres varies according to length and diameter, the longer and thinner fibres being the more carcinogenic (see, e.g., Pott, 1980; Stanton et al., 1981). Further, there is no evidence that the carcinogenicity of fibres vanishes at the arbitrary counting cutoff value of 5 um. Because of their much greater number, fibres <5 um may be the dominant contributors to the cancer risk of a particular aerosol. Were all asbestos aerosols to have the same fibre size distribution, the different carcinogenic potentials of fibres of different sizes would not be important. A count all fibres >5 um would always count the same fraction of the asbestos present and the same fraction of carcinogenic potential. Unfortunately, fibre size distributions vary tremendously, even for aerosols of the same fibre type. Thus, there is a highly variable relationship to fibres <5 um and carcinogenic potential.

Evidence for a differing unit fibre exposure risk, part of which may be attributed to fibre size distribution effects, is seen in the lung cancer risk calculated from mortality and exposure data in 14 studies of asbestos exposed workers (USEPA, 1986a). Figure 2, which summarizes all studies for which dose-response information is available, depicts the percentage increase in carcinogenic risk for an exposure to one fibre (optical) per ml for one year. The horizontal bar is the best estimate of risk for a particular study. The wide vertical bar is

the uncertainty in the study associated with the number of lung cancer deaths and with epidemiological uncertainties in the data (effects of low tracing, e. g.). The thin narrow line is an additional two- to five-fold estimated uncertainty in the average measure of exposure for the study. As can be seen, the uncertainty of the risk estimated from the data of a single study is enormous, often exceeding an order of magnitude. There is no evidence that fibre type plays a particularly important role in these differences; the greatest differences are between exposures to the same fibre type. Exposures to virtually pure chrysotile aerosols differ as much as 30-fold (e. g., the studies of McDonald et al., 1980 vs. Dement et al., 1983). Differences as great as a factor of ten even exist between risk estimates from studies of the same process (e. g., Weill et al., 1979 vs. Finklestein, 1983).

The geometric mean risk from all studies, excepting chrysotile mining and milling, each weighted by the reciprocal of its estimated variance, is 1% per fibre year/ml of exposure. The calculated uncertainty in that value is a factor of three; the calculated uncertainty in the risk associated with an unmeasured exposure circumstance is a factor of ten. The extrapolation of these risks estimated from occupational circumstances to exposures two or more orders of magnitude less adds even greater uncertainties to any risk estimation process.

It is within the framework of these uncertainties that we must consider the various measurements of airborne levels of mineral fibres in the non-occupational environment. Fibre concentrations must be interpreted cautiously and meaningful measures of concentrations in terms of fibres >5 um at ambient airlevels are extremely difficult to obtain. Mass measurements, while suffering the loss of important information on fibre size, may relate best to carcinogenic risk. Mass certainly better accounts for the length dependence of carcinogenic risk than any fibre count. For the fibres >8 um it also accounts well for carcinogenic risk according to diameter (Bertrand and Pezerat, 1980; see also paper by Peto, this conference). Ideally, of course, the best measurement of fibre aerosols is one in which every fibre is identified and sized, allowing any of the various measures of exposure to be utilized. It remains to be seen whether this can be achieved on a practical basis. These various analytical considerations are summarized in Table 3.

GENERAL AMBIENT AIR

Asbestos of the chrysotile variety has been found to be a ubiquitous contaminant of ambient air. Table 4 lists fibre concentration data from a variety of studies involving the measurement of urban and rural air from 1969 through 1986. As can be seen, arithmetic mean air concentrations were of the order of 1-3 ng/m^3 in 1970, a period where asbestos was extensively used in construction, including relatively uncontrolled spray applications for fire-proofing purposes in the United States. During daytime hours, shorter term sampling indicated higher levels to be present than in 24-hr samples. Greater uncertainty exists with earlier data because analysis techniques were under development and control of asbestos contamination in laboratory processing was less stringent than now. In recent years there has not been a systematic study of asbestos in the urban air. However, virtually all studies of outside air taken in conjunction with studies of building air show mean concentrations to be less than 1 ng/m^3. Because of the above mentioned limitations on the counting of fibres >5 um, most such measurements have only provided upper limits of exposure. (See, however, Rodelsberger (this conference).)

Few data exist on the fibre size distribution of asbestos in the general ambient air. From ratios of f >5 um to total fibres, it would appear to be similar to that of chrysotile size distributions in occupational enviornments. There, the percentage of fibres >5 um is between 5 and 0.5% (Nicholson et al., 1972; Gibbs and Huang, 1980). Data from Kohyama (this conference) indicate that 2% of fibres in the ambient air of Japan are >5 um in length.

BUILDINGS WITH ASBESTOS-CONTAINING SURFACING MATERIALS

Considerable data have accumulated in recent years on the air concentrations of asbestos fibres associated with the use of asbestos-containing surfacing materials. The data, however, represent information from a moving target. Prior to the early 1970's both the hazard and the extent of use of asbestos in buildings

was not fully appreciated. Conditions in some buildings deteriorated to a point that was unacceptable by anyone's standards and extremely high air concentrations occurred. For example, phase contrast microscopic measurements in excess of 10 f/ml were measured for short periods of time in a school library during book replacement as a result of inadvertent contact with ceiling material (Sawyer, 1977). Increasing awareness and concern of the public for the presence of asbestos in buildings led to elimination of the worst of exposure circumstances and contamination was noted less frequently.

A variety of studies, using transmission electron microscopy, were undertaken to evaluate the quality of air in several different building circumstances. Results from these studies are listed in Table 5. Different methods of analysis were used by different investigators, but the circumstances sampled and the condition of sampling were likely to be a far more important factor than differences in analytical methods in the results that were obtained. Most of the earlier studied focused on the potentially more severe exposure circumstances and, thus, were not representative of all building circumstances. Other studies also chose buildings for sampling by non-random criteria and, similarly, do not provide a representative sample of all buildings. Overall, the studies present a reasonably consistent picture. In buildings with evidence of severe damage or deterioration, the probability of detecting contamination was high. On the other hand, if the surfacing material or thermal insulation was undamaged, has only minor damage or the surface was sealed to prevent dusting, excess air concentrations were rarely detected.

Nicholson et al., 1975; 1976

Nicholson et al. analyzed 116 samples of indoor and outdoor air collected in and about 19 commercial and public buildings in five U. S. cities. The buildings studied were chosen by local or federal air pollution control agencies on the basis of ease of access, either as a government building or through a willing building owner. On the one hand, the choice was not random, but neither was any building selected because of a perceived hazard. After collection, the samples were coded by the EPA and analyzed with no knowledge of the sites from which they were collected. The results provided no evidence of contamination of buildings with

cementitious or plaster-like surfacing material, but the air concentrations in some buildings with surfacing material composed of a loosely bonded mat were in excess of control samples and samples collected in buildings with cementitious/plaster material. In this set of samples, and that below, open face filters were utilized. The possiblity that some non-respirable asbestos material contributed to the mass cannot be excluded.

Nicholson et al., 1978; 1979

Twenty-five samples were collected in primary and secondary schools. The sampling was conducted to reflect the general ambient background of schools with substantially damaged surfacing material. Observation of the sample collection was done to assure that the material collected did not reflect an episodic release of fibres near the sampler. However, schools were in operation during the sampling and normal student activity (except for vandalism) took place over the course of sampling. Two short term samples of custodial sweeping showed even higher concentrations than those listed, but were uncertain because of low sample volume.

Sebastien et al., 1980

Sebastien published data from samples collected in 25 buildings in Paris. Over half the samples were collected in one large school building containing sprayed material with both amphibole and chrysotile fibres. Substantial damage was reported to have occurred in many of the buildings sampled, including areas of the school building from which most samples were taken. In some cases visible dust was reported on tables and other building furniture. As with the Nicholson school study, the buildings were not selected randomly, but were those brought to the attention of the researchers through written inquiries for help by building owners or occupants.

USEPA, 1983

A sampling of 25 schools, chosen by a random procedure from those in a large city, was reported by the U. S. Environmental Protection Agency. The results of the survey indicated a substantially increased air concentration (a

population weighted mean concentration of 179 ng/m^3) in building areas with sprayed surfacing materials. Thirty-one outside samples averaged 6 ng/m^3. Of special concern were samples collected in schools that had asbestos material present, but not on the floor or in the room in which the samples were taken. These data showed an average concentration of 53 ng/m^3, indicating dispersal of fibres from the source. Additionally, numerous small respirable clumps and bundles of asbestos were noted, but not included in the listed mass concentrations. One concern with this study, which indicates concentrations as high as those that were measured in buildings selected because of the presence of extensive damage, is that the sample taking was not routinely monitored. In some cases the samples, which were collected over a 5 day period, were in classrooms under the control of the teacher; in other cases they were in corridors with no continuous observation of sampling conditions. The possibility of atypical activities occurring during sampling cannot be excluded.

Ontario Royal Commission, 1984

A report of 63 samples taken in 19 buildings was reported by The Royal Commission of Matters of Health and Safety Arising from the Use of Asbestos in Ontario. All of the buildings selected had asbestos surfacing material. However, qualitative exposure evaluation (algorithms) indicated minimal problems in all but six buildings. A major problem with this study is that of analytical sensitivity. The count of a single fibre would appear to correspond to a concentration of 1 f/l. Thus, the analytical sensitivity (the concentration at which four fibres would be counted) is at a concentration forty times above that of typical ambient air. In only five buildings were asbestos fibres >5 um detected, but in those, concentrations substantially exceeded typical background (where few fibres of any length were detected). There was a poor correlation of either mass or fibre levels with algorithm estimates of hazard.

Chatfield, 1985b

Chatfield has reported on concentrations measured in eight Ontario office and school buildings. Concentrations ranged from undetectable levels to 17 ng/m^3. The average of all samples but two was 1.1 ng/m^3. Those two samples had

concentrations of 640 and 360 ng/m^3, the mass (360 ng) in one case being contributed by one fibre. Fibre counts > 5 um were severely limited by the analytical sensitivity of the counting protocol. In 57 samples only 12 such fibres were observed, 6 in one sample. The statistical significance of either the mass or >5 um fibre concentration is difficult to assess.

Burdett and Jaffrey, 1986

Sampling results from 15 commercial, school or domestic buildings in Great Britain indicated relatively low fibre concentrations. The analytical sensitivity of the protocol for the average of a sample test (up to 26 samples for an individual building) ranged from 1 f > 5 um/l (2 building sample sets) to 0.1 f >5 um/l (3 building sample sets). The analytical sensitivity of most sample sets was about 0.3 f >5 um/l; the analytical sensitivity of a typical single sample, however, was only 2-3 f > um/l or 20-30 times typical ambient air. Detectable results (an average of more than four fibres counted) were observed in four of the 15 buildings. The highest measured concentration was in a school with "some damage" to sealed spray material; asbestos fibre concentrations ranged from <35 to 250 f all sizes/l and from <3 to 12 f >.5 um/l (avg. = 2 f/l), levels substantially above background. Average mass concentrations in the buildings were generally <0.1 ng/m^3; the highest average concentration measured was 15 ng/m^3. However, as direct preparation techniques were utilized, one must note the possibility of fibre obscuration.

Building maintenance activities

In addition to the above measure of building air during undisturbed conditions, measurements indicate that routine maintenance activities can be a substantial source of short term building air contamination, if done without taking proper precautions. Among the groups reporting on such activities, the Royal Commission reported increased air levels from inspections above suspended ceilings and maintenance work therein. In one case the exposure to a worker above the ceiling was 12 f >5 um/ml. Earlier, Sawyer (1977) had reported optical fibre counts during routine building maintenance of from 0.2 f/ml to 17.1 f/ml.

Thermal insulation materials are also readily damaged during the course of maintenance or repair of high temperature equipment or during the course of building activities. In many circumstances these materials are located in other than the public use areas of buildings. However, debris can be tracked from these areas into public areas by maintenance personnel if proper precautions are not taken.

Asbestos abatement activities

One serious potential source of non-occupational asbestos exposure, is fibres released during asbestos abatement work. While procedures have been specified that should minimize building contamination following renovation, removal, enclosure or encapsulation of asbestos materials, these may not always be followed (see e. g. Burdett, this conference). The U. S. Environmental Protection Agency has monitored the efficacy of controls and cleanup procedures in four schools under taking removal of asbestos materials and in one school encapsulating surfacing material. The results are shown in Table 6. As can be seen, no measureable contamination was present in the schools after completion of the work. In the case of removal, some escape of fibres during removal work occurred, but it was successfully cleaned up.

THE USE OF AIR MONITORING FOR HAZARD EVALUATION

The principle source of asbestos contamination in virtually all buildings is the active or inadvertent dislodgement of the material by building occupants during the course of their use of the building or by maintenance activities undertaken by building personnel. Control of the former is often difficult and where damage caused by building users is common the only recourse may be removal of the material or enclosure by other building products to preclude potential for future damage. In contrast to surfacing material, where control of damage may be difficult, the ability to control thermal insulation is much greater. Encapsulation of pipe covering by appropriate covering material and establishment of an appropriate building maintenance program will go far to eliminate exposures to

building occupants and maintenance personnel. The extent to which the various abatement options are utilized in a building would of course depend on the potential for continued fibre release and for appropriate control. Future building use and the frequency of renovation work also play important roles in any decision to remove or treat asbestos materials in a building.

Air monitoring is generally not a satisfactory means of evaluating whether a specific control activity should be adopted. It only samples a point in time and usually the circumstances are artificial. Absence of fibre contamination when no building activity is taking place does not provide any information on what may occur in the future. Further, to accurately establish an average level for a building, from which one might make a highly uncertain risk assessment, would involve such extensive sampling that it would be totally impractical. One generally must undertake abatement activities based upon the observed conditions and building circumstances rather than air monitoring.

One important fact is that one cannot generalize to all buildings from measurements made in buildings selected according to various criteria for sampling. Buildings with intact asbestos provide no information on the hazard in buildings that are severely damaged. The fact that most buildings have material in good condition, with little evidence of release, does not mean that one should not act to control emissions in buildings with severe problems. Thus, average building air concentrations cannot be used to justify non-action in a particular building. It is well to keep in mind that many people have drowned in rivers having an average depth of one foot. The converse is also true. The finding of substantially elevated concentrations in some building with severe problems does not indicate the likelihood of fibre release in other buildings with quite different materials and condition.

OTHER BUILDING MATERIALS

Weathering of asbestos cement wall and roofing materials was shown to a be source of asbestos air pollution (Nicholson, 1978). Seven samples taken in a school constructed of asbestos cement panels after a heavy rainfall showed asbestos concentrations from 20-4500 ng/m^3 (arithmetic mean = 780 ng/m^3); all but two

samples exceeded 100 ng/m^3. The source was attributed to asbestos released from the asbestos cement walkways and asbestos cement roof panels which was entrained into the school air after dry conditions obtained. No significantly elevated concentrations were observed in a concurrent study of houses constructed of similar material. Here roof water runoff landed on the ground and was not reentrained, while that of the schools fell to a smooth walkway allowing easy reentrainment when dry. Contamination from asbestos cement siding has also been documented by Spurny et al. (1980).

Air contamination from fibres released from wearing of vinyl asbestos tile has been reported by Sebastien et al. (1982). They measured concentrations of asbestos up to 170 ng/m^3 in a building with worn asbestos floor tiles.

PRIVATE DWELLINGS

Asbestos is commonly found in a wide variety of products in the home environment. Most notably among the potential sources of airborne asbestos are thermal insulation products on boilers and high temperature water lines, insulation material in various space heaters; textured paints, old wallboard and joint compounds, and air supply duct materials. Additionally a variety of household products in past years has been found to contain asbestos materials. Depending on the region these may continue to be produced and include appliances such as hair dryers, toasters, electrical cords, and portable heaters. Vinyl asbestos floor tile is commonly used in homes. However, the potential for release in home circumstances is very limited unless the tile is sanded or physically abraded during home renovations. Of greater concern is subflooring materials containing asbestos. Generally, release of asbestos fibres from such architectural materials is limited; however, during building alterations, either by the owner or outside contractors, contamination may occur.

Burdett has measured air concentrations in 24 buildings, mostly private houses, having warm air heaters containing asbestos. All but three buildings had

concentrations less than the analytical sensitivity of the counting protocol (1 f >5 - um/l). In two buildings average concentrations of 1 f >5 um/l were measured.

Nicholson (1987) undertook measurements of asbestos air concentrations in homes using asbestos paper air ducts for air conditioning systems. Most of the homes also had chrysotile-containing textured paint in all living areas. The results of this sampling are shown in Table 7. There was no statistical difference between air concentrations in homes with asbestos-paint and those without nor between samples collected during operation of the air conditioning system and those taken with it off. However, there was a significant difference between the concentrations of all indoor samples and those taken outdoors for control purposes. The difference is small and would not warrant any current abatement action. However, a problem exists in that homeowners unaware of asbestos content may disturb the painted surfaces during renovations.

FRICTION MATERIAL DEGRADATION

One of the more significant remaining sources of environmental asbestos exposure may be emissions from braking of automobiles and other vehicles. Measurements of brake and clutch emissions in the U. S. reveal that, annually, 2.5 tons of unaltered asbestos are released to the atmosphere and an additional 68 tons fall to roadways, where some of the asbestos is dispersed by passing traffic (Jacko et al., 1973). Air concentrations from such releases, however, were not measured by Jacko et al.

Substantially elevated chrysotile asbestos concentrations have been found in subway systems, the cars of which used chrysotile pads in brake systems. Analyses of samples collected during 1976 in the Toronto subway indicated concentrations up to 2.7 fibres of all sizes per ml and, with one exception (a value of 20,000 ng/m^3), mass concentrations up to 2500 ng/m^3 (Chatfield, 1983). Lower values were found in a 1980 survey and attributed to the use of direct analysis techniques. A 1981 study of the Stockholm subway found concentrations of from 0.10 to 0.12 f >5 um/ml and mass concentrations from 170-430 ng/m^3.

The data on the contribution of automobile braking to ambient air asbestos concentrations are extremely limited. Lanting and den Boeft (1983) reported concentrations in a traffic tunnel to be approximately ten times those of urban air (5 f >5 um/l vs. approx. 0.7 f/l for urban air). They suggested vehicle braking as the source of the excess. An earlier report by Alste et al. indicated concentrations at a freeway exit averaged 0.5 f(all sizes)/ml over nine hour sampling periods, much higher than at a distant site. Williams and Muhlbaier (1982) measured asbestos emissions from braking in a test dynamometer and estimated that normal driving releases 2.6 ug of airborne asbestos per km of travel. Using the ratio of this value to total lead emissions/km and measured ambient lead levels, they estimated the contribution of automobile braking to be 0.063 ng/m^3. This procedure is likely to underestimate the effect of braking as a significant fraction of the emitted lead will rapidly settle to the ground, while the emitted asbestos will tend to remain aloft. It remains possible that the major contribution to the ambient air of cities is from automobile braking, but data are lacking to support or refute this possibility. Data supporting this possibility are presented by Kohyama (this conference).

OTHER FIBRE EXPOSURES

Man-made and other mineral fibres have largely replaced the asbestos minerals in products where their potential release is high as in thermal insulation or surfacing materials. Fortunately, most man-made mineral fibres are of a non-respirable diameter. Thus, the use of such fibres carries a much lesser risk than the use of asbestos minerals. However, in the absence of regulation, the use of other naturally occurring fibrous minerals in increasing rapidly. Some of these, as well as some man-made mineral fibres, are of the same size and durability as asbestos and may present equal health risks.

Ambient air concentrations

There are very limited data on the presence of non-asbestos inorganic fibres in the general environment. They are noted by analysts as present, usually in

numbers exceeding asbestos, but not quantified. Gypsum fibres are commonly present in the air of buildings during renovation; special procedures can remove their confounding effect from air samples (Burdette, 1985). Friedrichs et al. (1983) have quantified the presence of other fibres in ambient air samples in West Germany. Table 8 lists their results in terms of fibres of all sizes. As can be seen, the concentrations of fibres of the three listed non-asbestos minerals were less than the chrysotile and amphibole concentrations, but large numbers of other fibres were not identified. Altree-William and Preston analyzed 193 samples using a scanning electron microscope and found average concentrations of 0.32, 1.47 and 5.10 f(all sizes)/l, respectively, for asbestos, other minerals and organic fibres. Spurney and Stober identified mineral fibres in West German urban and rural air. Total fibre concentrations ranged from 4-15 f/l, less than 6% of which were asbestos fibres. The percentage fibre distribution are some aspects of anlaysis of single fibres shown in Table 9.

Source related

Fibrous glass materials are common constituents of thermal and acoustic insulation materials. Balzer et al. (1976) sampled building and outside air to evaluate if erosion occurred from fibrous glass lined ducts. Their data indicated concentrations of glass fibres in the ambient air to range from 0.26 to 4.5 f/l and concentrations of other fibres to range from 1.5 to 3.3 f/l. The fibres enumerated were those thicker than 1.6 um and longer the 4.8 um (glass fibres of these dimensions were distinguishable in a petrographic microscope). They suggested that their study indicated a significant reduction in such fibres after passage through a standard building air filter and after passage down a fibrous glass lined duct. However, the data supporting this conclusion were scant and not subject to verification by statistical analysis. See presentation by Gaudichet et al. (this conference) for extensive data on man-made mineral fibre air pollution.

A variety of non-asbestos minerals are used at an increasing rate as replacements for asbestos. Most important among these are attapulgite and wollastonite. The fibres of attapulgite are generally less than 5 um in length. They are used in drilling muds, "kitty litter" adsorbents, filters and as fillers in pesticides, fertilizers, paints and spackles, pharmaceuticals and cosmetics. To the

extent these uses are uncontrolled, environmental contamination may occur. Particular concern exists with the use as pet waste adsorbents. However, no air level data are available. Wollastonite occurs as long thin fibres and is also used as a filler or as a reinforcing fibre in insulation and wall board. Mine and mill concentrations of, respectively, 1 and 20 f/ml have been reported, but no data exist for non-occupational exposures.

SUMMARY

Numerous sources of asbestos exist that may contribute to non-occupational exposures. Important among these is the potential for exposure from damage and deterioration of building surfacing materials. Even more important is the potential exposure from improperly controlled maintenance activities in buildings. Evidence exists suggesting a significant contribution of vehicle braking to ambient asbestos levels, but more substantive data are required to establish its extent. Many asbestos materials are present in homes and fibres may be released during home renovations or repairs. Little information exists on the levels of other mineral fibres in the non-occupational environment or on the relative contribution from potential sources.

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Table 1

POTENTIAL SOURCES OF ASBESTOS IN THE NON-OCCUPATIONAL ENVIRONMENT

I. Industrial activity
- Mine, mill and factory operations
- Building renovation and demolition

II. Building operations
- Inadvertant damage or detioration of asbestos materials
  - Surfacing materials
  - Thermal insulation
  - Cement products
- Maintenance activities

III. Vehicle braking
- Automobiles
- Subway cars

IV. Home materials
- Heating systems
- Air supply systems
- Appliances
- Wallboard, spackle, textured paint

Table 2

LIFETIME RISKS OF DEATH/100,000 FROM MESOTHELIOMA AND LUNG CANCER FROM A CONTINUOUS LIFETIME EXPOSURE TO 0.1 F/L

Risk estimation	Lifetime risk
U. S. Consumer Product Safety Commission (1983)	2.3-3.4
Doll and Peto (1985)	appx. 0.6 (males)
U. S. Environmental Protection Agency (1986)	2.4-4.2
U. S. National Academy of Sciences (Breslow et al., 1986)	4.2-11.2

Table 3

ADVANTAGES AND DISADVANTAGES OF PREPARATION AND COUNTING METHODS

	ADVANTAGES	DISADVANTAGES
	PREPARATION METHODS	
Direct method	Fibre size maintained	Some fibres obscured Sampling conditions may be critical Possible fibre loss
Indirect method	No obscuration of fibres Losses less likely Sampling conditions less stringent	Information on fibre size distribution lost
	TEM versus SEM	
SEM	Preparation techniques less critical Scanning time less per area scanned	No standard methodology available Only fibres thicker than 0.2 um usually counted
TEM	Fibres of all sizes can be counted Standard methodologies available	Extremely long scanning times may be required Sample preparation critical
	COUNTING METHODS	
All fibres	None	Small fibres overwhelm count Relates least to biological hazard Variable counts according to instrument resolution Time consuming
Fibres >5 um	Relates best to optical counts	Problems with low counts Does not consider clusters or fibre bundles
Mass	Preparation techniques are less stringent May relate best to carcinogenic risk	Mass may be dominated by a few fibres or clusters Difficult to relate to optical counts

Table 4

SUMMARY OF AMBIENT AIR ASBESTOS CONCENTRATIONS

Sample set	Collection period	Number of samples	Arithmetic average conc. (ng/m^3)	f >5 um/l
Quarterly composites of 5 to 7 24-hour U.S. samples (Nichloson, 1971; Nicholson and Pundsack, 1973)	169-70	187	3.3 C[a]	
Quarterly composites of 5 to 7 24-hour U.S. samples (U.S. EPA, 1974)	1969-70	127	3.4 C	
16-hour samples of 5 U.S. cities (U.S. EPA, 1974)	1974	34	13 C	
5-day samples of Paris, France (Sebastien et al., 1980)	1974-75	161	0.96 C	
5-day, 7-hour control samples for U.S. school study (Constant et al., 1983)	1980-81	31	6.5 (6C, 0.5A[a])	
12-hour samples in Toronto, Ontario (Chatfield, 1983)	1980-81	24	0.83[b]	c
12-hour samples in Southern Ontario (Chatfield, 1983)	1980-81	48	0.20[b]	c
UK Urban and rural background (Le Guen et al., 1983)	1979-81	8	<1-5	-
Long term samples in 3 West German cities (Friedrichs et al., 1983)	1982	6	-	2.8 C[b], 2.6A[b]
Urban Switzerland (Litistorf et al., 1985)	1977	10	0.74	0.4
Rural Switzerland (Litistorf et al., 1987)	1981-83	10	0.23	c
Rural Austria (Felbermayer, 1983)	1978-1980	143		≤0.1

a. C, chrysotile; A, amphibole
b. exceptionally high sample contributed all the mass
c. less than a detection limit of approximately 4 f/l
d. fibres of all sizes

Table 5

SUMMARY OF AMBIENT AIR ASBESTOS IN BUILDINGS

Sample set	Collection period	Number of samples	Arithmetic average conc. (ng/m^3)	f >5 um/l
U.S. buildings with friable asbestos in plenums or as surfacing materials (Nicholson et al., 1975, 1976)	1974	54	48 C	
U.S. buildings with cementious asbestos material in plenums or as surfacing materials (Nicholson et al., 1975, 1976)	1974	28	15 C	
New Jersey schools with damaged asbestos surfacing materials in pupil use areas (Nicholson et al., 1978)	1977	27	217 C	
Buildings with asbestos materials in Paris, France (Sebastien et al., 1980)	1976-77	135	35 (25C, 10A)	
U.S. school rooms/areas with asbestos surfacing material (Constant, 1983)	1980-81	54	183 (179C, 4A)	
U.S. school rooms/areas in building with asbestos surfacing material (Constant, 1983)	1980-81	31	61 (53C, 8A)	
Ontario buildings with asbestos surfacing materials (Ontario Royal Commission, 1984)	1982	63	2.1	a
Ontario office and school buildings (Chatfield, 1985)	1977-82	55	1.1[b]	a,c
U.K. schools, laboratories and factories (Burdett and Jaffrey, 1986)	1983-85	114	1.5	<0.1-2[d]

C, chrysotile; A, amphibole

a. Less than a detection limit of approximately 4 f/l.

b. Two additional samples had concentrations of 640 and 360 ng/m^3. The 360 ng/m^3 was from a single fibre.

c. One sample had a concentration of 20 f/l. All others were less than the detection limit of approximately 4 f/l.

d. Most sample sets had average concentrations less than a detection limit of 0.3 f/l.

Table 6

GEOMETRIC MEAN OF CHRYSOTILE FIBRE AND MASS CONCENTRATIONS BEFORE, DURING AND AFTER ASBESTOS ABATEMENT

	Concentrations							
	Before abatement		During abatement[a]		Immediately after abatement		After school resumed	
	f/l[b]	ng/m^3	f/l	ng/m^3	f/l	ng/m^3	f/l	ng/m^3
Encapsulation								
Rooms with unpainted asbestos	1423.6	6.7	117.2	0.6	13.7	0.1	248.1	1.2
Rooms with painted asbestos	622.9	2.7	-	-	0.8	0.0	187.2	0.8
Asbestos free rooms	250.6	1.2	0.5	0.0	9.3	0.0	30.7	0.2
Outdoors	3.5	0.0	0.0	0.0	6.5	0.0	2.8	0.0
Removal								
Rooms with asbestos	31.2	0.2	1736.0	14.4	5.6	0.1	23.9	0.2
Asbestos free rooms	6.1	0.1	12.0	0.1	1.6	0.0	18.1	0.1
Outdoors	12.6	0.1	1.3	0.0	20.0	0.1	7.9	0.0

[a] measurements outside work containment areas
[b] fibres of all lengths

From: EPA (1985-1986a)

Table 7

ASBESTOS CONCENTRATIONS IN
HOMES CONTAINING ASBESTOS PRODUCTS

Sampling circumstance	No. of samples	Asbestos concentration (ng/m^3)
	Asbestos in textured paint	
A/C fans off	12	6.1 (2.0-12.7)
A/C fans on	12	2.9 (0.0-11.0)
Average		4.5
	No asbestos in textured paint	
A/C fans off	3	4.5 (3.9-5.4)
A/C fans on	3	2.2 (0.4-3.8)
Average		3.3
Outside air	7	0.9 (0.0-4.3)

A/C, air conditioning
( ) range

Table 8

CONCENTRATIONS OF FIBRES OF ALL SIZES MEASURED IN THREE WEST GERMAN CITIES DURING 1982

City	Air concentrations (f/m^3) Chrysotile	Amphibole	Rutile	Fe-oxide	Glass	Total	
Dusseldorf	2320	1350	330	630	660	24160	
Dortmund	2600	2390	-	630	2490	31800	Monday-Friday
Duisburg	1980	2610	440	480	1410	35970	
Dusseldorf	750	720	-	700	360	16510	
Dortmund	3320	1780	510	760	1270	23490	Friday-Monday
Duisburg	5740	6890	1460	610	1220	24070	
Averages	2790	2620	460	640	1230	26000	

From: Friedrichs et al. (1983)

Table 9

PERCENTAGES OF VARIOUS MINERAL FIBRES IN WEST GERMAN URBAN AND RURAL AIR

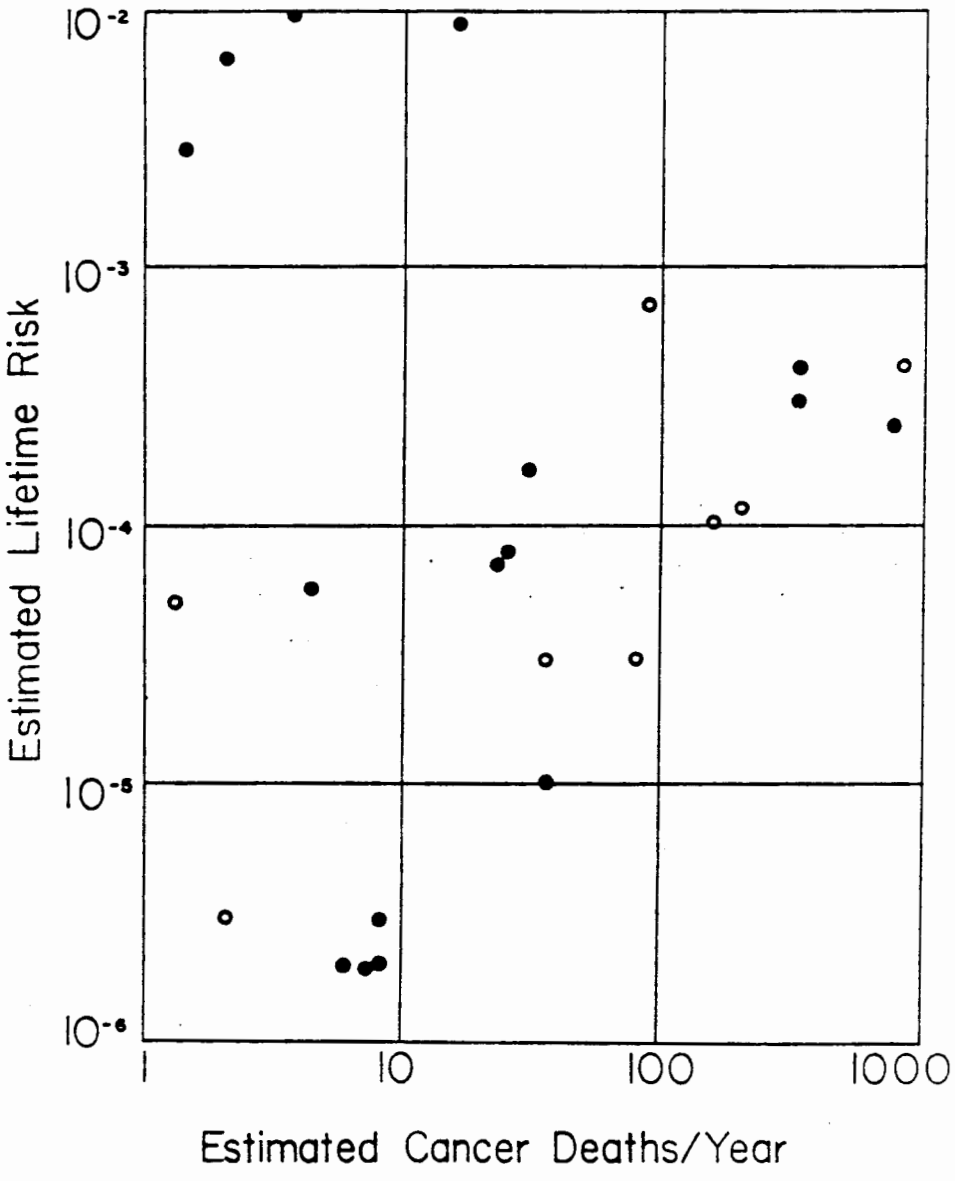
Fibre type	Evaluated samples (% of fibres) A	B	C	D	E
Potential non-contaminated asbestos fibres	1.02	0.82	1.94	0.52	-
Potential contaminated asbestos fibres	1.51	1.22	6.80	1.04	0.41
Potential asbestos fibres leached of Mg or Fe	1.02	0.82	5.83	0.52	0.41
Other fibrous silicates	2.54	1.22	9.71	1.04	-
Fibrous gypsum	24.37	38.36	46.60	53.88	27.06
Contaminated fibrous gypsum	15.74	20.40	2.91	3.11	1.22
Fibrous ammonium sulfate	48.22	3.66	0.16	15.02	30.74
Unidentified fibre-like particles	5.58	33.50	26.05	24.87	40.16

From: Spurney and Stober (1981)

FIGURE CAPTIONS

Figure 1: Regulatory action according to individual and population risk for lifetime exposure to various environmental agents. ● regulatory action taken; o regulatory action not taken or deferred. Data from Travis et al. (1987).

Figure 2: The percentage increase in lung cancer per f-y/ml of exposure in 14 asbestos exposed cohorts. The open bar reflects the estimated 95% confidence limits associated with measures of response. The line represents the uncertainties associated with measures of exposure, generally $\pm$ a factor of two.


10^{-2}
10^{-3}
10^{-4}
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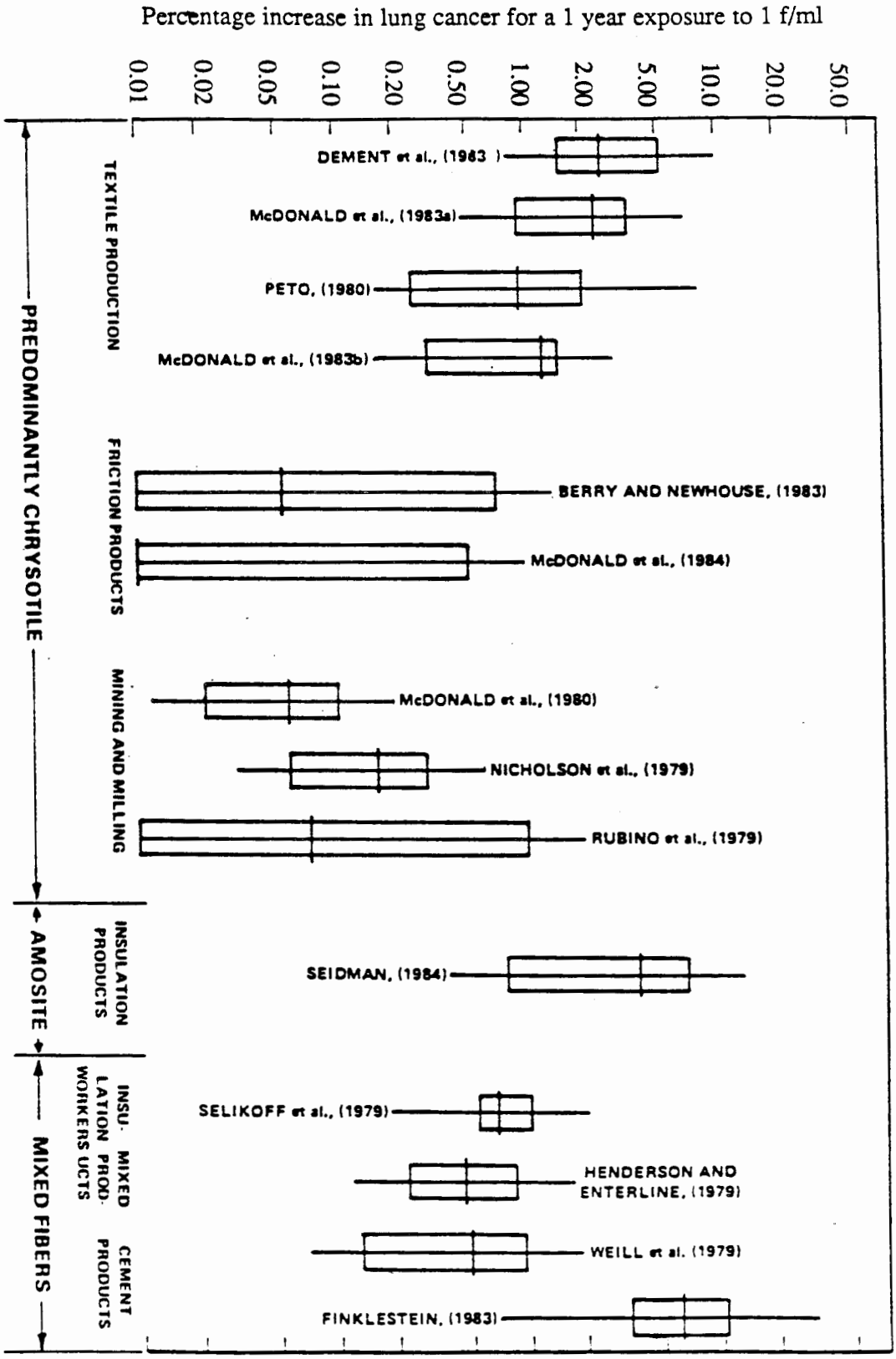
10^{-6}
Estimated Lifetime Risk
1
10
100
1000
Estimated Cancer Deaths/Year



Epidemiological study and predominant exposure