PART C - PUBLIC COMMENTS AND RESPONSES

Prepared by the Staff of the Air Resources Board and
the Department of Health Services

February 1986

PART C - PUBLIC COMMENTS AND RESPONSES

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I. County of Siskiyou Air Pollution Control District

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County of Siskiyou

AIR POLLUTION CONTROL DISTRICT

COUNTY AIR POLLUTION CONTROL BOARD:
(BOARD OF SUPERVISORS, EX-OFFICIO)

AIR POLLUTION SPECIALIST
KENNETH L. CORBIN

October 7, 1985

William Loscutoff, Chief
Toxics Pollutants Branch
Attn: Asbestos
Air Resources Board
P. O. Box 2815
Sacramento, Ca. 95812

Dear Mr. Loscutoff:

In reviewing the draft report to the Scientific Review Panel on Asbestos (Dec. #2296W/Arch.109W-7-01-85, Part A), I noted no mention of the quarry in Siskiyou-Trinity Counties or of the surfacing of unpaved roads in this area. Enclosed is a newspaper article which describes a recent road project utilizing serpentine materials. No doubt there are other projects we are not aware of.

Sincerely,

EDMOND W. HALE
AGRICULTURAL COMMISSIONER

Kenneth L. Corbin

Kenneth L. Corbin
Air Pollution Control Specialist

KLC:jh

Enclosure

001

ogramming. Her husband, Fred, was strumental in bringing the service via enhancor to the Valley in the mid-1970s. he original intent was to have ucational TV available for school assrooms, however the station reached any private residents.

"I would've loved to vote against it, t I don't know if it was a justified use school funds," said Bennett.

County Schools Superintendent said Dais indicated that to continue using school funds for the translator was questionable since educational programming was no longer being provided.

The board's decision allows one year before the translators will be shut down. In the meantime, said Dais, the county schools office will seek to terminate its license with the Federal Communications Commission for operating the trans-

Asbestos-laden rock used to rebuild logging road

JOHN TRUMBO

PORT JONES—"Caution, driving this ad may be hazardous to your health." Such a sign does not exist on the U.S. rest Service's Parks Creek Road, hich begins near Edgewood and stretches [illegible] to the Trinity County line, but the day may come when it ay well qualify for such a billboard if sting next summer shows high levels of bestos in the road dust.

The road was rebuilt this summer with ck material obtained from an existing arry on Forest Service land at the d's bottom. The project raises several oncerns – the asbestos hazard issue, the ck of oversight by other agencies and closeness of the Pacific Crest Trail hich passes within 150 feet of the footall field-sized rock pit.

The quarry straddles the Siskiyou-Trinity county line and is located in an area known to have asbestos-laden serpentine rock. The project itself is totally contained on rest Service managed land and was one without any local or state agency put.

Mount Shasta District Ranger Ken owalter discounts the asbestos oblem. "We consider it safe," he said in an interview recently. In fact, tests done two years ago showed levels of asbestos ranging from as little as 1 percent to as much as 20 percent, varying with core samples in the pit area. Nevertheless, Showalter said precautions were taken with regard to asbestos content, to the point of advising the contractor – R&D Roadbuilding of Redding – that "this rock pit is known to contain asbestos which can be dangerous if breathed. Contractor is advised to take suitable precautions such as performing dust abatement and using breathing equipment."

More recent tests, done a year ago by the National Institute for Occupational Safety and Health in San Francisco showed asbestos in all four core samples, ranging from 1 to 30 percent by volume.

Melvin Okawa of NIOSH, who prepared the report on the tests, told the Pioneer Press there was no problem, even if there was 100 percent asbestos, "if it doesn't get into the air." He said that to be safe, the Forest Service should take air samples "in the breathing zone" along Parks Creek Road during the dry season when it has logging traffic.

Such a study was last done in the Parks Creek Road area in 1981 by a private firm hired by the Forest Service.

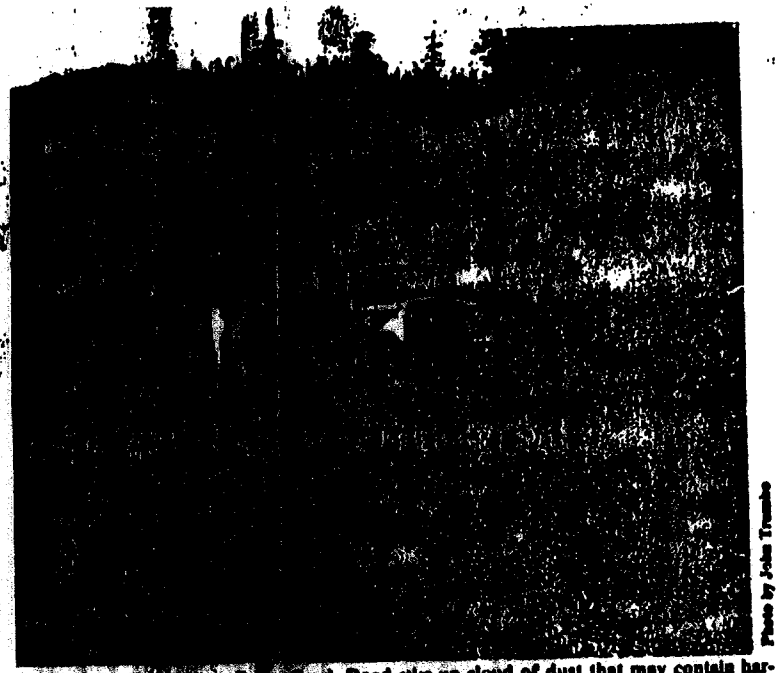

Photo by John Trumbo

LOGGING TRUCK on Parks Creek Road stirs up cloud of dust that may contain harmful levels of asbestos fibers. The Forest Service says it will do an air sample test next summer.

The Radian Corporation study showed asbestos airborne samples ranging from 0.01 to 0.21 fibers per cubic centimeter. Recently, the federal Occupational Safety and Health Administration reduced the permissible occupational exposure of asbestos fibers by 75 percent from 2 fibers to 0.50 fibers per cc.

Whether or not a new study will reveal a higher level of airborne asbestos is yet to be seen, said Terry Shields, civil engineer for the Shasta-Trinity Forest, headquartered in Redding. He said there will be more testing next summer.

"There's a good chance it will be less," he said, adding that the contractor applied a palliative to keep down the dust while construction was in progress.

The Radian tests showed a peculiar pattern of asbestos concentration. Airborne samples taken inside vehicles showed up to 20 times the concentration of samples obtained at roadside. With the recent rocking of the road Shields wouldn't speculate what the new tests will show for inside vehicle concentrations.

Showalter said there was a higher than average amount of traffic on the Parks Creek Road as a Forest Service road because it was a main arterial in the forest for logging into both Siskiyou and Trinity counties. The asbestos may pose a threat to truck drivers.

The quarry site, known to be atop a once lucrative asbestos mine, provided

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22,000 cubic yards of rock base material for the Parker Creek road project. Showalter said it was preferred to hauling in rock simply because it was cheaper supply for material. The Forest Service has been eyeing the site for several years.

Forest Service geologist, Alex Tary of Redding, wrote in the followup correspondence to the testing done by NIOSH that "the rock is present in usable quantity at the proposed quarry site, but due to the nature of it, it may be necessary to avoid some of it due to asbestos content and blend the rest until a suitable mixture of competent material and fines is obtained..." According to Showalter, the rock pit material which appeared to have high amounts of asbestos was avoided rather than blended for roadbase gravel.

Showalter said an environmental assessment was done and opportunity given for public comment, and that there were no objections when the project was being planned 18 months ago.

Since the project was located entirely on Forest Service managed land, neither Siskiyou or Trinity counties were advised for oversight. According to Walter Pajalich, a mining engineer for the Forest Service regional headquarters in San Francisco, "there would be no need to go to the counties because any reclamation is our own. A plan of operation (normally required when private individuals or firms desire to do mining on federal land) is not required."

Doug Sprague of the state Division of Geology and Mines confirms that the project is out of reach of the California Surface and Reclamation Act. "You're dealing with whether or not a state law has been pre-empted. Siskiyou County normally would be the lead agency in requiring reclamation and a public hearing on SMARA. The question is if the federal agency must turn to itself for a permit. I can't answer that," Sprague said.

"But I think they would be required to comply with their own regulations," he noted.

Siskiyou County Planning Director Bob Sellman said he was unaware of the project prior to being asked last week. "We have no jurisdiction, except what they voluntarily give us. On federal land we get zip," Sellman said.

According to the state office of Geology and Mines, the Forest Service can proceed pretty much unhindered with its projects as long as there exists a memorandum of understanding between it and the county. Sellman was unsure if [illegible] do anything it wants on its land?

Apparently, according to Sprague, that is the case. "SMARA is a convoluted legal arrangement. The attorney general has given an opinion that it does apply to all lands in California, but cautioned us to look at what kinds of lands are involved (meaning federal lands).

"If you ask me should the operator have a permit and reclamation plan, my answer would be yes," Sprague commented.

Showalter said the Forest Service exercises greater caution than the state for its own projects on the forest. "We're building 50 to 80 miles of new road each year (in the Shasta-Trinity Forest) and rebuilding 100 miles per year. Generally we are more strict than the state," he said.

"The pit looks better now than it ever did," he claimed. "We've improved the slope and seeded it. That's never been done before," Showalter noted.

As to the proximity of the Pacific Crest Trail to the rock pit, Showalter suggested most people wouldn't even notice it was there.

Besides, said Shields, "Our philosophy on the Pacific Crest Trail is that it does not dictate the surrounding activities. We put clear cuts in the PTC. The original intent was to show people what's going on in the forest. If that is logging or a rock pit, then that's what it is."

Showalter said a public notice in the Mount Shasta Herald in July 1982 produced no comments regarding the nearness of the PCT to the rock pit.

As to the question of just how much asbestos will be flying in the dust next summer, Shields commented, "If it exceeds the (acceptable) levels we'll have to take additional steps." He did not say [illegible]

"The fact that we're taking precautions shows we are concerned. We just don't want this blown all out of proportions," said Showalter. He said the road will remain a gravel road. "We will continue to maintain a dust-abated, crushed rock surface."

As to whether or not asbestos is a real concern of the Forest Service, the agency's official environmental policy states, "The most common form of asbestos is chrysotile, which is found in serpentine rock deposits. Asbestos fibers are released to the atmosphere primarily through human activity...

Inhalation of asbestos fibers has been associated in humans with asbestosis, respiratory cancer and mesothelioma (a rare cancer of the pleural and abdominal lining).

"Because hazardous levels of airborne asbestos have been found near quarries and near roads surfaced with serpentine rock, the precautions herein have been developed."

Showalter says the Forest Service has followed its own policy on precautions.

THE ROCK PIT is visible to the left of the vehicle, while the Pacific Crest Trail is to the right. This view looks toward the Siskiyou County side.

Worst case testing on asbestos road

FORT JONES--Tests done in 1981 to deterimine asbestos dust hazard on Parks Creek Road near Edgewood were a "worst possible case," says the Forest Service civil engineer who conducted them.

Jim Mandigo of the Pleasant Hill office for the Pacific Southwest region of the Forest Service said the tests done in 1981 were to establish data that would define the problem in its worst context. "The roads (we tested) were the ones our field representatives believed had the highest potential for asbestos hazard." When asked if the Parks Creek Road was one of the worst potential asbestos roads in California, Mandigo said he didn't know.

The road was rerocked this summer with serpentine gravel obtained from a rock quarry at the road summit near the Trinity County line. The pit is known to contain asbestos and be in an area where asbestos mining has been done.

Tests done by a private corporation in 1981 showed asbestos contentrations ranging from one to 20 percent in rock pit samples. Tests for airborne asbestos fibers indicated up to 0.27 fibers per cubic centimeter -- below current minimums set by the federal Office of Health and Safety Administration.

Mandigo said the air samples were obtained by placing a collector at road level and then driving by it with a vehicle to stir up dust.

Samples obtained in the vehicle were gathered by placing the collector on the

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dash and driving up and down the 9 miles of road "20 or 30 times."

"It was a condition no one would duplicate," said Mandigo.

Mandigo said the concern about asbestos road dust surfaced in 1977 when the Environmental Protection Agency discovered problems with an off-road-vehicle area on Bureau of Land Management land in Southern California in 1977. At the same time the EPA's attention was drawn to a rock quarry in Maryland.

"They hired someone to do a scoping study which was completed in early 1981. They found was it wasn't as serious as they had first thought. The EPA ended up writing a 'guidance' document instead of regulations," said Mandio.

The environmental assessment prepared by the Forest Service for the Parks Creek Road project indicates the rocking with the asbestos-laden serpentine is planned to continue west to Highway 3 in Trinity County.

Mandigo said asbestos dust testing will be done on the road this summer. The road is heavily used by logging traffic and is maintained as a gravel surface, with palliatives to minimize dust.

STATE OF CALIFORNIA
GEORGE DEUKMEJIAN, Governor

AIR RESOURCES BOARD
1102 Q STREET
P.O. BOX 2815
SACRAMENTO, CA 95812

November 5, 1985

Kenneth L. Corbin
Siskiyou County Air Pollution
Control District
525 South Foothill Drive
Yreka, CA 96097

Dear Mr. Corbin:

Comments on Part A of the Draft Asbestos Report

Thank you for your comments on the draft asbestos report.

My staff has made note of the quarry in Siskiyou County you mentioned and has used the newspaper article you provided in conducting further research into the use of asbestos-containing rock as road surfacing material.

If you have other questions or comments, please contact Todd Wong at (916) 322-0289.

Sincerely,

William V. Loscutoff, Chief
Toxic Pollutants Branch
Stationary Source Division

cc: Peter D. Venturini
Edmond W. Hale, Air Pollution Control Officer,
Siskiyou County APCD

II. Asbestos Information Association

ASBESTOS INFORMATION ASSOCIATION
NORTH AMERICA
1745 Jefferson Davis Highway, Crystal Square 4, Suite 509
Arlington, Virginia 22202 • (703) 979-1150

October 18, 1985

Mr. William V. Loscutoff, Chief
Toxic Pollutants Branch
Attention: Asbestos
Air Resources Board
P.O. Box 2815
Sacramento, CA 95812

Dear Mr. Loscutoff:

The Asbestos Information Association/North America (AIA/NA) appreciates the opportunity to comment on the Air Resources Board draft report on asbestos. As a representative of asbestos miners, millers and product manufacturers in the United States and Canada, AIA/NA has a strong interest in the development of reasonable regulations for the safe use of asbestos.

AIA/NA recognizes the importance of this draft report setting forth potential exposures to asbestos and their related risks as a first step toward determining whether any regulations are necessary to control asbestos emissions. At the same time, it is clear that further work will be necessary to determine the efficacy and feasibility of potential control measures. We thus look forward to continued communications with the Board as it moves toward considering regulatory options. Those efforts are likely to be aided by the ongoing U.S. Environmental Protection Agency program to revise the existing NESHAPS regulations for asbestos. EPA will be reviewing the same issues as are likely to arise in California, and we assume California will be able to benefit from the Agency's efforts.

With respect to the current draft document, we would like to raise several issues concerning both its risk assessment and the exposure estimates presented.

Although the California staff has drafted its own assessment of potential risks at various exposure levels, it has reached conclusions that fall in the same range as prior risk assessments authored by the Consumer Product Safety Commission, National Research Council and Ontario Royal Commission, as well as Dr. Nicholson who has performed risk assessments for both EPA and OSHA (Part B, p. 73). In each

of these assessments, the same issues of choice of epidemiology studies, conversion of historical measurements to today's monitored exposures, determination of the shape of the dose-response curve, and consideration of fiber types arise.

A detailed assessment of these issues was contained in Dr. Kenny S. Crump's comments on the OSHA/Nicholson risk assessment, which we enclose for your information. Dr. Crump is a recognized risk assessment expert who has often worked for EPA and OSHA. As Dr. Crump emphasizes in his report, each of the government risk assessments, and for similar reasons California's new assessment, must be understood to be "upper limit assessments" because they:

(1) Assume a linear dose-response relationship;

(2) Assume the same potency for all forms of asbestos despite significant data indicating lesser potency for chrysotile, particularly with respect to mesothelioma; and

(3) Include within the calculated risk the substantial portion of the lung cancer risk attributable to cigarette smoking.

As Dr. Crump details in his report, risks of exposure to chrysotile fibers, even accepting the upper limit assumption of a linear dose-response relationship, are likely to better be estimated for non-smokers as at least an order of magnitude lower than the assessments employed by OSHA. 1/

1/ Dr. Crump also discusses selection of epidemiology studies to predict risks and notes that OSHA omitted from its consideration studies of Canadian asbestos miners and millers, an omission also made in the California assessment (Part B, p. 45). Such omissions are questionable in the OSHA context where the Agency was considering all possible workplace exposures and are particularly troublesome in the California context given that one of the focuses of emission concern will be fiber emissions from mines and mills within the state (Part A, p. 5). To the extent California is to be considering whether further mining and milling emissions controls are appropriate, it is inappropriate not to

(Footnote Continued)

In addition, because the California risk assessment is intended to predict risks at much lower exposure levels (0.001 fibers/cc and lower vs. 0.1 fibers/cc and higher) than the OSHA risk assessment, even greater uncertainty exists that such upper level limit assessments are appropriate. In extrapolating risks to even lower levels than OSHA extrapolated, considerable likelihood exists that the linear dose-response relationship overestimates human risk.

In sum, we urge California to exercise great care in employing its risk assessment to predict risks at the very low, often near ambient, asbestos exposures, identified in its monitoring program. Despite the general agreement of its assessment with other recent assessments, all such assessments must be recognized as upper limit estimates of risk that may greatly over-estimate actual human health effects.

We also caution the Board against over-reliance on the exposure estimates set forth in the draft report. As the draft report acknowledges, "no long-term asbestos sampling data are available and no method has been developed to extrapolate long-term average concentrations from limited short-term observations" (Part A, p. III-23).

Despite those limitations, it is significant to note that the Board's extensive monitoring program in fact found very little, if any, evidence that the identified emission sources contributed to ambient asbestos levels. The very low level of ambient asbestos found can be seen in two ways.

First, the sampling results indicated that even near potential emissions sources under conditions most likely to lead to elevated ambient levels, very little asbestos was

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(Footnote Continued)

acknowledge that risks among miners and millers of chrysotile have been found to be much lower than for other asbestos occupational groups.

In addition, the assumption that amphiboles are present at half the level of detection at mine sites (p. III-18), seems inappropriate for consideration of airborne asbestos levels. As the report notes, it is not surprising that the only monitored asbestos near the mine was chrysotile, and assumptions of amphibole presence should not be made.

found. For example, as shown in Table III-3, average asbestos levels at mine and manufacturing plant sites (40,325 f/m³ at King City and 12,725 f/m³ at Stockton) were in the same range as average measurements in many background locations without any identified emission sources (e.g., Oildale, 31,908 f/m³, Sherman Oaks, 16,998 f/m³, San Diego, 13,860 f/m³). In addition, monitored levels at individual sites varied considerably. For example, at the same mining site where the highest reading (although only slightly higher than some other background measurements) was found, another reading detected no asbestos (see Table III-2). Given the difficulties of measurement at such low levels, it is impossible to state with any confidence that mines, mills or plants contribute to ambient exposures. 2/

Second, all of the measurements are in fact quite low and well within the often reported ambient levels found worldwide. Even the highest measured average reading -- 40,325 f/m³ -- translates to but 1.2 to 12 ng/m³ (using the TEM to PCM and PCM to ng/m³ conversion factors set forth in Appendix A). 3/ As the NAS/NRC report cited by the draft report notes (at p. 220), ambient exposures in the 1 to 10 ng/m³ and even higher range have been reported in many studies of areas with no identifiable asbestos emission sources.

Accordingly, it would appear that the sampling study confirms that little reason should exist for concern about potential asbestos emission sources in California. Even short term measurements in areas where asbestos emitters might be expected to be most likely to be contributing to ambient exposures have not identified any significant contributions to asbestos levels.

2/ In light of these monitoring results, we question the estimated fiber emissions for mines and mills (Table I, p. 5). These estimates are based on studies done a number of years ago before up-to-date control measures were implemented and are significantly higher than more recent engineering estimates made at the two California mines.

3/ That is, 40,325 f/m³ by TEM corresponds to 403 to 40.3 f/m³ by PCM, which corresponds to 12 to 1.2 ng/m³.

As a related matter, a recent report on "The Significance of Asbestos and Other Related Fibers in Environmental Ambient Air" by Dr. B. T. Commins is enclosed and invited to your attention.

AIA/NA would appreciate being kept informed as California continues to consider asbestos air emissions. We would be glad to provide further information if that would be useful.

Sincerely,

B. J. Pigg
President

Enclosures

OSHA HEARING ON A PROPOSED REVISION OF THE ASBESTOS STANDARD

Testimony by Dr. Kenny S. Crump
on behalf of the Asbestos Information
Association/North America
Submitted May 15, 1984

My name is Kenny S. Crump. I have expertise in biostatistics and quantitative risk assessment. As further detailed in my attached curriculum vitae (Appendix I), I have extensive experience in critiquing and performing quantitative risk assessments.

I earned a Ph.D. in mathematics from Montana State University in 1968 and was a Professor of Mathematics and Statistics from 1966 to 1980 at Louisiana Tech University. In 1974 and 1975 I was a visiting scientist at the National Institute of Environmental Health Sciences (NIEHS). Since 1978, I have been the president of Science Research Systems, Inc., in Ruston, Louisiana.

I have authored numerous articles in refereed scientific publications, as listed in my curriculum vitae, particularly on issues relating to quantitative risk assessment. I have consulted for and prepared reports for many government agencies, including NIEHS, the Environmental Protection Agency, the Council on Environmental Quality, and the Congressional Office of Technology Assessment, as well as for a number of private industry

groups. I have been a member of National Academy of Science panels, including the panel that issued the report, "Risk Assessment in the Federal Government: Managing the Process" (NRC, 1983). I have developed quantitative risk assessments for the Occupational Safety and Health Administration (OSHA) on workplace arsenic exposure in 1982 and in 1983 on ethylene oxide.

I am pleased to have the opportunity to comment on the OSHA quantitative risk assessment for asbestos-related cancers.

I. INTRODUCTION

Quantitative risk assessment is inherently uncertain. As the NAS Committee on Risk Assessment on which I served wrote: "The dominant analytic difficulty of [risk assessment] is pervasive uncertainty (NRC, 1983, at 11). Such uncertainty should be recognized when making decisions based upon the results of risk assessments.

Foremost among the reasons why risk assessment for substances such as asbestos is uncertain is the unavailability of any direct evidence of the health effects of exposures at the levels now prevalent in industry. If the risks of asbestos at the levels being considered by OSHA today -- below 2.0 fibers/cc -- are to be assessed, it is necessary to make a number of assumptions about the dose-response relationship between asbestos and health effects at these lower levels.

In each of the eleven studies upon which OSHA relies to assess asbestos risks, workers were exposed to asbestos at levels considerably above the current standard of 2 fibers/cc. OSHA

assumes in its prediction that cumulative exposures achieved at the low exposure levels prevalent in the workplace today are equivalent in risk to cumulative exposures of workers obtained at much higher fiber concentrations in the past. It is not possible to verify directly this assumption. As OSHA states, 48 Fed. Reg. at 51101: "At this time, it does not appear possible to determine whether intensity of exposure has an effect on disease separate from that of cumulative exposure."

A quantitative risk assessment such as conducted by OSHA involves a number of components requiring decisions or assumptions for which definitive data do not exist. The NAS Committee listed a number of such components. For example, in dose-response assessment, the NAS Committee lists the need to determine, inter alia, (a) "what dose-response models should be used to extrapolate from observed doses to relevant doses," (b) "how should exposures to other carcinogens, such as cigarette smoke, be taken into consideration," and (c) "how should one deal with different temporal exposure patterns in the study population and in the population for which risk estimates are required." (NRC, 1983, at 31). An additional crucial determination is what were the levels of exposure in the study populations. In assessing current exposures, the same crucial determination must be made, namely, as phrased in the NAS report, "how should one estimate the size and nature of the populations likely to be exposed." (NRC, 1983, at 32).

As set forth in the NAS report, the most important issues in reviewing risk assessments are issues of interpretation of the assumptions lying behind the assessment. My comments thus are

concerned with the interpretations of the OSHA risk estimates as well as the calculations themselves. Quantitative risk assessments can play a useful role in standard-setting despite the uncertainties and the assumptions required. However, they can be of most value when the assumptions and inherent uncertainties are clearly displayed.

Based upon its risk assessment, OSHA expresses asbestos-related mortality in units of deaths per 100,000 workers. Most risk assessments express risk in a similar fashion. On the surface such estimates appear comparable to similar data on the risks of motor vehicle or industrial accidents. However, there is a major difference. Estimates of the latter type are based directly on observed deaths, whereas estimates of asbestos-related deaths are extrapolated values based upon assumptions. The risks predicted by OSHA at various levels of asbestos exposure must be understood within the context of these assumptions.

II. SUMMARY

OSHA has developed what I would term an upper limit assessment of asbestos risk. In dealing with uncertainty, OSHA has, in a number of instances, made assumptions that tend to minimize the possibility of underestimating the risk. In addition, the uncertainties in some of their assumptions appear to be underestimated by OSHA. The three most significant assumptions in OSHA's risk assessment that lead to upper limit estimates of risk are the assumptions of: (1) a linear dose-response relationship; (2) the same potency for all forms of asbestos; and (3) attribution

of the lung cancer component of risk caused by smoking to the overall risk of asbestos. In addition, OSHA makes a number of other assumptions about some of the cohort studies upon which it relies that I will discuss.

OSHA assumes a linear dose relationship between asbestos and cancer. Very little consideration is given to the uncertainty concerning this assumption. This assumption provides upper limit estimates of risk. Although it is very unlikely to underestimate risk, it will overestimate risk considerably if it is not valid. Even though a linear dose-response model has scientific support, there remains considerable uncertainty about the concept. This is particularly true for the asbestos/mesothelioma relationship for which virtually no epidemiological dose-response data exist. Later in my testimony I present some estimates of mesothelioma risks derived from the Armitage-Doll multistage model of cancer, which are consistent with the epidemiological data, and which are much smaller than those estimated by OSHA.

OSHA assumes the same potency for all forms of asbestos in all operations. Yet, the epidemiologic evidence indicates the cancer risk from asbestos exposure depends upon fiber type and the setting in which exposures occur. There is considerable uncertainty in applying the OSHA estimates made from many different industrial operations to a specific occupational setting.

OSHA does not distinguish among the asbestos risks of smokers and non-smokers. Yet, the additional risk of lung cancer in asbestos workers is determined largely by their smoking habits -- with the risk being confined chiefly to smokers. Separate estimates of risks in smokers and in non-smokers can provide a much

clearer picture of the risks and of the implication of the proposed standard change. I make such estimates in a later section of this testimony.

Under the OSHA risk assessment the extra risk from 45 years under a 0.5 f/ml standard (assumed to produce average exposures of 0.125 f/ml) is 5/1000. My estimates corresponding to this same exposure are 2.5/1000 for smokers and .3/1000-.5/1000 in nonsmokers. These differences stem principally from 1) omitting two studies used by OSHA in estimating lung cancer risk and treating other studies somewhat differently, resulting in a potency for lung cancer which is 65% of that estimated by OSHA; 2) recognizing the difference in mesothelioma risk posed by chrysotile and amphiboles and estimating risk only from studies with predominantly chrysotile exposures, thereby estimating a potency 1/5 of that estimated by OSHA (therefore, the risks I estimate apply to predominant chrysotile exposures only); and 3) recognizing the difference in lung cancer risks posed by asbestos in smokers and nonsmokers and making separate estimates for these groups.

III. GENERAL RISK ASSESSMENT ISSUES RELEVANT TO REVIEW OF THE ASBESTOS DATA

In order to assess the asbestos data base, it is important to recognize several general issues of risk assessment that have particular relevance to asbestos. As discussed in detail below, one must be cognizant of:

(A) The varying methods of expressing risk and their importance in understanding the meaning of the calculated risks.

(B) The uncertainty in the assumption that the asbestos/cancer dose response relationship is linear and the consequent upper limit type of estimates that result from this assumption.

(C) The crucial importance of accurate determinations of exposures both in the historical cohorts from which dose-response relationship are predicted and in the workplace today under any given OSHA standard.

(D) The uncertainty regarding the contribution to risk of high transient exposures to asbestos and the related assumption that risk depends only upon cumulative exposures irrespective of intensity.

(E) The variation in risk found in studies of different asbestos fiber types in different settings.

III.A. Measures of Risk

OSHA expresses the results of their risk assessment in terms of asbestos-related cancer mortality per 100,000 exposed. This is the additional risk of an asbestos-related cancer death (probability of death from cancer in an exposed worker minus the corresponding probability in the absence of exposure) multiplied by 100,000. This measure of additional risk treats deaths equally regardless of when they occur, e.g. at age 20 or age 70. Although additional risk is a useful and commonly used measure, it thus does not reflect the effect of increased risk upon life expectancy. Also, additional risk must be focused upon specific causes of death since the probability of death is 1.0 for all individuals. If something were to cure heart disease, the additional risk of lung cancer would be higher because of removal of competing causes of death; however, life expectancy would also be increased considerably. To give a more complete indication of the effect of a risk factor, in my testimony I will estimate risk

both in terms of additional risk and loss of life expectancy.

III.B. The Shape of the Dose-Response Curve

The data available for evaluating the shape of asbestos dose-response curves are limited and generally of poor quality. Only a few studies (Enterline, et al., 1972; McDonald, et al., 1980a; Peto, 1980; and Dement, et al., 1980) had available fiber concentrations measured during the relevant time periods and these data are directly pertinent only to cancer risks at much higher exposures than found in the workplace today. The Simpson Committee (Health and Safety Executive, 1979) plotted relative risks of lung cancer against cumulative exposure to asbestos for a cohort of Quebec chrysotile miners (McDonald, et al., 1980a) and cohorts of production workers and maintenance-service workers (Enterline, 1972). Dement et al. (1980) made a similar plot for a cohort of asbestos textile factory workers. All of these plots seem to be reasonably well fit by a straight line.

There is a theoretical argument (Crump, et al., 1976) that suggests that cancer incidence should vary approximately linearly with dose for low doses, particularly when there is an appreciable background of carcinogenesis in unexposed populations. Because of the appreciable background of lung cancer among smokers, this argument suggests that lung cancer incidence might vary linearly with asbestos exposure in smokers. The argument is less applicable to non-smokers because they have a far lower incidence of lung cancer.

There is essentially no support for the point of view that a linear model underestimates risk at low doses by appreciable amounts. Therefore, it seems reasonable to assume that for lung cancer a linear model is conservative; i.e., it is either nearly correct or else errs in the direction of overestimating risks from low doses of asbestos. A similar statement would hold for putative risks of gastrointestinal cancer.

There is very little experimental evidence which bears upon the dose response curve for mesothelioma. Generally, the studies for which reasonably good exposure measurements are available (e.g., Enterline, et al., 1972; McDonald et al., 1980; Peto, 1980; and Dement, et al., 1980) include very few cases of this disease. The theoretical argument for linearity at low doses (Crump et al., 1976) is weaker for cancers like mesothelioma which are rare in the general population. This suggests there is greater uncertainty regarding the assumption of a linear dose response for mesothelioma than for lung cancer.

The theoretical arguments for linearity of the dose-response curve at low doses do not, for the most part, apply to a disease such as asbestosis for which the severity of the disease is related to exposures and which dose not normally occur in the absence of exposure to asbestos. Peto (1978) expressed this point of view, saying, "There are not grounds for assuming a linear dose-response for such a generalized progressive disease, and although a qualitative dose response has been demonstrated at very high exposures levels, there may well be a safe or virtually safe threshold." After thorough review of the evidence on

asbestos-related diseases, the Royal Commission on Asbestos in Ontario (Dupre et al., 1984) concluded "on the basis of the available data, our best judgment as to the lifetime occupational exposure to asbestos at which the fibrotic process cannot advance to the point of clinical manifestation of asbestosis is in the range of 25 f/cc-yrs. and below." Based upon this determination, asbestosis would not pose a threat under a 0.5 f/ml standard as it would require a minimum of 50 years of work to sustain any clinically detectable damage, even if exposures averaged as high as the standard itself.

III.C. Exposure Measurements.

The estimation of the risk from lifetime exposure to a certain fiber concentration involves applying this concentration to a dose-response relationship estimated from studies of health effects from past exposures. Such estimation of a dose-response relationship requires quantitative information regarding both health effects and exposure levels in a previously-exposed population. These two types of information are of equal importance and an estimated dose-response relationship is no more accurate than the least accurate of the estimates of health effects or exposures. A risk assessment based upon a study of a historical cohort for which no exposure data are available has about the same appeal as one based upon a contemporary cohort for which detailed exposure data are available, but for which the future health effects can only be surmised. Each of these data bases lacks a key ingredient necessary for a cogent assessment of risk. Generally, with respect to asbestos, health effects are measured

much more accurately than are exposures. Consequently, the preponderance of the uncertainty about dose-response relationships stems from uncertainty about exposure rather than about health effects.

III.C.1. Limited Exposure Data on Some Cohorts

Many of the asbestos studies relied on by OSHA in its risk assessment have either very limited or no data on past exposures levels. In such studies, health effects from asbestos are demonstrated by comparing disease rates in a cohort exposed to asbestos with those in a control population which is similar in many ways except with respect to asbestos exposure. These studies can be used to further confirm the existence of a relationship between asbestos exposure and health effects by demonstrating that those with longer (and presumably greater) exposures suffered greater incidences of asbestos-related diseases. Although this type of analysis can be used to establish that a dose-response relationship exists and to study certain aspects of that relationship, without exposure information, risks from exposures to various concentrations of asbestos--as are needed for a quantitative risk assessment--cannot be estimated.

What is needed ideally is a cohort with complete followup in which each member worked for a given period to a known fixed concentration. The differential concentration levels and exposure durations of various subcohorts would be used to estimate the parameters of the model. However, nothing like this was available for some of the cohorts.

Accordingly, some important differences among the studies

employed by OSHA to assess asbestos risks thus exist with regard to their suitability for use in risk assessments. Some of the studies apparently have available no environmental measurements from the relevant periods which would permit quantification of a dose-response curve; studies in this category are of very limited value for risk assessment purposes. For example, for the Selikoff et al. (1979) and Seidman et al. (1979) cohorts, no industrial hygiene measurements were made at the site of exposure. Consequently estimated exposures are quite uncertain. In applying the OSHA model to these cohorts, due to data limitations, OSHA did not divide the cohorts into categories by exposure durations and concentration levels but instead assumed an average duration d and an average concentration level f for each complete cohort. This averaging approach could introduce bias. Also, it is difficult to ascertain how well the model describes the data.

As a result, the OSHA estimate of 15 f/cc average exposure in the Selikoff et al. cohort is highly uncertain. Exposures experienced by insulation workers are extremely variable; exposures apparently commonly ranged over 100 f/ml for brief periods during certain operations. It is by no means clear that an uneven intermittent exposure such as this would entail the same risk as an average constant exposure. It is also unclear how the average duration of exposure of d = 25 years for the Selikoff et al. cohort was derived, as a review of Selikoff et al. (1979) revealed no information at all on duration of exposure.

Similarly, although Seidman et al. (1979) had relatively good information on the duration of exposure, no monitoring data

on the exposed workers was available. OSHA thus derived exposure estimates from measurements made 21 to 31 years later in other plants in Texas and Pennsylvania. The reasonableness of these estimates is open to question. It is certainly plausible that the exposure measurements in these plants made after the dangers associated with asbestos became known were less, and perhaps far less than exposures experienced 21-31 years earlier under wartime conditions. The CPSC Advisory Panel on Asbestos (CPSC, 1983) identified the weakness in the exposure estimates in the Selikoff et al. and Seidman et al. studies by placing these studies in a separate category (Level II).

III.C.2. The Need to Convert Historical Data to Modern Measurements.

Modern practices for monitoring occupational exposures typically involve the use of membrane filter counting techniques and data from personal samplers. Unfortunately, these types of industrial hygiene data are not available for most cohorts in which detectable amounts of health effects have been observed. Older measurements were of partical counts made using impingers, and must be converted to fiber counts.

Despite the shortcomings associated with the use of historical impinger measurements, the exposure estimates obtained from such data are vastly superior to those from studies for which no industrial hygiene measurements are available, (e.g., the Selikoff et al. and Seidman et al. studies).

Among the available exposure data, the most detailed estimates of exposures come from studies in which individual work

histories have been coupled with exposure estimates from static samplers to obtain a detailed exposure profile for each worker. These kinds of estimates were made for the cohort of Quebec miners and millers (McDonald, et al., 1980a) and studies of workers in U.S. manufacturing plants (Dement, et al., 1980, Weill, et al., 1979, Henderson and Enterline, 1979).

In making these estimates, older measurements of dust concentrations made using impinger techniques were converted to fiber counts based upon side-by-side measurements of dust and fibers made relatively recently. The correlation between side-by-side fiber counts and dust measurements has been found to be rather poor (Gibbs and Lachance, 1974). Moreover, these dust-fiber conversions cannot account for the possibility that earlier dust-fiber ratios might have been substantially different from those during the period side-by-side measurements were made, owing to differences in plant processes or the quality of the asbestos used.

There is considerable uncertainty in the methods used by OSHA in converting from particles to fibers For the Enterline et al. cohort OSHA used a conversion factor of 1.4 f/cc per mppcf which was an average value obtained by Hammad et al. (1979) for the cement operation where the Weill study was conducted. However, a sizable portion of the Enterline et al. exposures did not involve asbestos cement. Other operations have had larger conversion factors. Use of a conversion factor of 2.0 for the Enterline et al cohort, as employed by the CPSC (1983) panel on asbestos, would reduce the risk estimated by OSHA from this

cohort by about 40%. Enterline himself employed a conversion factor of 3.0 (Enterline, 1981), which would reduce the risk estimated by OSHA by more than a factor or 2.

Particle counts were also converted to fibers/cc for the Dement cohort. OSHA's risk assessment notes the likelihood that exposures have been underestimated in the Dement study. The assessment notes that the estimates derived after conversion that exposures in this textile plant were less than 10 fibers/cc subsequent to 1935 in contrast with exposures in the British textile plant studied by Peto of 30-45, or 15-22, fibers/cc (depending upon how those data are converted to modern measurement methods). OSHA further notes the unlikelihood the Dement plant exposures are accurate given that a greater percentage of deaths from asbestosis (9.4% vs. 5.3%) were found in the U.S. plant than the British plant. (OSHA Ex. 84392, at 38-39).

In the study by Newhouse, et al. (1980), rather than converting old particle counts, the equipment used during earlier times was still available, and historical working conditions were simulated with help from employees who remembered past work practices. However, this approach likewise cannot compensate for possible changes over the years in asbestos raw materials.

III.C.3. Making Proper Allowances for Modern Fiber Measuring Techniques.

When estimating dose-response relationships for asbestos, even when historical measurements in fibers/cc exist, it is important that the effects of modern membrane filter counting

techniques be accounted for as completely as possible. Although, formerly, whole field counting was sometimes employed, most current membrane filter counts are made using a graticule grid. Beckett, et al. (1976) estimated that use of graticule grids increases fiber counts by a factor of 1.5 for amosite and 2.5 for chrysotile as compared with full-field counting. Additionally, it has been estimated that fiber concentrations from data collected from personal samplers are on average twice as great as those data collected from static samplers (Health and Safety Executive, 1979). On the other hand, the CPSC Advisory Committee reported (without a reference) that measurements from static samplers were twice those from personal samplers. Thus, the relationship between personal and static samplers is open to question. Doubtlessly, differences between personal and static samples are dependent upon the placement of the static sampler in a particular sampling situation. At any rate, this issue represents an additional source of uncertainty in health risk estimates for asbestos.

III.C.4. Average Exposures in Relation to the Permissible Exposure Level.

To determine an appropriate standard, attention should be focused upon the risks which would ensue from lifetime exposure to levels that would result from enforcement of the standard rather than from exposure at the standard. Actual average exposure levels will depend upon the type of operation, the industrial hygiene practices in individual locations, and the methods of enforcement.

Table 1 presents a summary of 3,729 fiber concentration measurements from five asbestos industries by the Factory Inspectorate of the Health and Safety Executive in Great Britain. The fiber collections were made using personal samplers, and modern membrane filter techniques were used for making the fiber counts. The measurements were made during the period 1972 to 1978 and therefore were subject to the two fibers per cubic centimeter (f/cc) standard in the 1969 British Asbestos Regulations. Although average concentrations vary from industry to industry, all are at least four-fold less than the 2 fibers/cc standard.

Similarly, the OSHA field staff collected 949 eight-hour time-weighted average samples between June 1, 1979 and May 31, 1983 (48 Fed. Reg. at 51095). These samples were collected in many different industries. Seventy-seven percent (77%) of these samples were below 0.5 fibers/cc, suggesting that the current average exposures are no greater than 0.5. As these measurements do not represent a random sample, but were likely taken in areas where noncompliance was suspected, these measurements possibly overstate current average exposures.

Based upon a study of the variability in fiber measurements, Dr. Gordon Bragg (OSHA Doc. No. H-033C) has concluded that in order to have reasonable confidence of complying with a 2 fiber/cc standard average exposures would need to be about 0.5 fiber/cc or lower.

Consequently, exposure monitoring in both the U. S. and Great Britain, and also considerations of average levels needed to provide compliance with a 2 f/cc standard in view of the variability in exposure measurements, as well as inter-day varia-

bility, all indicate that the current 2 f/cc standard will lead to average exposures no greater than 0.5 f/cc. To make a realistic assessment of the effect of a 2 f/cc standard, therefore, average exposures of 0.5 fiber/cc are more reasonable than exposures of 2.0 f/cc. Although we have no experience with a 0.5 fiber/cc standard, the same requirements for confidence that the standard is being met given the variability of exposures and monitoring should result in average exposures of about one-fourth that amount, or 0.125 f/ml. (cf Bragg, OSHA Doc. No. H-033C).

III.D. Effect of High Transient Exposures.

OSHA's risk estimates assume that no unique risk is created by high transient asbestos exposures. That is, OSHA assumes the very high peak exposures characteristic of some asbestos operations, particularly in the past, are equally as hazardous as cumulative exposures experienced over longer periods of time (e.g., 15 minutes exposure at 96 fibers/cc is assumed to be equivalent to eight hours exposure at 3 fibers/cc). OSHA further assumes that any such peak exposures are reflected in the average exposure estimates used for historical cohorts. This is unlikely to have been the case as fiber measurements were probably made during periods of "normal" operation. The Royal Commission on Asbestos in Ontario (Dupre et al., 1984 at 121) noted the likelihood of sporadic exposures of a very high level for the Finkelstein cohort, in particular.

Although a systematic study of very high transient exposures would be difficult, it is possible that such exposures are the

source of much of the risk experienced by asbestos workers. These exposures are apt not to be reflected by routine sampling methods. Regarding this possibility, J. Peto stated:

> There thus appears to be little evidence that variations of the order of 2- to 3- fold in static sampling measurements can discriminate those at high risk, which raises the possibility that the ambient background level is not the primary source of inhaled fibres. This suggestion is supported qualitatively by the observation that personal sampling sometimes reveals very high transient exposures during certain activities, and the relative contributions of these peaks and the baseline levels should be examined in more detail. If certain work practices constitute the major source of risk and actual exposures are considerably higher than static sampling suggests, dose-response analyses based on static measurements may be misleading. Avoidance of such practices, which may, by accident of design, not occur during personal sampling, may be more useful than the imposition of very stringent hygiene standards without adequate personal monitoring.
>
> (Peto, 1980).

Consequently, high transient exposures are probably not adequately reflected in the exposure estimates used by OSHA and these exposures may have been responsible for a significant portion of the additional risk in some of the studies. This effect, whose magnitude is unknown, will tend to cause health risks under current standards to be overestimated.

III.E. Health Effects of Different Fiber Types in Different Settings.

Although a great deal of asbestos epidemiological data are available, risks estimates may be less well-founded for asbestos than for other hazardous substances found in the workplace for which far less data are available. There are several sources of evidence which imply that cancer risk is not simply a function of

fiber concentrations alone but depends upon asbestos type -- e.g., whether chrysolite, amosite, or crocidolite -- and also upon fiber dimensions.

Different epidemiologically studied cohorts have been exposed to different types of fibers and to industrial operations which produce fibers with differing physical dimensions. Thus, rather than representing a unique substance, asbestos fibers present quantitatively unique health risks depending upon the type of industrial operation. Modern populations are exposed primarily to chrysotile. In contrast, most of the populations from which risk estimates were derived were exposed to substantial amounts of crocidolite or amosite. In the population studied by Seidman et al. (1979) exposures were solely to amosite. Data from studies involving exposures to amosite or crocidolite are of questionable relevance for estimating risks to current and future workers exposed to chrysotile.

Chrysotile is eliminated more efficiently from the lungs than the amphiboles. Wagner (1974) observed that the amount of dust in the lungs was about 15 mg for rats exposed for 24 months to amphiboles, but only about 0.45 for rats with comparable exposures to chrysolite. In a study comparing the fiber in lungs of persons dying of asbestos-related diseases with controls, Wagner et al. (1982) found 100 times more amphibole fibers in the lungs of cases than controls, but about an equal number of chrysotile fibers. This was despite a much greater industrial usage of chrysotile.

Stanton et al. (1977) implanted glass fibers of different fiber distributions into the pleura of Osborne-Mendel rats and sacrificed them 25 months later. Tumor response was highly dependent upon fiber dimensions, with the greatest response from long thin fibers - longer than 8 microns and less than 0.25 microns in diameter. This strongly suggests that different fiber types and different industrial processes entail different risks.

The differing physical and chemical properties of chrysotile as compared to the amphiboles suggest that chrysotile is less dangerous than the amphiboles. Amphibole fibers are straight whereas chrysotile fibers have a curved shape. This gives amphiboles fiber a smaller effective diameter and allows them to penetrate more deeply into the lungs. Chrysotile also dissolves more rapidly than amphiboles, resulting in faster clearance rates for chrysotile; this also implies that the amphiboles are biologically active for a longer period of time.

Epidemiological studies also strongly suggest that crocidolite is more effective in producing mesotheliomas than chrysotile. Berry and Newhouse (1983) studied workers at a friction materials factory in which exposure was to chrysotile except for two well-defined limited periods during which crocidolite was used. A comparison of crocidolite exposures in mesothelioma cases to controls matched for sex, year of birth, year started work at factory, control still alive when case died, control employed at factory during crocidolite periods for same time as case, and exposure to chrysotile, revealed six mesotheliomas, five of whom had been exposed to crocidolite and ten controls, only two of whom had been exposed to crocidolite. A statistical analyses of these results yielded a p-value of 0.028, indicating an association between crocidolite exposures and mesotheliomas. These authors concluded that "This study, together with a recent study of textile workers exposed only to chrysotile, confirms that mesotheliomas are rare after exposure only to chrysotile and provide further evidence of the association of this tumour with amphibole asbestos."

The cohort of Quebec miners (McDonald et al., (1980) was exposed exclusively to chrysotile, except for 113 workers in a small textile operation at Asbestos, Quebec, which produced gas mask filter pads from crocidolite for a few months during World War II (McDonald, 1977). Of the roughly 2,200 deaths among those working near the town of Asbestos, which includes those who worked in the textile operation, there were only four deaths from mesothelioma. Two of the four cases were among the small frac-

tion of the cohort that worked in the textile operation during the time the crocidolite was being used. A third case spent most of his life as an electrician's helper and could have been exposed to crocidolite. The remaining case was employed as a bagger during ages 17-18, and the rest of his work history has not been investigated. Thus, a relationship appears to exist in this cohort between crocidolite exposure and mesothelioma.

Of 56 known deaths among persons employed in the manufacture and handling of Canadian military gas mask cannisters containing pure crocidolite during 1939 to 1942, four (7%) of the deaths were certified on the death certificate as due to malignant mesothelioma. Two of these deaths involved the peritoneum. An additional five deaths were considered by pathologists reviewing the cases to be due to mesothelioma, several of which involved the peritoneum. On the other hand, only 0.25% (11 out of 4,463) of the deaths among Canadian chrysotile miners were certified as due to mesothelioma, and, as noted above, several of these which occurred at Asbestos are likely to have been due to very brief exposure to crocidolite.

Weill et al. (1979) found that, among asbestos cement plant workers exposed to comparable levels of total asbestos dust, those exposed to chrysotile only experienced a significantly lower incidence of respiratory cancer than those exposed to a mixture of chrysotile and crocidolite. A similar result was found to hold in this cohort for prevalence of asbestosis (Weill et al., 1977). Likewise, Enterline et al. (1972) found that, among retirees who had been exposed to comparable levels of total asbestos dust, maintenance-service workers within the higher

exposure groups had higher SMRs for respiratory cancer than production workers with comparable exposures. Only 20% of those production workers were exposed to amosite or crocidolite, whereas for maintenance-service workers this figure was 71%.

Therefore, fiber for fiber, chrysotile appears to be less dangerous than the amphiboles, particularly in producing mesotheliomas. However, OSHA did not consider differences in fiber types in its risk estimates. Consequently, its risk predictions are apt to have overestimated the risk of mesothelioma in modern populations exposed almost exclusively to chrysotile.

IV. ASSESSMENT OF OSHA'S ESTIMATE OF LUNG CANCER RISK.

OSHA's estimate of the lung cancer risks of asbestos rests on three basic elements, each of which involves considerable uncertainty: (a) the shape of the dose-response curve; (b) the potency of asbestos; and (c) a failure to separate the risks of smokers and non-smokers. Any asbestos-induced lung cancer risk augments an already sizable risk due to smoking. The epidemiology studies have demonstrated that lung cancer among asbestos workers is almost exclusively found among smokers. The data demonstrate that few if any lung cancers will be found among asbestos-exposed non-smokers. Moreover, smokers already have a high risk of lung cancer; asbestos exposures at the levels prevalent today do not substantially increase that risk. The OSHA risk assessment does not separate the components of lung cancer risk attributable to smoking from those due to asbestos.

IV.1. The Shape of the Asbestos/Lung Cancer Dose-Response Relationship

If asbestos induces cancer through the same mechanism as smoking, then there is reason to believe that the response should be approximately linear at low dose (Crump et al., 1976), just as assumed in the OSHA model. Most of the dose responses for lung cancer are approximately linear (e.g., McDonald et al., 1980, Enterline et al., 1972). However, the Finkelstein (1983) lung data exhibit a curious U-shaped dose response.

These data do not mean that the linear dose response for lung cancer at low doses has been unequivocally proven. The inevitable misclassification of exposures in epidemiologic studies will tend to make a dose-response appear linear when it is threshold-like.[a] Also, the mechanism by which asbestos causes lung cancer is not well understood. There are theories, which have credence, that at least a fraction of asbestos-induced lung

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[a] For example, suppose that the true disease rates in groups exposed to doses of 30, 50, 100 ug/m3 (units are irrelevant) are there is a threshold between 50 and 100 ug/m3, so that persons exposed to 50 ug/m3 or below experience no increased risk. In an actual study persons are divided into exposure groups and an entire group is assigned an average exposure. Suppose that because of errors in exposure classification, 1/4 of the individuals in each exposure group actually should have been in the adjacent lower exposure group and 1/4 in the adjacent higher exposure group. This error doesn't change the response rate in the 30 ug/m3 dose group because it is exchanging with the 50 ug/m3 group and both have response rates of .05. However, the response rate in the 50 ug/m3 group is increased from .05 to (.75)(.05) + (.25)(.2) = .0875, and the response rate in the 100ug/m3 group is decreased from .2 to (.75)(.05) + (.25) = .175. Thus, because of uncertainty of dosing, the apparent response rate is .05, .0875, and .175 for 30, 50, and 100 ug/m3, respectively. This response is for practical purposes linear despite the fact that the true underlying response is a threshold.

cancers are manifestations of scarring of lungs (cf. Ripstein et al., 1978), and consequently might not occur at doses low enough for which scarring does not take place.

Although the linear assumption for lung cancer may be well-founded, no one knows for sure if it is valid. Thus, the OSHA estimates for lung cancer should be regarded as upper limits with the understanding that the true risks are probably much smaller than those estimated by OSHA if the linearity assumption is invalid.

IV.1.A. Estimates of Lung Cancer Potency

OSHA used K_L = 0.01 as its estimate of lung cancer potency. This estimate was both the geometric mean and the median of the eight K_L's derived from non-mining operations. If the mining operations were included, the geometric mean of the lung cancer K_L would be decreased by 30%.

Because of the great uncertainty discussed earlier in the exposure estimates for the Selikoff et al. (1979) and Seidman et al. (1979) cohorts, a persuasive argument can be made for omitting these studies from quantitative estimates. The CPSC (1983) Panel placed these two studies in a separate category because of the weakness of the exposure estimates. The Seidman et al. study also involved brief exposures (less than four years) exclusively, which makes it less suitable than other studies for estimating the effect of long term exposures. Also, the fiber type in these studies is unrepresentative of most modern exposures in that the Seidman et al. cohort was exposed exclusively to amosite and the Selikoff et al. cohort was likewise exposed to considerable

amounts of amosite.

Even if the Selikoff et al. and Seidman et al. studies are used for making quantitative estimates, the K_L's obtained from these studies could well be reduced. The CPSC Panel's estimate of K_L from the Selikoff et al. cohort was 1/2 of OSHA's. Whereas the CPSC estimation method agrees with that used by OSHA for other cohorts, OSHA applied a special method to the Selikoff et al. cohort which ignored data from the older age groups. By considering the possibility that the control group used for the Seidman et al. cohort was inappropriate, Liddell (see Acheson and Gardner, 1983) obtained K_L = .011, as opposed to OSHA's estimate of .068. Indeed, a plot of lung cancer mortality versus exposure duration reveals an anomalous dose-response relationship, but which can be explained by a higher background incidence of lung cancer in Seidman et al.'s cohort than existed in the control population of New Jersey white males.

It also seems possible that Dement et al. used an inappropriate control group for lung cancer. U.S. national death rates were used as a standard even though the lung cancer rate in the county in which the plant was located was 75% above the national rate. Acheson and Gardner (1983) commented on this as follows:

> "Although Dement and his colleagues (1982) attribute this to the presence of a large number of ex-shipyard workers who had worked in wartime naval construction, the Atlas of Cancer Mortality for US Counties (Mason et al, 1975) shows that the lung cancer mortality rates in women are also significantly high in this county, a finding unlikely to be due to shipyard work. Even though women were employed in the shipyards, the numbers involved were small (Blot et al, 1979)."

Liddell (see Acheson and Gardner, 1983) estimated K_L = .023

(verified independently by me) from the Dement et al. cohort when he allowed the background lung cancer risk to differ from that of the U.S. standard population. Not only does this modification provide a better fit to the Dement et al. data, the estimated background rate agrees closely with the 75% excess of local lung cancer rates over national rates (See Figure 3 of Acheson and Gardner, 1983). The lower estimate of K_L = 0.023 also reduces the discrepancy between this and other studies which show a much smaller K_L.

The Finkelstein (1983) study did not find a dose response for lung cancer. The lowest lung cancer rate (11.9 per 1000 man-years) occurred in the highest exposure category (180 f-yrs/ml), a somewhat higher rate (13.6 per 1000 man-years) was reported in the lowest category (44 f-yrs/ml), and the largest rate (26.1 per 1000 man-years) occurred in the middle exposure group (92 f-yrs/ml). As concluded by the CPSC (1983) Panel "no sensible dose-response for lung cancer can be inferred from these results." These responses would be more compatible with a monotone dose-response if the background lung cancer rate were higher than in the control population, but this would imply that K_L was overestimated for this cohort.

If (1) the K_L's derived from the Selikoff et al. and Seidman et al. studies are omitted because of inadequate exposure information and inappropriate fiber type, (2) the K_L estimated by Liddell for the Dement et al. study is substituted for that estimated by OSHA, and (3) K_L = .0033 is used for Enterline et al. (based upon CPSC's conversion from mppcf to f/cc), the geo-

metric mean of the six remaining K_L's (also omitting those derived from mining operations) is 0.0065, which is 65% of the value used by OSHA. This appears to be a more likely estimate of K_L under modern exposure conditions.

IV.B Smoking and Lung Cancer

The vast majority of lung cancers now occurring in the U.S. would not occur except for cigarette smoking. Because of the multiplicative interaction between asbestos and cigarettes in promoting lung cancer, smokers form an easily identifiable subpopulation which is at high risk relative to non-smokers from the effects of asbestos. Separate quantification of the risk for smokers and non-smokers can give a much clearer picture of the risks and of the implications of regulatory control.

There are striking differences in the risks of lung cancer between asbestos-exposed persons who smoke and those who do not (Hammond, et al., 1979; Selikoff, et al., 1980; McDonald, et al., 1980a; and Berry, et al., 1972). Smokers have far higher risks of lung cancer than non-smokers. In fact, lung cancer among asbestos workers has been confined almost exclusively to smokers.

Because of the effects of smoking upon those diseases, separate estimates of risk should be made for non-smokers and various categories of smokers. These estimates can be used to estimate the overall risk in a population with any projected mixture of smoking habits. Otherwise, risk estimates might be significantly biased if smoking habits differ between the histo-

rical population from which risk estimates are required. Separate risk estimates for smokers and non-smokers are also useful for evaluating the effectiveness of strategies for improving worker health which involve restricting the access of smokers to areas containing asbestos.

If present trends continue, future workers will smoke significantly less than those in former cohorts for which health data are available. Likewise, future cigarettes are likely to contain less carcinogenic material than those smoked by past asbestos workers. These issues need to be taken into account when assessing risks to future asbestos workers.

Similarly, some of the increased incidence of lung cancer in non-smoking asbestos workers might have been caused by the cigarette smoke generated by co-workers (passive smoking) and the synergistic interaction of this smoke with asbestos. Recent studies (Hirayama, 1981; Trichopoulos et al., 1981, 1983; Correa et al., 1983 and Repace, 1984) implicate passive smoking as a cause of lung cancer among non-smokers. If smokers were restricted to asbestos-free areas in asbestos plants, the effect upon lung cancer of exposure to asbestos in these plants might be even less than that estimated for non-smoking cohorts based upon current data.

Table 2 shows the effect of asbestos-induced lung cancer upon life expectancy for regulatory standards of 2.0 and 0.5 fibers/cc and several exposure durations. These calculations were made by applying OSHA's lung cancer model with $K_L = 0.01$ to to the mortality rates for all causes and lung cancer in non-smoking U.S. veterans and in veterans who smoked 21-39

cigarettes/day (Kahn, 1966). For a maximum lifetime exposure of 45 years under a 0.5 f/ml standard, the loss of life expectancy is 13 days in smokers and 1.3 days in non-smokers. Thus, by smoking, an asbestos worker increases his asbestos-related loss of life expectancy ten-fold or by 12 days. However, this 12 day loss of life expectancy is trivial compared to that engendered by smoking alone. As indicated by the lower part of Table 2, smoking reduces life expectancy by an amount ranging from two to four and one-half years.

Table 3 shows a similar pattern expressed in terms of additional risk. For 45 years work under a 0.5 f/cc standard, the additional lung cancer risk estimated using the OSHA model is 3.2 cancers per 1000 workers in smokers but less than 1/2 of a cancer per 1000 workers for non-smokers. Since the lifetime risk of lung cancer in smokers is about 100 cancers per 1000, a lifetime of work under the proposed new standard is estimated under the OSHA model to increase lung cancer in smokers by 3%.

The additional risk of lung cancer resulting from an 0.5 fiber/cc standard will thus be confined principally to smokers, and using OSHA's estimates, will be only about 3% of the lung cancer risk resulting from smoking. These estimates assume that cigarettes are and will remain as dangerous as those smoked in the 40's and 50's, because the U.S. veterans from whom the smoking risks are derived smoked during that period. Any lessening in the lung cancer risk from safer cigarettes will concomitantly reduce the lung cancer risk from asbestos in smokers.

In sum, OSHA's prediction of lung cancer risk from asbestos exposure is an upper limit estimate that assumes linearity of the dose-response curve. It is based on a number of cohort studies for which valid exposure data do not exist. Assuming the linearity assumption is valid and omitting, as did OSHA, studies involving mining and milling operations, lower estimates of risk are predicted by eliminating studies not having exposure data, by reevaluating the risk estimated from some of the other studies, and by estimating the risks separately for smokers and non-smokers. For example, with a 0.5 fiber/cc standard (and consequent 0.125 fibers/cc average exposure) the lung cancer risks from 45 years of work are:

	Loss of Life Expectancy (days)	Cases per 1000
OSHA Estimated of K_L	12	2.9
Average Asbestos-Exposed Smoker*	8.5	2.1
Asbestos-Exposed Non-Smoker*	0.85	0.28

*Decrease K_L by 35% by omitting Selikoff et al. and Seidman et al. studies and recalculating Dement et al. and Enterline et al. K_L's.

All of these risks are very small compared to the lung cancer risk to a smoker not exposed to asbestos of 74/1000 or 375 days less of life expectancy. Thus, the additional risk of lung cancer from 45 years of exposure at a 0.5 f/ml standard is estimated to be a small fraction (about 3%) of the risk due to smoking.

V. ASSESSMENT OF OSHA'S ESTIMATE OF MESOTHELIOMA RISK.

A substantial proportion of the asbestos risk predicted by OSHA is comprised of its estimate of the risks of developing mesothelioma. These estimates appear to be considerably more uncertain than those for lung cancer. Also, OSHA's selective use of data from only four of the 11 studies used to predict lung cancer risk causes these estimates to be biased upward.

V.A. Dose-Response Model for Mesothelioma.

OSHA's dose-response model for predicting mesothelioma risk is based on two assumptions. First, it assumes that mortality increases as the cube of elapsed time less ten years since first exposure during exposure and approximately as the square of elapsed time since the end of exposure less ten years after exposure is over. Second, it assumes that incidence is a linear function of the intensity of exposure.

The model thus assumes the following functional form:

$$I = \begin{cases} K_M f\left[(t-10)^3 - (t-10-d)^3\right] & t > 10 + d \\ K_M f(t-10)^3 & 10 < t < 10 + d \\ 0 & t > 10 \end{cases}$$

where I is the mesothelioma deaths per person-year among survivors, t is the elapsed time in years since first exposure, d is

duration of exposure, 10 is the lag time in years from first exposure until the mortality from mesothelioma begins to increase, f is the intensity of exposure in f/ml, and K_M is the mesothelioma potency constant estimated from the data.

Most studies of mesothelioma predict that the mortality risks are a power of elapsed time since first exposure, as assumed by the OSHA model. However, we cannot be sure that this steep rate of increase extends indefinitely into old age as assumed by OSHA. In the Selikoff cohort, which contains the best information on mesothelioma mortality in old age, the number of mesotheliomas in the oldest group (55+ years since first exposure) is only about 1/2 the number predicted from the OSHA model. Although some of this shortfall may be due to underreporting in old age, it is also possible that the deficit is real. If so, the OSHA model will overestimate risk at oldest ages. None of the cohorts contain information on mesothelioma risk after 30 years past termination of exposure. OSHA's assumption that the risk will continue to increase represents an assumption which is not presently verifiable.

The continuing increasing risk of mesothelioma long after exposure is terminated is observed principally from workers exposed to large quantities of amphiboles (e.g., Seidman et al. cohort). However, as chrysotile is eliminated much more rapidly than the amphiboles, this continuing increase in risk is far more uncertain for chrysotile. This point was made by OSHA with respect to lung cancer (OSHA Doc. 84-392 at 9), but is even more applicable to mesothelioma.

It is certainly plausible that risk could decrease during

later years after cessation of exposure, particularly after exposure to chrysotile. If so, the OSHA model would overestimate risk, particularly from early brief exposures such as are estimated in OSHA's Table 18. For example, if risks remained constant after 35 years from cessation of exposure, OSHA's estimated risk from one year exposure to 0.5 f/ml beginning at age 20 would be reduced from 47 to about 19 per 100,000 and if the risk went to zero after 35 years, the risk would drop to 6 per 100,000. Although it is unlikely that the risk would drop off to zero, these calculations demonstrate that most of the estimated mesothelioma risk is derived from late ages for which the OSHA model is not directly verifiable.

The second assumption, namely a linear dose response, is particularly subject to doubt for mesothelioma because there is virtually no dose response data for this cancer. Finkelstein (1983) contains a table showing dose-response data for mesothelioma derived from a total of only nine mesotheliomas. The Simpson Report (Health and Safety Executive, 1979) contained a table (Table 31X) showing a dose response for mesothelioma derived from a case control analysis of data of McDonald et al.; however, the table did not appear in the published paper (McDonald et al., 1980). For two of the four studies from which OSHA derived estimates of K_M (Selikoff et al., 1979 and Seidman et al., 1979) no measurements of fiber concentrations for the exposed cohorts are recorded.

Figure 1 shows a plot of the Finkelstein (1983) mesothelioma data, with linear, quadratic, and cubic dose response curves.

The linear model appears to fit only slightly better than the quadratic, and even the cubic model falls well within the crude 90% confidence bounds. Thus the Finkelstein data does not allow one to discriminate among linear, quadratic, and cubic dose response models.

Consequently a linear dose response for mesothelioma is an assumption which has not been verified observationally. Since it seems biologically implausible that a dose response for cancer would ever be supralinear (Crump, 1984) the linear assumption appears very unlikely to lead to an underestimate of risk from exposure to low concentrations. However, it could possibly provide an overestimate. There have been two general arguments which suggest that a linear dose response is plausible for many carcinogens. One such argument applies for carcinogens that "act by directly causing a mutation in DNA" (NRC, 1977). However, this argument may not be applicable to the carcinogenic mechanism of asbestos in producing mesotheliomas because asbestos has not been shown to be particularly mutagenic. The other general argument holds for carcinogens that produce cancers by the same mechanism by which background tumors are produced (Peto, 1978). However, since the background rate of mesotheliomas is either zero or--at most--very small, this argument is not applicable either.

Regulatory agencies have utilized a linear dose response for carcinogenesis as both a prudent approach and one which may be approximately correct in many cases. However, the above considerations suggest there is greater uncertainty in applying this approach to mesotheliomas than in other situations.

V.B. The Uncertainty Range in OSHA's Mesothelioma Estimates

OSHA quantified the uncertainty in their estimate of K_M and K_L by defining a range for each estimate. These ranges were described as follows:

> The ranges listed are the results of uncertainties in estimates of exposure (usually a factor of two), methodological differences that led to alternate evaluations of risk, statistical variation in both risk measures and exposure measures, and adjustments made to account for inappropriate comparison group and background rates. (OSHA Ex. 84-349, at 22)

These ranges do not cover the large uncertainty regarding whether the model used is correct. Therefore, I assume OSHA's ranges are meant to be interpreted somewhat as follows: Assuming the model used by OSHA is correct, then the risks from a given exposure are in some sense highly likely to lie between the risks obtained by applying the OSHA model and using the extremes of the range. If this is the intended interpretation then the ranges appear to me to be too small. Some examples will help illustrate this point.

OSHA estimated $K_M = 5.7 \times 10^{-8}$ from the Seidman study and provided a range of from 3×10^{-8} to 11×10^{-8}. Thus K_M is assumed to be estimated to within a factor of 2. The exposures in the Seidman cohort are estimated from measurements made at two newer but similar plants in 1967, 1970 and 1971--about 30 years after the exposures to the cohort. Average measurements were 30 f/cc in plant Y and 40 f/cc in plant X. However, individual measurements varied greatly, from 2.5 f/cc to 163 f/cc. Furthermore,

the earlier measurements made during 1967 averaged 80 f/cc in plant Y and 49 f/cc in plant X. These earlier estimates of exposures average almost twice that assumed by OSHA for the Seidman et al. cohort. Consequently, even if use exposure data from these plants is accepted, it would be reasonable to about double the estimate. Temporal variations in estimates, large variations among individual measurements, and considerable uncertainty regarding whether these estimates are applicable to a factory that operated 30 years earlier during wartime conditions suggest that exposure estimates for the Seidman cohort are very uncertain -- by much more than a factor of 2. Concerning OSHA's estimation procedure for K_M, OSHA estimated $K_M = 5.7 \times 10^{-8}$ using a nonlinear regression method. When I applied a maximum likelihood estimation procedure to the same data, I obtained $K_M = 5.0 \times 10^{-8}$, with 90% lower and upper confidence limits 2.6×10^{-8M} and 8.7×10^{-8}. Consequently, statistical variation alone dictates an uncertainty K_M about equal to the range provided by OSHA. The uncertainty in exposures is difficult to quantify but it seems to me that it should be at least a factor of 4. Thus statistical variation and uncertainty of exposures suggest that the range should be at least a factor of eight rather than a factor of two as OSHA obtained.

Similarly, Finkelstein (1983) stated that his exposure estimates were "judged to be accurate to within a factor of 3 to 5." When I estimated K_M using a maximum likelihood method I obtained $K_M = 1.9 \times 10^{-7}$ with lower and upper 90% limits of 0.85×10^{-7} and 3.7×10^{-7}. These limits differ from the estimated K_M by about a factor of 2. Coupling this with Finkelstein's estimated uncer-

tainty in exposure of 4 leads to an eight-fold uncertainty in the estimate of K_M. OSHA, on the other hand, suggested a three-fold range of uncertainty.

V.C. Selection of Data.

As detailed earlier, considerable data indicate a difference in potency among asbestos fiber types in the causation of mesothelioma. OSHA did not take these differences into account. It was thus assumed that chrysotile (the form of asbestos predominantly used today) is as potent as crocidolite, thus likely overestimating the effects of current workplace exposures.

OSHA based its prediction of mesothelioma risk on but four of the eight cohort studies it employed to estimate lung cancer risk. Two of those studies (Seidman et al. and Selikoff et al.) have already been discussed (Section III.C.1) as being particularly inappropriate for risk assessment because of lack of exposure data. In three of these four studies workers were exposed to considerable amounts of amphiboles. The Seidman et al. cohort was exposed exclusively to amosite. The cohort of Finkelstein was exposed to a mixture of 75% chrysotile and 25% crocidolite (Dupre et al., 1984). The insulators studied by Selikoff et al. were exposed to chrysotile and amosite. In the fourth study, the textile workers studied by Peto et al. were exposed predominantly to chrysotile but also had some exposure to crocidolite. The K_M estimated from the Peto et al.--involving principally chrysotile exposures--data was smaller than K_M's estimated from the studies

involving greater exposures to amphiboles by factors ranging from 2 to 17.

These four studies also generally had higher estimates of the lung cancer potency K_L. As OSHA noted, these four studies had four of the five largest K_L values. Consequently, it would be expected that K_L values from these studies would tend to be larger also than those from the remaining studies. To compensate for this potential source of bias, OSHA multiplied the geometric mean of the four K_M's by the ratio of the geometric mean of the K_M's for these four studies to the geometric mean of the K_L's for all eight studies used in estimating lung cancer risk. This modification reduced OSHA's estimate of K_M from 2.91×10^{-8} to 1×10^{-8}. However, it is not clear that this modification is an adequate remedy for this source of bias. Also, it does not take into account the differing degrees to which chrysotile and the amphiboles produce mesothelioma.

With the assistance of the original investigators, I have been able to calculate K_M's for two additional studies for which exposures were predominantly to chrysotile. These are the Dement et al. study, where exposures were to only chrysotile, and the Weill et al. study, in which 77% of the workers were exposed exclusively to chrysotile.

Table 4 contains the mesothelioma data for the Dement et al. cohort. The person-years in this table, as well as the details of the mesothelioma case (20+ years of employment and a latency of about 40 years) were furnished through the courtesy of Dr. Dement. Ten years is taken as the average duration and 7.5 f/cc as the average fiber concentration. Table IV of Dement et al.

(1983) indicates that the average duration of work was about ten years. Dement et al. do not furnish data that are particularly appropriate for determining average exposure. Mean fiber exposures by job category range from near zero up to 78 f/cc for 1930-1944, 24 f/cc for 1945-1964, and 17 f/cc for 1965-1974, but the number of person years in each exposure category is not given.

These data suggest that average exposures were probably in the range 5-15 f/cc. Assuming 7.5 f/cc for the average exposure, then the estimated K_M is 2.2×10^{-9}. This figure could be revised if more accurate data on average exposures become available. In view of the likely underestimate of exposures in this population, as noted by OSHA (OSHA Doc. 84-392, at 39), average exposures were possibly larger than 7.5 f/cc.

This estimated potency of $K_M = 2.2 \times 10^{-9}$ is considerably smaller than those estimated by OSHA from four studies, and is about five-fold smaller than the value preferred by OSHA in their estimates of mesothelioma risk. Moreover, the ratio $K_M/K_L = 2.2 \times 10^{-9} / .042 = 5.2 \times 10^{-8}$, which is about 20-fold less than those in the four studies used by OSHA; this indicates that the assumption implicitly made by OSHA of a constant ratio is not universally valid.

Table 5 contains mesothelioma data for the Weill et al. (1979) cohort. The numbers of mesotheliomas were obtained from the observation by Weill et al. that only any two mesothelioma deaths were recorded (both pleural), one 18 years and one 19 years after initial employment. The person-years in each five-

year age interval were estimated from Weill et al. (1979) Table 3 by averaging the number of workers entering the interval and the number entering the subsequent interval, and multiplying the result by 5. (In the 35+ group, the number of persons entering the group was multiplied by 5, assuming an average followup of five years.) From Table 5 of Weill et al. the average employment duration of the cohort was d = 4.5 years. This same table provides an average dust concentration of 16.15 mppcf or, upon converting to f/cc by multiplication by 1.4, f = 22.6 f/cc.

These values result in an estimate of $K_M = 7.0 \times 10^{-10}$, which is about 13 times smaller than that used by OSHA. Even this may be an overestimate of the effort of chrysotile alone. According to Table 7 of Weill et al., 420i of the workers (77%) were exposed solely to chrysotile, whereas only one of the two mesothelioma deaths came from this group. Thus it appears that an analysis restricted to workers exposed only to chrysotile might result in an even smaller K_M.

Further followup of this cohort is nearing completion (Dr. Janet Hughes, personal communication). It is recommended that this analysis be updated using only data on workers exposed exclusively to chrysotile. In the interim the results in Table 5 represent the best information available for this cohort.

Using these analyses, we now have two K_M's from studies for which exposures were to chrysotile only ($K_M = 2.2 \times 10^{-9}$ for Dement et al. and $K_M = 7.0 \times 10^{-9}$ for Peto et al.) and one K_M from a study for which exposures of 77% of population were solely to chrysotile ($K_M = 7.0 \times 10^{-10}$ for Weill et al.). The geometric mean of these K_M's is 2.0×10^{-9}, which is 1/5 of the value used by OSHA.

Because of the clear difference in the ability of chrysotile and the amphiboles to produce mesothelioma, it is more appropriate to estimate mesothelioma risk in modern populations exposed to chrysotile using data from studies involving chrysotile exposure. The best evidence currently available from such studies indicates OSHA's choice of studies overestimates risk by a factor of 5.

Whenever the additional followup of the Weill et al. cohort is complete, an analysis of that data restricted to the 4201 workers exposed only to chrysotile should be used to update K_M for that cohort. It may be possible to calculate K_M's for other populations exposed to chrysotile and, if so, it should be done. Such a possibility may exist with the workers studied by Berry and Newhouse, although it does not appear possible to make such a calculation using their published report only. Although crocidolite was used at this plant during two brief periods, it might be possible to restrict the analysis to workers not exposed to crocidolite. It should be noted that of the ten cases of mesothelioma in this study, only one was not exposed to crocidolite, and apparently this worker had worked for many years in another plant manufacturing asbestos cement products.

V.D. Predictions of Risk of Mesothelioma from Multistage Model of Cancer

The multistage model of cancer (Crump et al., 1976); Crump, 1984) is generally considered to be a biologically plausible model for cancer as there is considerable evidence that cancer is a multistage process. This model has been used extensively by regulatory agencies for cancer risk assessment. OSHA [Federal

Register 48, (1983) no 78, April 21, pp. 17284-17319] used this model in estimate risks from exposure to ethylene oxide. OSHA also considered the multistage model to be the most appropriate model for the prediction of excess risk from exposure to ethylene dibromide (Federal Register 1983, Vol. 48, pp. 45956-46003).

The multistage model, in its most detailed and complete form (Day and Brown, 1980 and Crump and Howe, 1984), is derived from the assumptions that cancer is initiated in a single cell only after the cell passes through several stages. Cells compete independently to be the first to produce a tumor. The rate at which a cell passes through a dose-related stage is assumed to be proportional to the instantaneous dose.

The model predicts a linear response at low dose whenever either 1) cancers occur "spontaneously" without a carcinogenic insult, or 2) there is only one dose-related stage; otherwise the model predicts a nonlinear response (Crump et al., 1976). The evidence for spontaneous occurrence of mesotheliomas is lacking; consequently, the only way the multistage model can predict a linear response at low dose is for there to be only one dose-related stage. Since there is essentially no dose-response data for mesothelioma, the number of dose-related stages for mesothelioma is open to question.

To determine the range of risks predicted by the multistage model, I have fit the model to the mesothelioma data used by OSHA assuming either one, two or three stages are dose-related. The details of my analysis are included in Appendix II.

Tables 4-9 compare the observed mesotheliomas with the num-

ber predicted by the OSHA and multistage models. Table 10 summarizes the fits of the models. The multistage models provide an excellent fit to each of the data sets except for the model with one dose-related stage applied to the Seidman et al. and Weill et al. data; in these cases the fits are somewhat marginal. By contrast, the OSHA model provides an inadequate fit to the Weill et al. data, a marginal fit to the Selikoff et al. data, and an acceptable fit to the remaining data sets.

The estimated potency parameters z from the multistage model have the same ordering with respect to size as the corresponding parameter K_M for the OSHA model; from largest to smallest: Finkelstein, Seidman et al., Selikoff et al., Peto et al., Dement et al. Weill et al. OSHA used an intermediate value of K_M in their risk assessment, which happened to be 2/3 of the K_M obtained from the Selikoff et al. data. To compare results from the multistage model with those from the OSHA model, I shall follow OSHA in using values which are 2/3 of the values estimated from the Selikoff data, namely $z = 7.3 \times 10^{-7}$ for one dose-related stage, $z = 8.0 \times 10^{-8}$ for two dose-related stages, and $z = 3.9 \times 10^{-9}$ for three dose-related stages.

Table 11 shows several estimates of the loss of life expectancy from mesothelioma from 1, 20 and 45 years of work under a 2.0 or 0.5 f/cc standard. Table 12 shows similar results for extra lifetime risk. These estimates are specifically made to compare risks under the multistage model with those made using the OSHA model. They do not reflect the effect of exposure to chrysotile only. As noted earlier, risks from exposure to chry-

sotile are estimated to be about 1/5 of the estimates in Tables 11 and 12.

As expected, the multistage model with one affected stage is very similar to the OSHA model. For example, for 45 years of exposure under a 0.5 f/cc standard, the OSHA model predicts a loss of life expectancy of 6.2 days whereas the multistage with one affected stage predicts 5.6 average days lost. However, the risk under the multistage model is far less if there is more than one dose-related stage. For two dose-related stages, the corresponding loss of life expectancy is only 0.073 days or 1 3/4 hour, and for three stages, 4×10^{-4} days or 35 seconds.

Similar results hold for additional risk. Assuming one dose-related stage, the additional lifetime risk is one per thousand, with two dose-related stages 1.5 per 100,000, and three dose-related stages seven per 100 million.

All of these estimates are made from models which are biologically plausible and which agree with existing data. The OSHA model is essentially equivalent to assuming a multistage model with one affected stage. This assumption implies a linear dose response. Two or three dose-related stages, which imply quadratic and cubic dose responses, are also plausible and predict much smaller risks. Thus, in this respect, the OSHA estimates represent upper limit estimates. The mesothelioma risks may be as large as estimated by the OSHA model, but it is unlikely that they are much larger. On the other hand, the risks could be far smaller than estimated by this model.

V.E. Summary of Estimates of Mesothelioma Risks

OSHA estimated mesothelioma risk assuming a linear dose-response relationship and assuming chrysotile and the amphiboles are equally potent in causing mesotheliomas. My review of the data suggests that, while the linear assumption might be appropriate for developing upper limit estimates, there is greater uncertainty regarding this assumption with respect to mesothelioma than with respect to lung cancer. The data are equally compatible with multistage models predicting linear and non-linear dose responses.

OSHA also assumed no difference in risk of mesothelioma from chrysotile and the amphiboles. However, I believe there is considerable data to indicate that chrysotile is less risky. OSHA has already omitted from its risk calculations data from mining and milling operations, on the grounds that these exposures are not representative of those in the populations of workers OSHA has responsibility to protect. I believe this principle should also be applied to the chrysotile-amphibole question, and that risk to modern day workers, who are exposed almost exclusively to chrysotile, should be estimated from studies in which chrysotile exposures predominate.

Even if one does not accept the difference between chrysotile and amphiboles in mesothelioma, my analyses suggest that OSHA's selection of only four data sets resulted in an estimate of K_M which is too large. The two additional K_M's I have estimated are 5 and 13 times smaller, respectively, than the K_M used by OSHA.

Based upon the analyses reported earlier, I consider the most appropriate studies for this purpose to be those of Peto et al. ($K_M = 7.0 \times 10^{-9}$), Dement et al. ($K_M = 2.2 \times 10^{-9}$), and Weill et al. ($K_M = 7.0 \times 10^{-10}$). Peto et al. and particularly the Weill et al. studies involved some exposures to crocidolite and therefore may overestimate the risk from pure chrysotile. A reanalysis of the Weill et al. data involving only the 4201 workers exposed exclusively to chrysotile should be carried out and used to recalculate K_M for this cohort. A similar analysis is recommended for any other study for which it is possible to identify appropriate groups exposed only to chrysotile.

The geometric mean of the values of K_M from these three studies is 2 x 10-9, which is the same as the K_M estimated from Dement et al. study. Consequently, estimates of risk from chrysotile exposure were developed for both the OSHA model and the multistage model using parameter estimates derived from the Dement et al. study. The mesothelioma risks predicted from exposure under a 0.5 f/cc standard for 45 years, compared to the risks predicted using OSHA's value of K_M are as follows:

	Loss of life expectancy (days)	Risk per 1000
using OSHA's estimate of K_M	6.2	1.6
predicted from predominant chrysotile exposure		
OSHA model	1.2	.313
Multistage model		
one affected stage	1.0	.20
two affected stages	.012 (17 min)	.003
three affected stages	.0007 (6 sec)	.00002

VI. COMPARISON OF RISKS FROM ASBESTOS WITH OTHER OCCUPATIONAL RISKS.

One way to evaluate the effectiveness of a particular occupational standard to protect workers' health is to compare the residual risks with other risks encountered as a result of employment. Tables 13 and 14 compare asbestos risks I have calculated, as well as those predicted by OSHA's risk assessment, from lifetime employment under a 2 or 0.5 f/cc standard with hazards of commuting to work, industrial accidents, and exposure to other chemicals regulated by OSHA.

Risks estimated for a lifetime of work under a 0.5 f/ml standard using the OSHA model are somewhat less than accidental risks in the safest occupation of trade (e.g., 21 days loss of life expectancy from asbestos exposures vs. 24 days from working in trade). The asbestos risk is about 60% of the accidental risk

in manufacturing, and only about 10% of the accidental risks in construction and mining or quarrying--industries for which exposure to asbestos is likely.

However, my estimates of the risk from asbestos are lower than those estimated by OSHA. The reasons for this are threefold: 1) my estimate of the potency K_L for lung cancer is 65% of OSHA's. This is because I omitted two studies which I didn't consider appropriate for quantitative risk assessment (Selikoff et al., 1979 and Seidman et al., 1979) and because my estimates differed from OSHA's in two other studies; 2) my estimates of mesothelioma risk are derived from studies with predominant exposure to chrysotile, with the result that they are about 1/5 those of OSHA under a one-affected-stage model, and about 1/80 those of OSHA under a two-affected-stage model; 3) I estimated risks separately for smokers and non-smokers and found that the bulk of the risk is confined to smokers.

The largest risk I estimate is for smokers assuming a one-stage model for mesothelioma. This risk is about 1/2 that estimated by OSHA. My risk estimates are not greatly affected by the model used to estimate mesothelioma risks. This is becuase under chrysotile exposure mesothelioma risks are estimated to be much smaller than risk of other types of cancer. The risk to non-smokers is estimated to be about 1/5 to 1/7 that of smokers, and about 10% of the accidental risks in the safest occupations.

About 50% of the risk in non-smokers accrues from the risk from cancers other than lung cancer or mesothelioma--estimated for both smokers and non-smokers as 10% of the risk of lung

cancer in smokers. Although I have not considered the evidence from these other cancers in this testimony, there is considerable disagreement among scientists regarding the relationship of asbestos to these cancers. For example, the CPSC Panel on Asbestos was unable to agree on the interpretation of these cancers, and estimated risk from only lung cancer and mesothelioma. If I have followed CPSC in this regard, my risk estimates for non-smokers would be halved and those for smokers would be reduced by about the same absolute amount.

It is also instructive to compare risks from asbestos under the proposed standard to those from other substances recently regulated by OSHA, namely EtO, EDB and arsenic. I have estimated asbestos risks resulting from a .5 f/ml standard (as opposed to risks from exposure to .5 f/ml) by assuming that a .5 f/ml standard would result in an average exposure of 0.125 f/ml. For consistency, I will make a similar assumption for these other chemicals--that average exposures will be 1/4 the standard. Table 14 shows that the risks I have estimated for asbestos are in the same range as those estimated under other standards OSHA has recently promulgated. Perhaps the best comparison is with arsenic since estimates for the other two chemicals are made from animal data. My estimates of asbestos risks for smokers are in the middle of the range of those I made for arsenic risks and my estimates of asbestos risks in non-smokers are below the range of the estimates I made for arsenic. Overall, it appears that an .5 f/ml standard for asbestos would be no less stringent than OSHA standards for these three chemicals.

References

Acheson, E. D., and Gardner, M. J. (1983). Asbestos: The Control Limit for Asbestos. Health and Safety Commission. London:Her Majesty's Stationery Office (OSHA Exp. 84-243).

Berry, G., and Newhouse, M. L. (1983) Mortality of workers manufacturing friction materials using asbestos. British Journal of Industrial Medicine 40:1-7.

Blot, W. J., Stone, B. J., Fraumeni, J. F., and Morris, L. E. (1979). Cancer mortality in U.S. counties with shipyard industries during World War 2. Environmental Research 18:281-290.

Correa, P., Pickle, L. W., Fontham, E., Lin, Y., and Haenszel, W. (1983) Passive smoking and lung cancer. Lancet, Sept. 10: 595-597.

CPSC. (1983). Chronic Hazard Advisory Panel on Asbestos. U.S. Product Safety Commission, Directorate for Health Sciences, Washington, D.C. (OSHA Ex. 84-256).

Crump, K. S., Hoel, D. G., Langley, C. H., and Peto, R. (1976). Fundamental carcinogenic processes and their implications to low dose risk assessment. Cancer Research 36:2973-2979.

Crump, K. S. (1983). Testimony by Kenny S. Crump, Ph.D.: OSHA Hearing on Ethylene Oxide, 48 pages.

Crump, K. S. (1984). Mechanics Leading to Dose-response Models. In: (Paolo Ricci, ed.) Principles of Health Risk Assessment Prentice-Hall, pp. 187-227.

Crump, K. S., and Howe, Richard B. (1984). The multistage model with a time-dependent dose pattern: applications to carcinogenic risk assessment. Risk Analysis (to appear).

Day, N. E., and Brown, C. C. (1980). Multistage models and primary prevention of cancer. J. Nat. Cancer Inst. 64:977-989.

Dement, J. M., Harris, R. L., Symons, M. J., and Shy, C. M. (1983). Exposures and mortality among chrysolite asbestos workers. Part II: Mortality. Am J. Indus. Med. 4:421-434. (OSHA Ex. 84-037)

Doll, R. and Peto, R. (1976). Mortality in relation to smoking: 20 years' observations on male British doctors. British Medical Journal 2:1515-1536.

Enterline, P. E., DeCoufle, P., and Henderson V. (1972). Mortality in relation to occupational exposure in the asbestos industry. J. Occup. Med. 14:897-903 (OSHA Ex. 84-043).

Finkelstein, M. M. (1983). Mortality among long-term employees of an Ontario asbestos-cement factory. Br. J. Ind. Med. 40:138-144 (OSHA Ex. 84-240).

Ham, J, Y. Y, Diem, J., and Weill, H. (1979). Evaluation of dust exposure in asbestos cement manufacturing operations. Am. Ind. Hyg. Assoc. J. 40:490-495 (OSHA Ex. 84-248).

Hammond, E. C., Selikoff, I. J., and Seidman, H. (1979). Asbestos Exposure, Cigarette Smoking and Death Rates. In Health Hazards of Asbestos Exposure (I. J. Selikoff and E. C. Hammond, eds.). New York Academy of Sciences: New York (OSHA Ex. 84-047).

Hayes, W. J., Jr., et al. (1971). Evidence of safety of long-term high, oral doses of DDT for man. Arch. Environ. Health 22:119.

Health and Safety Executive (1979). Asbestos: Final Report of the Advisory Committee, Volumes I, II. London: Her Majesty's Stationery Office, 100 p. and 104 p. (OSHA Ex. 84-216).

Hirayama, T. (1981). Nonsmoking wives of heavy smokers have a higher risk of lung cancer: a study from Japan. Br. Med. J. 282:183-85.J. - 1981

Hoel, D. G., Kaplan, N. L., and Anderson, M. W. (1983). Implication of nonlinear kinetics on risk estimation in carcinogenesis. Science 219:1032-1037.

Kahn, H. A. (1966). The Dorn study of smoking and mortality among U.S. veterans: Report on eight and one-half years of observations. In: Epidemiological Approaches to the Study of Cancer and Other Chronic Diseases, National Cancer Institute Monograph 19 (William Haenszel, ed.). U.S.DHEW, U.S. Govt. Printing Office, Washington, D.C.

Liddell, F. D. K. (1982). Some new and revised risk extrapolations from epidemiological studies on asbestos workers. Proceedings of the BGA Symposium February, 1982, BGA-Berichte (in press).

Mason, T. J., McKay, F. W., Hoover, R., Blot, W. J., and Fraumeni, J. F. (1975). Atlas of Cancer Mortality for U.S. Counties: 1950-1969. Washington: U.S. Government Printing Office.

McDonald, J. C., Liddell, F. D. K., Gibbs, G. W., Eyssen, G. E., and McDonald, A. D. (1980) Dust exposure and mortality in chrysotile mining, 1910-75. Br. J. Indus. Med. 37:11-24 (OSHA Ex. 84-065).

McDonald, J. C. (1977). Exposure relationships and malignant mesothelioma. In: (H. W. Glen, ed.). Proceedings of the Asbestos Symposium, Johnnesburg. Randburg: National Institute for Metallurgy, 1978:67-90.

National Safety Council. (1982). Accident Facts 1982 Edition (OSHA Ex. 84-339).

Newhouse M. L., Berry, G., and Skidmore, J. W. (1982). A mortality stu: of workers manufacturing friction materials with chrysolite asbestos. The Annals of Occupational Hygiene, Inhaled Particles V, 26(1-4):899-909 (OSHA Ex. 84-163).

Nicholson, W. J., Perkel, G. and Selikoff, I. J. (1982). Occupational exposure to asbestos: population at risk and projected mortality-1980-2030. American Journal of Industrial Medicine 3:259-311.

NRC. (1977). Drinking Water and Health. National Academy of Sciences. U.S. Environmental Protection Agency contract no. 68-01-3139.

NRC. (1983). Risk Assessment in the Federal Government: Managing the Process. Committee on the Institutional Means for Assessment of Risks to Public Health, Commission on Life Sciences. Washington: National Academy Press.

OSHA. (1983). Occupational exposure to inorganic arsenic; supplemental statement of reasons for final rule. Federal Register 98, No. 10 (Jan. 14): 1864-1903.

Peto, R. (1978). Carcinogenic effects on chronic exposure to very low levels of toxic substances. Environmental Health Perspectives 22:155-159.

Repace, J. L. (1984). Consistency of research data on passive smoking and lung cancer. Lancet, March 3: 506.

Seidman, H., Selikoff, I. J., and Hammond, E. C. (1979). Short-term asbestos work exposure and long-term observation. Ann. N. Y. Acad. Sci. 330:61-89 (OSHA Ex. 84-087).

Selikoff, I. J., Hammond, E. C., and Seidman, H. (1979). Mortality experience of insulation workers in the United States and Canada. Ann. J. Indust. Med. 1:8-22 (OSHA Ex. 84-090).

Stanton, M. F., Layard, M., Tegeris, A., Miller, E., May, M., and Kent, E. (1977). Carcinogenicity of fibrous glass: Pleural response in the rat in relation to fiber dimension. J. National Cancer Institute 58:587-597 (OSHA Ex. 84-093).

Trichopoulos, D., Kalandidi, A., Sparros, L., and MacMahon, B. (1981). Lung cancer and passive smoking. Int. J. Cancer 27:1-4.

USDOT (1977). Fact Book: Statistical Information on Highway Safety. U.S. Department of Transportation, National Highway Traffic Safety Administration, National Center for Statistics and Analysis, Washington, D.C. (October)

Wagner, J. C., Berry, G., Skidmore, J. W., and Timbrell, V. (1974). The effects of inhalation of asbestos in rats. Brit. J. Cancer 29:252-269 (OSHA Ex. 84-096).

Wagner, J. C., Berry G., and Pooley, F. D. (1982). Mesothelioma and asbestos type in asbestos textile workers: a study of lung contents. British Medical Journal 285:603-606.

Walker, A. M., Loughlin, J. E., Friedlander, E. R., Rothman, K. J., and Dreyer, N. A. (1983). Projections of asbestos-related disease 1980-2009. Journal of Occupational Medicine 25(5):409-425 (OSHA Ex. 84-312).

Weill, H., Rossiter, C. E., Waggenspack, C., Jones, R. N., and Ziskind, M. M. (1977). Differences in lung effects resulting from chrysotile and crocidolite exposure. In: Inhaled Particles IV (W. H. Walton, ed.). Oxford:Pergamon Press, 789-98.

Weill, H., Hughes, J., and Waggenspack. (1979). Influence of dose and fiber type on respiratory malignancy risk in asbestos cement manufacturing. Am. Review of Respiratory Diseases, 2:345-354.

APPENDIX I

CURRICULUM VITAE

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Date of Birth	October 13, 1939
Place of Birth	Haynesville, Louisiana
Marital Status	Married
Children	Three

Education

1961	B.S. Electrical Engineering	Louisiana Tech University
1963	M.A. Mathematics	University of Denver
1968	Ph.D. Mathematics	Montana State University

Honors

B.S. cum laude, Omicron Delta Kappa, Phi Kappa Phi, Tau Beta Pi, Eta Kappa Nu, Who's Who in American Colleges and Universities, Engineering Honor Freshman, Louisiana Tech Sigma Xi Research Award-1977, Sigma Pi Sigma.

Research Interests

Application of statistics and stochastic processes to problems in biology and health.
Methodology for assessment of effects upon human health from environmental exposures.

Professional Society Memberships

American Association for the Advancement of Science
American Statistical Association
Biometric Society
Institute of Mathematical Statistics
Sigma Xi, The Scientific Research Society of North America
Society for Epidemiologic Research
Society for Risk Analysis
Society for Mathematical Biology

Professional Experience

1961-1963	Research Associate, Denver Research Institute
1963-1966	Instructor of Mathematics, Montana State University

Professional Experience (continued)

1966-1980	Professor of Mathematics and Statistics, Louisiana Tech University
1967-1968	Research Associate, Department of Statistics, State University of New York at Buffalo (on leave)
1969 (summer)	Research participant, Statistics group, Mathematics Section, Oak Ridge National Laboratory, Tennessee
1974-1975	Visiting Scientist, National Institute of Environmental Health Sciences, Research Triangle Park, North Carolina (on leave)
1978-present	President, Science Research Systems, Inc. Ruston, Louisiana

Committees and Offices

1976-1979 Officer, Louisiana Chapter American Statistical Association Secretary-Treasurer - 1976-1977; Vice-President - 1977-1978; President - 1978-1979

1978-1979 United States Congress Office of Technology Assessment; member of Tolerance Advisory Panel-Environmental Contaminants in Food.

1979-1980 National Academy of Sciences; member of Diesel Impacts Study Committee and Panel on the Health Effects of Diesel Emissions.

1980-1983 American Statistical Association; member of Committee on Statistics and the Environment

1981-1982 National Academy of Sciences; member of Committee on Institutional Means for the Assessment of Risks to Public Health

Selected Testimony (hearings)

Royal Commission on Matters of Health and Safety Arising From the Use of Asbestos in Ontario August 13, 1981 (presented findings resulting from review of asbestos health effect literature, critiques of risk assessments carried out by other investigators, and independent risk calculations.)

Congress of the United States, House of Representatives, Committee on Science and Technology May 20, 1982 (reviewed EPA's carcinogenic risk assessment on formaldehyde.)

Occupational Safety and Health Administration Hearing on Exposure to Inorganic Arsenic, June 18, 1982 (critiqued quantitative risk assessments and presented independent findings.)

Occupational Safety and Health Administration Hearing on Ethylene Oxide July, 1983 (reviewed OSHA's quantitative risk assessments and presented independent findings.)

Selected Testimony (trials)

United States versus 2116 Boxes of Boned Beef et al. (diethystilbestrol), Wichita, Kansas, October, 1980.

Victoria Palmer et al. versus Nova Scotia Forest Industries (phenoxy herbicides), Sydney, Nova Scotia, May, 1983.

Northwest Coalition for Alternatives to Pesticides et al. versus Block et al. and Oregonians for Food and Shelter (phenoxy herbicides), Eugene, Oregon, August, 1983.

United States versus Keplinger et al. (IBT), Chicago, Illinois, September, 1983.

Areas of Consulting Experience

Environmental Statistics
Bioassay Statistical Design and Analysis
Environmental Epidemiology
Cancer Epidemiology
Health Risk Assessment (especially cancer)

Publications in Refereed Journals

1. Crump, K. S. and Mode, C. J. (1968). A general age-dependent branching process I. Journal of Mathematical Analysis and Applications 24, 494-508.

2. Crump, K. S. and Mode, C. J. (1969). A general age-dependent branching process II. Journal of Mathematical Analysis and Application 25, No. 1, 8-17.

3. Crump, K. S. and Mode, C. J. (1969). A branching process with correlations among siblings. Journal of Applied Probability 6, 205-210.

4. Crump, K. S. (1970). On systems of renewal equations. Journal of Mathematical Analysis and Applications 30, No. 2., 425-434.

5. Crump, K. S. (1970). On systems at renewal equations: The reducible case. Journal of Mathematical Analysis and Applications 30, No. 3, 517-528.

6. Crump, K. S. (1970). Migratory populations in branching processes. Journal of Applied Probability 7, 565-572.

7. Crump, K. S. and Hoel, D. G. (1970). Some applications for renewal theory on the whole line. Journal of Applied Probability 7, 734-746.

8. Crump, K. S. and Howe, R. B. (1972). Nonparametric estimation of the age of a Galton-Watson branching process. Biometrika 59, 533-538.

9. Hoel, D. G. and Crump, K. S. (1974). Estimating the generation-time of an age-dependent branching process. Biometrics 30, 125-235.

10. Crump, K. S. and Hoel, D. G. (1974). Mathematical models for estimating mutation rates in cell populations. Biometrika 61, 237-252.

11. Crump, K. S. and Howe, R. B. (1974). Estimation of the age of a Bellman-Harris branching process. Mathematical Biosciences 19, 175-184.

12. Crump, K. S. (1975). On point processes having an order statistic structure. Sankhya 37, Series A, 396-404.

13. Crump, K. S. (1976). Numerical inversion of Laplace transforms using a Fourier series approximation. Journal of the Association for Computing Machinery 23, 89-96.

14. Crump, K. S., Hoel, D. G., Langley, C. H. and Peto, R. (1976). Fundamental carcinogenic processes and their implications to low dose risk assessment. Cancer Research 36, 2973-2979.

15. Crump, K. S. and Gillespie, J. H. (1976). The dispersion of a neutral allele considered as a branching process. Journal of Applied Probability 13, 208-218.

Publications in Refereed Journals (continued)

16. Crump, K. S. (1976). A birth-death-migration solution to the geographical distribution of a neutral allele in a continuous finite habitat. Mathematical Biosciences 30, 159-167.

17. Guess, H. A. and Crump, K. S. (1976). Low-dose extrapolation of data from animal carcinogenesis experiments--analysis of a new statistical technique. Mathematical Biosciences 32, 15-36.

18. Crump, K. S. (1977). Mathematical models for mutations in cultures of diploid cells. Mathematical Biosciences 33, 177-188.

19. Crump, K. S., Guess, H. A. and Deal, K. L. (1977). Confidence intervals and tests of hypotheses inferred from animal carcinogenicity data. Biometrics 33, No. 2, 437-451.

20. Crump, K. S. and Gillespie, J. H. (1977). The geographical distribution of a neutral allele. Theoretical Population Biology 12, 10-20.

21. Guess, H. A., Crump, K. S. and Peto, R. (1977). Uncertainty estimates for low-dose extrapolations of animal carcinogenicity data. Cancer Research 37, 3475-3483.

22. Guess, H. A. and Crump, K. S. (1978). Maximum likelihood estimation of dose-response functions subject to absolutely monotonic constraints. Annals of Statistics 6, No. 1, 101-111.

23. Garner, J. B., Crump, K. S., and Stephenson, J. L. (1978). Transient behavior to the single loop solute cycling model of the renal medulla. Bulletin of Mathematical Biology 40, 273-300.

24. Crump, K. S. (1977). Open Query: Theoretical Problems in the modified Mantel-Bryan procedure. Biometrics 33, 752-755.

25. Crump, K. S. and O'Young, W. C. (1979). Some stochastic features of bacterial constant growth apparatus. Bulletin of Mathematical Biology 41, 56-66.

26. Crump, K. S. (1978). Low-dose extrapolations of animal carcinogenicity data (reply to the letter of Nathan Mantel). Cancer Research 38, (June issue).

27. Crump, K. S. (1978). Models for carcinogenic risk assessment (Technical Comment), Science 202, 1106.

28. Crump, K. S. (1979). Dose response problems in carcinogenesis. Biometrics 35, 157-168.

29. Daffer, P. Z., Crump, K. S., and Masterman. M. D. (1980). Asymptotic theory for analyzing dose response survival data with application to the low-dose extrapolation problem. Mathematical Biosciences 50, 207-230.

Publications in Refereed Journals (continued)

30. Crump, K. S. (1981). An improved procedure for low-dose carcinogenic risk assessment from animal data. Journal of Environmental Pathology and Toxicology, Vol. 5, No. 2, 675-684.

31. Crump, K. S. (1982). Designs for discriminating between binary dose response models with applications to animal carcinogenicity experiments. Communications in Statistics, 11(4), 375-393.

32. Krewski, D., Crump, K. S., Farmer, J., Gaylor, D. W., Howe, R. B., Portier, C., Salsburg, D., Sielken, R. L., and Van Ryzin, J. (1982). A comparison of statistical methods for low-dose extrapolation utilizing time-to-tumour data. Fundamental and Applied Toxicology 3:140-160.

33. Crump, K. S. (1983). Ranking carcinogens for regulation (letter to the editor). Science, 219:4582, 236-238.

34. Crump, K. S. and Howe, R. B. (1984). The multistage model with a time-dependent dose pattern: Applications to carcinogenic risk assessment. Risk Analysis (to appear).

35. Crump, K. S. (1984). A new method for determining allowable daily intakes. Journal of Environmental Pathology and Toxicology (to appear).

Other Publications, Reports, Etc.

1. Johnson, A. M. and Crump, K. S. (1976). Transient solution of a solute cycling model of the renal medulla using Laplace transforms. Proceedings of the 1976 Summer Simulation Conference, 460-463.

2. Guess, H. A. and Crump, K. S. (1977). Best-estimate low-dose extrapolation of carcinogenicity data. Environmental Health Perspectives 22, 149-152.

3. Guess, H. A. and Crump, K. S. (1977). Can we use animal experiments to estimate 'safe' doses for chemical carcinogens? Environmental Health: Quantitative Methods: 13-30. SIAM, Philadelphia (ed. by Alice Whittmore).

4. Langley, C. H. and Crump, K. S. (1977). Possible advantages and disadvantages of nontransmitted single-cell human mutagenesis assays. Zentrallaboratarium fur Mutagenitatsprufung (Conference on population monitoring methods for detecting increased mutation rates, 1976), 83-85.

5. Crump, K. S. (1978). Estimates of Risks to Humans from Chemical Residues in Meat. Prepared for the United States Congress Office of Technology Assessment.

6. Crump, K. S. (1978). Estimation of Mean Pesticide Concentrations When Observations are Detected Below the Quantification Limit. Prepared for Food and Drug Administration.

7. Crump, K. S. (1977). Experimental Design. Proceedings of the Conference on TSCA Carcinogenicity Testing Methods, 140-141 (sponsored by National Center for Toxicological Research) Little Rock, Ark., Aug. 22-23.

8. Cohen, A. C. and Crump, K. S. (1978). Statistical Analysis of Radionuclide Levels in Food Commodities. Prepared for the Food and Drug Administration.

9. Crump, K. S. and Masterman, M. D. (1979). Assessment of Carcinogenic Risks from PCBs in Food. Prepared for the United States Congress Office of Technology Assessment. In: Environmental Contaminants in Food, Vol. II - Working Papers (available from NTIS).

10. Hoel, D. G. and Crump, K. S. (1981). Waterborne carcinogens: a scientists view. In: (R. W. Crandall and L. B. Lave, eds.) The Scientific Basis of Health and Safety Regulation. The Brookings Institution, pp. 173-195.

11. Crump, K. S. and Masterman, M. D. (1979). Review and evaluation of Methods of Determining Risks from Chronic Low Level Carcinogenic Insult. Environmental Contaminants in Food: 154:165. Congress of the United States Office of Technology Assessment. Library of Congress Catalog Card No. 79-600207.

Other Publications, Reports, Etc. (continued)

12. Crump, K. S. and Watson, W. W. (1979). GLOBAL79: A FORTRAN Program to Extrapolate Dichotomous Animal Carcinogenicity to Low Dose.

13. Crump, K. S., Howe, R. B., Masterman, M. D. and Watson, W. W. (1980). RANK: A FORTRAN Program for Risk Assessment Using Time-to-occurrence Data.

14. Crump, K. S. and Howe, R. B. (1980). A Small Sample Study of Permutation Tests for Detecting Teratogenic Effects. Prepared for the Food and Drug Administration under Contract 223-79-2274.

15. Crump, K. S. and Watson, W. W. (1980). Water Quality Criteria Calculated from Multistage and One-Hit Models. Prepared for the Environmental Protection Agency, Cincinnati, Ohio.

16. Crump, K. S. (1980). Evaluation of Uncertainties in the Estimation of Carcinogenic Risks. Prepared for the American Petroleum Institute, 46 pages.

17. Crump, K. S. and Howe, R. B. (1980). Carcinogenic, Mutagenic and Teratogenic Risk Assessment: An Annotated Bibliography. Prepared for the Environmental Protection Agency under Contract 68-01-5975, 30 pages.

18. Crump, K. S. and Howe, R. B. (1980). Approaches to Carcinogenic, Mutagenic and Teratogenic Risk Assessment. U. S. Environmental Protection Agency, Contract No. 68-01-5975, Task A, Subtask NO. 5 Summary Report, 169 pages.

19. Crump, K. S. (1980). Carcinogen-based Criteria: Assessment of Uncertainties. Proceedings of Symposium on the Development, Use and Value of Water Quality Criteria and Standards, George Washington University, June 23-25, 1980, 18 pages.

20. Crump, K. S. and Guess, H. A. (1980). Drinking Water and Cancer: Review of Recent Findings and Assessment of Risks. Executive Office of the President, Council on Environmental Quality, Washington, D. C. Contract No. EQ1OAC018, 109 pages.

21. Nisbet, I. C. T., Crump, K. S., Paxton, M. B. and Turim, J. (1980). Carcinogenic Risk Assessment for Hexachlorobenzene. Prepared for the U. S. Environmental Protection Agency, Contract No. 68-01-5824, 87 pages.

22. Crump, K. S. and Guess, H. A. (1982). Drinking water and cancer. In: (L. Breslow, J. E. Fielding and L. B. Lave, eds.) Annual Review of Public Health Vol. 3, pp. 339-357.

Other Publications, Reports, Etc. (continued)

23. Crump, K. S. and Howe, R. B. (1980). A Small Sample Study of Some Multivariate and Dose Response Permutation Tests for Use with Teratogenesis or Carcinogenesis Data. Prepared for the Food and Drug Administration under contract to Ebon Research Systems, 34 pages.

24. Crump, K. S. (1981). Statistical aspects of linear extrapolation. In: (ed. C. R. Richmond, P. J. Walsh, and D. Copenhaver). Proceedings of the Third Life Sciences Symposium, Health Risk Analysis, Gatlinburg, Tennessee, October, 1980, pp.381-392.

25. Crump, K. S. (1981). Issues related to carcinogenic risk assessment from animal data. Presented at the International School of Technological Risk Assessment, a NATO Advanced Study Institute, Erice, Italy. (in press)

26. Crump, K. S. (1981). Chlorinated drinking water and cancer: The strength of the epidemiologic evidence. In: (ed. R. L. Jolley, et al.) Water Chlorination: Environmental Impact and Health Effects, Volume 4, Book 2, Environment, Health, and Risk, Ann Arbor Science Publishers, pp. 1481-1491.

27. Crump, K. S. and Howe R. B. (1982). Examination of Options for Calculating Daily Intake Levels (DILS). Prepared for the Environmental Protection Agency, Order No. C2171NAST, 56 pages.

28. Crump, K. S. (1982). Implications of the Multistage Model to Risks from Partial Lifetime Exposure. Prepared for the Environmental Protection Agency, Order No. C2171NASR, 26 pages.

29. Crump, K. S. (1982). The Scientific Basis for Health Risk Assessment. Presented at the seminar sponsored by George Washington University Graduate Program in Science, Technology, and Public Policy and by the U. S. Environmental Protection Agency, Washington, D. C. March 2, 29 pages.

30. Howe, R. B., and Crump, K. S. (1982). GLOBAL 82: A Computer Program to Extrapolate Quantal Animal Toxicity Data to Low Doses. Prepared for the Office of Carcinogen Standards, OSHA, U.S. Department of Labor, Contract 41USC252C3.

31. Crump, K. S., and Howe, R. B. (1983). Review of Methods for Calculating Confidence Limits in Low Dose Extrapolation. In: (Krewski, D. ed.) Toxicological Risk Assessment, CRC Press, Inc.:Canada (in preparation).

32. Crump, K. S. (1982). Quantitative Assessment of Human Risk from Exposure to Carcinogens with Special Reference to Vinyl Chloride. Prepared for the Ontario Ministry of Labour, Occupational Safety and Health Division.

Other Publications, Reports, Etc. (continued)

33. Crump, K. S. (1982). Methods for Estimating Human Cancer Risks from Non-Human Data. Presented at the EPRI Workshop on Extrapolation from Animal Studies to Man, Carmel, California, December 1-2.

34. Crump, K. S. and Ng, T-H. (1983). Quantitative Risk Assessment for Environmental Exposure to Inorganic Arsenic. Prepared for EPA Environmental Criteria Assessment Office, Contract No. 68-02-3111, 41 pages.

35. Crump, K. S. (1982). Review of a Study of Asbestos in Drinking Water and Cancer in the San Francisco Bay Area. Prepared for the A/C Pipe Producers Association, Washington, D. C., 31 pages.

36. Crump, K. S. and Sims, S. E. (1982). The quantitative effect of migration upon geographic studies. (unpublished manuscript).

37. Rodricks, J. V., and Crump, K. S. (1982). Assessing the risks of food constituents. (unpublished manuscript).

38. Crump, K. S. (1983). Limitations of Risk Assessment Models. Presented at Toxicokinetics in the Evaluation of Safety of Chemicals Workshop, Electric Power Research Institute, November 30, December 1-2, San Diego.

39. Silvers, Abe and Crump, K. S. (1984). Examination of Risk Estimation Models. In: H. A. Milman and E. K. Weisburger, eds.) Handbook of Carcinogen Testing. (in preparation).

40. Crump, K. S., Silvers, A., Ricci, P. F., and Wyzga, R. (1984). Interspecies Comparison for Carcinogenic Potency to Humans. In: Paolo Ricci, ed. Principles of Health Risk Assessment, Prentice-Hall, pp. 271-314.

41. Crump, K. S. (1984). Mechanisms Leading to Dose-response Models. In: Paolo Ricci, ed. Principles of Health Risk Assessment, Prentice-Hall, pp. 187-227.

42. Crump, K. S. (1984). Methods for Carcinogenic Risk Assessment. In: Paolo Ricci, ed. Principles of Health Risk Assessment, Prentice-Hall, pp. 229-269.

43. Crump, K. S. and Ng, T. H. (1984). Cancer Incidence in the Denver SMSA in Relation to the Rocky Flats Plant. Report of research conducted under Department of Energy Contract #DE AC04-76EV01013, Subcontract 8115006 from Inhalation Toxicology Research Institute, Albuquerque, New Mexico.

44. Crump, K. S., Chase, Gerald R., Kotin, P., and Mitchell, R. S. (1984). A plan for the apportionment of risk for lung cancer claimants occupationally exposed to asbestos. Presented at the American Association for the Advancement of Science 150th Annual Meeting, May 27-29, New York, New York.

APPENDIX II

DETAILED DESCRIPTION

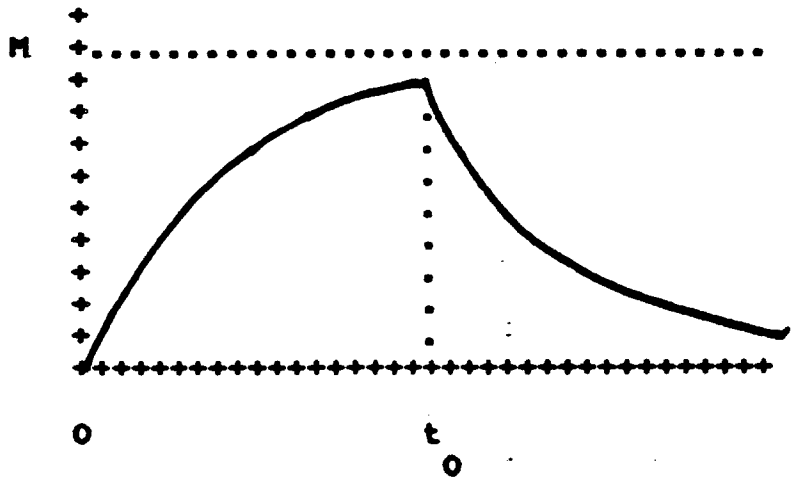
OF MESOTHELIOMA RISK CALCULATIONS

The dose required in the multistage model is the instantaneous internal tissue concentration. Wagner (1974) demonstrated that in rats fibers accumulate in the lung under constant exposure and there is a slow decrease in fiber levels after exposure is terminated. A qualitatively similar behavior should occur in the peritoneal cavity of humans also. To model this phenomenon, I have assumed that if an individual is exposed occupationally to a constant air concentration for a period of t_0 years and is not exposed thereafter, then the concentration of fibers insulting the peritoneum t years after onset of exposure can be expressed as

$$D(t) = \begin{cases} M[1-\exp(-r_1 t)] & \text{for } t < t_0 \\ M[1-\exp(-r_1 t)]\exp(-r_2 t) & \text{for } t > t_0 . \end{cases}$$

The parameter M is the maximum fiber concentration, r_1 is the rate at which fibers accumulate during exposure, and r_2 is the rate at which the internal fiber concentration decreases after exposure stops. This model is identical to the uptake and clearance model proposed by the Consumer

Product Safety Commission Chronic Hazard Advisory Panel on Asbestos (CPSC, 1983), except CPSC required r_1 and r_2 to be equal. Although $r_1 = r_2$ is predicted under linear first-order kinetics, this constraint would not be appropriate under nonlinear kinetics. Retention kinetics in biological systems are often nonlinear (Hoel et al., 1983). For example, the rates of uptake and washout of DDT are quite different in humans (Hayes, 1971). Since we don't know if linear kinetics are appropriate for asbestos, a more general form which does not require $r_1 = r_2$ is used. It is also assumed that M is proportional to the air concentration of asbestos, i.e., M = cf where f is occupational air fiber concentration in f/cc. This assumption is valid under linear kinetics but not necessarily under nonlinear kinetics. A graph of internal dose D versus time since onset of exposure, assuming a constant exposure to f f/cc up until time to and no exposure there after, is as follows:



In addition to the parameters c, r_1 and r_2 required for the uptake and clearance model, the multistage cancer model requires the following parameters:

k - the number of stages;

L - the minimum time required for a cancer to appear after exposure begins;

for i = 1 to k

a_i - the "background" parameter for the ith stage

b_i - the "potency" parameter for the ith stage

The instantaneous rate at time t after onset of exposure at which a cell goes through the ith stage is proportional to $a_i + b_i D(t)$. At least one of the a_i must be zero; otherwise mesotheliomas would occur spontaneously. Also, $b_i = 0$ if the ith stage is not dose-related. Further mathematical details of the multistage model are provided in Appendix III.

The parameters a_i, b_i and c only appear in the formula for mesothelioma incidence in a constant factor which I shall call z.

Consequently the parameters to be selected are z, r_1, r_2, k, L. The number of stages k will be fixed at k = 3. This choice is similar to the choice by OSHA of an exponent of 3 in their model. Similarly, I will assume (just as OSHA) a minimal latency between first exposure and occurrence of a mesothelioma of L = 10 years. The Selikoff et al, Seidman et al., Peto et al., and Finkelstein data sets were all fit first using common values for the uptake and washout rates r_1 and r_2. Although these rates could be different in the four studies because of differing physical and chemical properties of the fibers, common values of r_1 and r_2 provide an adequate fit to all data sets. These values were selected by an exploratory analysis as:

r_1 = .3/year, r_2 = .5/year for one-stage model;

r_1 = .13/year, r_2 = .07/year for 2-stage model; and

r_1 = .2/year, r_2 = .001/year for 3-stage model.

he only remaining parameter is the potency parameter z. This parameter as estimated by a maximum likelihood fit of the models to each of the ndividual data sets. The Dement et al. data could also be adequately fit sing these same values of r_1 and r_2, so these same values were applied to his data set also. However, different values were required to obtain an dequate fit to the Weill et al. data. Values used in fitting this data et were:

r_1 = .013/yr, r_2 = .36/yr for one-stage model;

r_1 = .20/yr, r_2 = 5.0/yr for two-stage model;

r_1 = .01/yr, r_2 = .80/yr for three-stage model.

APPENDIX III

FORMULAE FOR MULTISTAGE MODEL

Under the Armitage-Doll multistage model of cancer with three stages, the yearly mortality rate from mesothelioma at year t after exposure begins can be approximated by (Crump and Howe, 1984, eq. (A7)):

$$I(t) = \begin{cases} 0 & \text{for } t < L \\ [a_3 + b_3 D(t-L)] \int_0^{t-L} \int_0^{u_2} [a_1 + b_1 D(u_1)][a_2 + b_2 D(u_2)] du_1 du_2 & \text{for } t \geq L \end{cases}$$

where, as explained in the text, a_i is the background parameter for the ith stage, b_i is the potency parameter for the ith stage, L is the lag from when exposure begins and the mortality rate begins to increase, and D(t) is the internal fiber concentration resulting from a constant exposure to f f/ml for a work duration of t_0 years. As also described in the text, it is assumed that:

$$D(t) = \begin{cases} cf[1 - \exp(-r_1 t)] & \text{for } t < t_0 \\ cf[1-\exp(-r_1 t_0)]\exp[-r_2(t - t_0)] & \text{for } t \geq t_0 \end{cases}$$

Three special cases are considered:

3 dose related stages - $a_1 = a_2 = a_3 = 0$

$b_1 > 0,\ b_2 > 0,\ b_3 > 0$

2 dose related stages - $a_1 = a_2 = b_3 = 0$

$b_1 > 0,\ b_2 > 0,\ a_3 > 0$

1 dose related stage - $a_1 = b_2 = b_3 = 0$

$b_1 > 0,\ a_2 > 0,\ a_3 > 0.$

Let

$$M(t) = t^2/2 - t/r_1 + te^{-r_1 t}/r_1 - e^{-r_1 t}/r_1^2 + e^{-2r_1 t}/2r_1^2 + 1/2r_1^2$$

and $s = t - L$

Evaluating the integral for the three cases yields:

<u>3 dose-related stages</u> -

$$I(t) = \begin{cases} 0 & \text{for } t < L \\ zf^3 M(s)(1 - e^{-r_1 s}) & \text{for } L < t < L + t_0 \\ zf^3(1 - e^{-r_1 t_0})e^{-r_2(s-t_0)}\,[M(t_0) + (1 - e^{-r_1 t_0})\{[t_0 & \\ \quad + (1 - e^{-r_1 t_0})(r_2^{-1} - r_1^{-1})](1 - e^{-r_2(s-t_0)})/r_2 & \\ \quad + (1 - e^{-r_1 t_0})(e^{-2r_2(s-t_0)} - 1)/2r_2^2\}] & \text{for } t > L + t_0 \end{cases}$$

where $z = c^3 b_1 b_2 b_3$;

<u>2 dose-related stages</u> -

$$I(t) = \begin{cases} 0 & \text{for } t < L \\ zf^2 M(s) & \text{for } L < t < L + t_0 \\ \text{[same as corresponding expression for three dose-related stages except } f^3 \text{ is replaced by } f^2 \text{ and the product} & \\ (1 - e^{-r_1 t_0})e^{-r_2(s-t_0)} & \\ \text{appearing after } zf^3 \text{ is removed]} & \\ & \text{for } t > L + t_0 \end{cases}$$

where now

$$z = c^3 b_1 b_2 a_3;$$

1 dose related stage

$$I(t) = \begin{cases} 0 & \text{for } t < L \\ zf[s^2/2 - e^{-r_1 s}/r_1^2 - s/r_1 + 1/r_1^2] & \text{for } L < t < L + t_0 \\ zf[t_0^2/2 + [-t_0 + (1 - e^{-r_1 t_0})/r_1]/r_1 + & \\ \quad [t_0 - (1 - e^{-r_1 t_0})/r_1](s - t_0) + & \\ \quad (1 - e^{-r_1 t_0})\{(s - t_0) + (1 - e^{-r_2(s-t_0)})/r_2\}/r_2] & \text{for } t \geq L + t_0 \end{cases}$$

where

$$z = c^3 b_1 a_2 a_3.$$

TABLE 1
DISTRIBUTION OF ASBESTOS DUST EXPOSURE LEVELS IN DIFFERENT MANUFACTURING INDUSTRIES (BASED ON 4-HOUR PERSONAL SAMPLING DATA OBTAINED IN THE PERIOD NOV 1972-FEB 1978)

Industry	No. of Results	Range		Median	Percentage of results below:			Geometric standard deviation
		Min	Max		0.5	1.0	2.0	
Asbestos-cement	845	0.01	6.20	0.10	86.5	95.0	98.5	3.8
Millboard/paper	135	0.01	2.63	0.14	87.0	98.2	99.6	3.3
Friction materials	900	0.01	10.22	0.2	71.0	85.5	95.0	4.2
Textiles	1304	0.01	6.65	0.4	58.5	80.7	95.0	3.4
Insulation board	545	0.01	13.66	0.45	54.0	72.5	88.6	5.1

Asbestos dust concentration, fibers/ml

Source: Health and Safety Executive (1979)

Table 2

Loss of Life Expectancy in Days from Lung Cancer in Asbestos Workers and from Various Causes Due to Smoking

Asbestos Exposure	Smokers	Non-Smokers
1 year at 2 f/ml standard[a,b]	1.6	0.14
1 year at 0.5 f/ml standard	0.41	0.035
20 years at 2 f/ml standard[a,b]	31	2.8
20 years at 0.5 f/ml standard	8	0.69
45 years at 2 f/ml standard[a,b]	53	5.4
45 years at 0.5 f/ml standard	13	1.3

Smoking[c]		
(1)	Cancer of lung, esophagus and other respiratory sites; chronic bronchitis and emphysema; and pulmonary heart disease	690
(2A)	All causes in (1) plus ischaemic heart disease	1355
(2B)	All causes in (1) and (2A) plus various other causes probably attributable to smoking	1618

[a] Based upon OSHA estimate of K . Assuming exposure begins at age 20. Lung cancer rates for smokers and non-smokers were determined from study of U.S. veterans.

[b] Assumes 2 f/ml standard implies average exposures of 0.5 f/ml and 0.5 f/ml standard implies average exposure of 0.125 ml; asbestos exposure begin at age 20.

[c] Based upon data of Doll and Peto (1976).

Table 3

Extra Lung Cancer Mortality per 1000 Exposed

Asbestos Exposure	Smokers	Non-Smokers
1 year at 2 f/ml standard[a,b]	0.35	0.041
1 year at 0.5 f/ml standard	0.086	0.010
20 years at 2 f/ml standard[a,b]	7	0.81
20 years at 0.5 f/ml standard	1.7	0.20
45 years at 2 f/ml standard[a,b]	13	1.7
45 years at 0.5 f/ml standard	3.2	0.43

[a] Based upon OSHA estimate of K . Assuming exposure begins at age 20. Lung cancer rates for smokers and non-smokers were determined from study of U.S. veterans.

[b] Assumes 2 f/ml standard implies average exposures of 0.5 f/ml and 0.5 f/ml standard implies average exposure of 0.125 f/ml; asbestos exposure begins at age 20.

Table 4

Observed and Expected
Mesotheliomas for
Dement et al. (1983) Data

Years since First Exposure (ave)	Person Years	Observed Mesotheliomas	Expected Mesotheliomas OSHA	Multistage 1^a	Multistage 2^a	Multistage 3^a
10 (5)	11390	0	0	0	0	0
10-20 (15)	10921	0	.023	.044	.011	.024
20-30 (25)	8055	0	.43	.55	.56	.45
30+ (35)	2775	1	.56	.41	.43	.53
			K_M = 2.2E-9	z= 1.2E-7	z= 4.4E-8	z= 3.1E-8

[a] Indicates number of dose-related stages.

Table 5

Observed and Expected Mesotheliomas
for Weill et al. (1979) Data

Years since First Exposure (ave)	Person Years	Observed Mesotheliomas	Expected Mesotheliomas DSHA	Multistage a_1	Multistage a_2	Multistage a_3
10-15 (12.5)	31180	0	0.008	0.01	0.09	0.46
15-20 (17.5)	29473	2	0.18	0.38	0.80	1.6
20-25 (22.5)	25080	0	0.57	0.70	0.68	0.03
25-30 (27.5)	14018	0	0.70	0.58	0.38	.0003
30-35 (32.5)	3832	0	0.33	0.21	0.10	10^{-6}
35+ (37.5)	1565	0	0.21	0.11	0.04	10^{-8}
			K_M = 7.0E-10	z = 3.6E-8	z = 7.6E-9	z = 1.6E-10

[a] Indicates number of dose-related stages.

Table 6

Observed and Expected Mesotheliomas for
Selikoff et al. (1979) Data

Years since First Exposure	Person Years	Observed Mesotheliomas	Expected Mesotheliomas			
			OSHA	Multistage		
				1[a]	2[a]	3[a]
20-25	4939	3	2.2	3.9	2.7	2.8
25-30	12815	22	15.5	22.7	19.9	19.7
30-35	14711	47	37.9	46.6	47.0	44.5
35-40	8756	46	40.9	44.2	47.4	43.6
40-45	4391	25	33.5	31.0	32.7	32.4
45-50	2328	28	26.6	21.0	21.1	23.7
50+	872	9	16.3	10.5	9.4	13.3
Parameters			$K_m = 1 \times 10^{-8}$	$z = 1.1 \times 10^{-6}$	$z = 1.2 \times 10^{-7}$	$z = 5.9 \times 10^{-9}$

[a] indicates number of dose-related stages

Table 7

Observed and Expected Mesotheliomas for Seidman et al. (1979) Data

Years since First Exposure	Person Years	Observed Mesotheliomas	Expected Mesotheliomas			
			OSHA	Multistage		
				1[a]	2[a]	3[a]
10-15	3628	0	0.11	.66	.21	.10
15-20	3174	0	1.3	2.5	2.0	1.3
20-25	2618	2	3.2	3.5	3.6	3.1
25-30	2026	5	5.1	3.8	4.2	4.9
30-35	1383	7	5.9	3.3	3.7	5.5
35-40	98	0	0.63	.29	.31	.59
Parameters			K_m= 5.7×10^{-8}	z= 3.0×10^{-6}	z= 1.0×10^{-6}	z= 2.4×10^{-8}

[a] indicates number of dose-related stages

Table 8

Observed and Expected Mesotheliomas for
Peto Data

Years since First Exposure	Person Years	Observed Mesotheliomas	Expected Mesotheliomas			
			OSHA	Multistage		
				1[a]	2[a]	3[a]
10-15	1633	0	0.0054	0.13	.002	.001
15-20	1860	0	0.16	.291	.16	.15
20-25	1761	1	0.72	.999	.799	.81
25-30	1496	2	1.7	1.89	1.9	1.9
30-35	837	2	2.0	1.95	2.1	2.0
35-40	414	2	1.8	1.43	1.6	1.6
40-45	92	0	0.63	.421	.443	.53
Parameters			K_m= 7.0×10^{-9}	z= 4.0×10^{-7}	z= 1.910^{-8}	z= 6.1×10^{-10}

[a] indicates number of dose-related stages

Table 9

Observed and Expected Mesotheliomas for Finkelstein Data

Years since First Exposure	Person Years	Observed Mesotheliomas	Expected Mesotheliomas			
			OSHA	Multistage		
				1[a]	2[a]	3[a]
15-20	1182	1	0.54	1.2	.95	.66
20-25	1061	4	2.24	4.4	4.3	3.1
25-30	555	5	3.11	4.3	4.5	3.9
30-35	104	1	1.15	1.2	1.2	1.3
Parameters			$K_m = 12 \times 10^{-8}$	$z = 7.8 \times 10^{-5}$	$z = 2.7 \times 10^{-6}$	$z = 1.5 \times 10^{-7}$

[a] indicates number of dose-related stages

Table 10

Summary of Fits of Models
to Mesothelioma Data Sets

	Selikoff et al	Seidman et al.	Peto et al	Finkelstein et al	Dement et al	Weill et al
OSHA						
Chi-square	11.5	2.7	1.0	3.0	.8	20
d.f.	6	5	6	3	2	5
p-value	.07	.74	.99	.39	.67	.001
Multistage 1[a]						
Chi-square	4.0	8.6	1.0	.2	.97	8.5
d.f.	6	5	6	3	1	3
p-value	.76	.12	.99	.97	.32	.037
Multistage 2[a]						
Chi-square	4.4	6.3	.8	.1	.75	3.0
d.f.	6	5	6	3	1	3
p-value	.62	.39	.99	.99	.38	.39
Multistage 3[a]						
Chi-square	4.4	2.8	.8	.9	.72	.60
d.f.	6	5	6	3	1	3
p-value	.62	.73	.99	.83	.39	.90

[a] indicates number of dose-related stages

Table 11

Comparison of
Loss of Life Expectancy in Days from
Mesothelioma Risk Estimated from
OSHA Model and Multistage Model

Asbestos Exposure	OSHA	Multistage		
		No. of dose-related stages		
		1	2	3
1 year at 2 f/ml standard[a]	2.2	1.5	1.3×10^{-3}	4×10^{-7}
1 year at 0.5 f/ml standard[a]	0.56	0.37	8.2×10^{-5}	7×10^{-9}
20 years at 2 f/ml standard[a]	22	19	0.57	5×10^{-3}
20 years at 0.5 f/ml standard[a]	5.6	4.8	0.036	7×10^{-5}
45 years at 2 f/ml standard[a]	25	22	1.2	0.025
45 years at 0.5 f/ml standard[a]	6.2	5.6	0.073	4×10^{-4}

[a] Assuming exposure begins at age 20; background rates used were for 1976 U.S. white males.

Note: Estimates of loss of life expectancy from exposure to predominantly chrysotile are about 1/5 of these estimates.

Table 12

Comparison of
Mesothelioma Mortality per 1000 Exposed
Estimated from OSHA Model and Multistage Model

	OSHA	Multistage No. of dose-related stages		
		1	2	3
Asbestos Exposure				
1 year at 2 f/ml standard[a]	0.48	0.13	6×10^{-5}	7×10^{-9}
1 year at 2 f/ml standard[a]	0.12	0.033	3.7×10^{-6}	1×10^{-10}
20 years at 2 f/ml standard[a]	5.3	3.4	0.082	4×10^{-4}
20 years at 0.5 f/ml standard[a]	1.3	0.86	5.1×10^{-6}	6×10^{-6}
45 years at 2 f/ml standard[a]	6.2	4.5	0.23	4×10^{-3}
45 years at 0.5 f/ml standard[a]	1.6	1.1	0.015	7×10^{-5}

[a] Assuming exposure begins at age 20; background mortality rates used were for 1976 U.S. white males

Note: Estimates of mesothelioma risks from exposure to predominantly chrysotile are estimated to be about 1/5 of these estimates.

Table 13

Estimated Loss of Life Expectancy
from Various Occupational Causes

	Days	
	2 f/ml Standard	0.5 f/ml Standard
45 years work with chrysotile asbestos		
OSHA Model	83	21
Revised estimates[a]		
one affected stage for mesothelioma		
smoker	46	12
non-smoker	10	2.6
two affected stages for mesothelioma		
smoker	43	11
non-smoker	6.7	1.6
Other Occupational Hazards		
Accidents from 45 years at commuting to work by automobile[b]		43
Accidents from 45 years work[c]		
Trade		24
Service		34
Manufacturing		34
Government		48
Transportation and Public Utilities		150
Construction		193
Agriculture		260
Mining, quarrying		264
Average over all industries		58

[a] Footnote on following page.

[b] Derived from 1978 U.S. traffic and mortality statistics (National Safety Council, 1982). Assumes, as estimated by USDOT (1977), that 33.7% of automobile travel is home to work.

[c] Based upon 1981 Accident Rates (National Safety Council, 1982).

Table 14

Estimated Mortality per 1000 Workers
from Various Occupational Causes

	2 f/ml Standard	0.5 f/ml Standard
45 years work with chrysotile asbestos		
OSHA Model	19	5
Revised estimates[a]		
one affected stage for mesothelioma		
smoker	10.3	2.5
non-smoker	2.3	0.51
two affected stages for mesothelioma		
smoker	9.7	2.4
non-smoker	1.6	0.30
Other Occupational Hazards		
Accidents from 45 years at commuting to work by automobile[b]		3.3
Accidents from 45 years work[c]		
Trade		2.0
Service		2.8
Manufacturing		2.8
Government		3.9
Transportation and Public Utilities		12
Construction		16
Agriculture		21
Mining, quarrying		21
Average over all industries		4.7
Exposure for 45 years to OSHA standard (assuming, as with asbestos, that average exposures are 1/4 of standard)		
Ethylene oxide[d]	.24 - .95	
Ethylene dibromide[e]	.05 - 2	
Arsenic[f]	.8 - 7.3	

a Footnote on following page.

b Derived from age-specific 1978 U.S. traffic and mortality statistics (National Safety Council, 1982). Assumes, as estimated by USDOT (1977), that 33.7% of automobile travel is home to work.

c Based upon 1981 Accident Rates (National Safety Council, 1982). Accident rates are assumed same for all ages.

d Crump (1983), page 3.

e OSHA (1983b), Table 4, using estimates by Brown

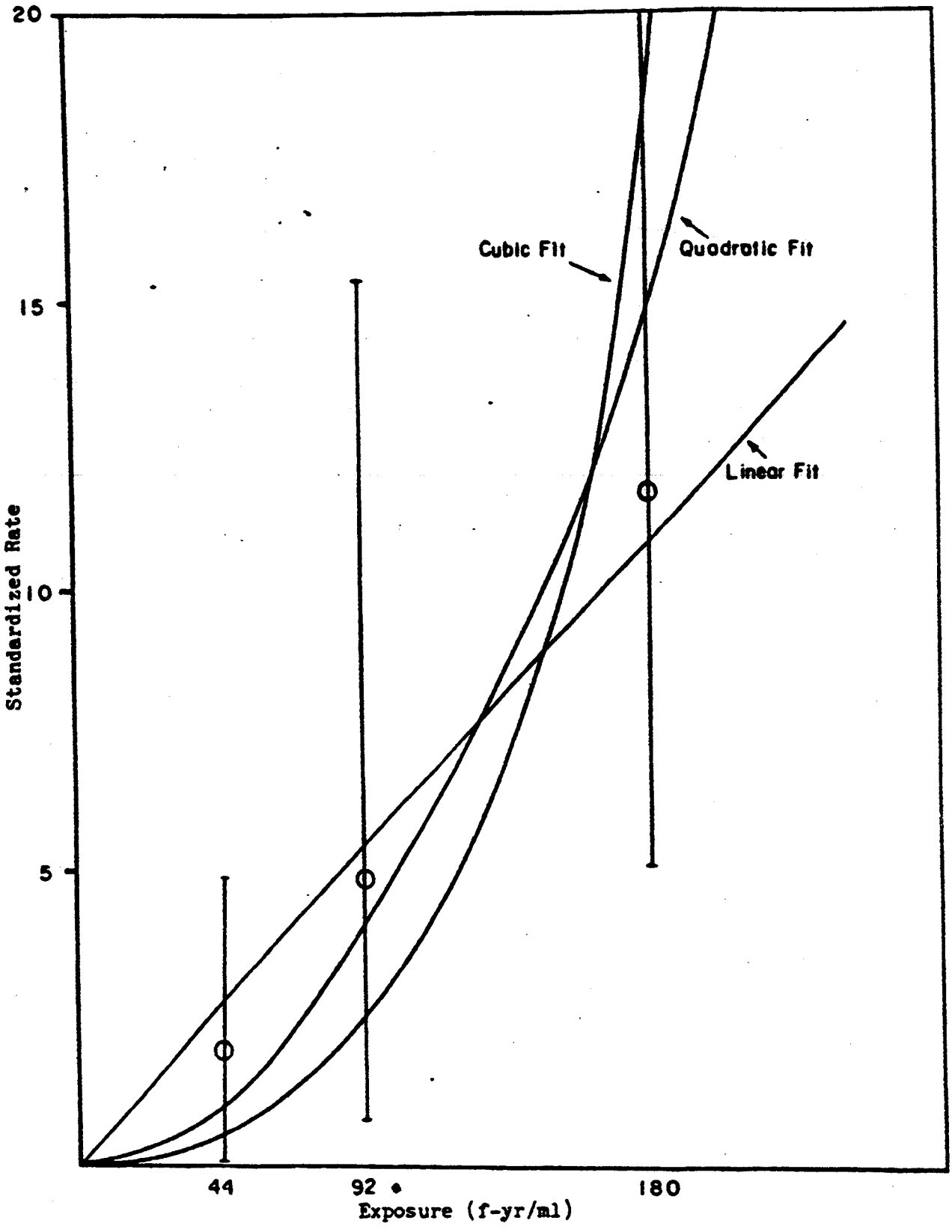
f OSHA (1983a), Table 4, using estimates by Crump

Footnote for Tables 13 and 14

a OSHA model for lung cancer is used with $K_L = 0.0065$ as explained in IV.B. Lung cancer background rates for smokers are taken as maximum of 1976 rate for U.S. white males and those of U.S. veterans (Kahn, 1969). Lung cancer rates in non-smoking U.S. veterans (Kahn, 1969) are used for non-smokers. Mesothelioma risks are estimated using the multistage model with parameters estimated from exposures to predominantly chrysotile (using same parameter values as used in Tables 11,12). Cancer rates for cancers other than lung cancer or mesothelioma are estimated, following OSHA, as 10% of the lung cancer rates in smokers.

FIGURE 1

Mesothelioma Incidence from Finkelstein Study
with Crude 90% Confidence Limits



SCIENTIFIC AND TECHNICAL REPORT STR 2

THE SIGNIFICANCE OF ASBESTOS AND OTHER MINERAL FIBRES IN ENVIRONMENTAL AMBIENT AIR

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June 1985

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THE SIGNIFICANCE OF ASBESTOS AND OTHER MINERAL FIBRES IN ENVIRONMENTAL AMBIENT AIR

by

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ISBN 0 9510544 0 6

This Report is dedicated to my wife Ann, and to Nicola, Julian, Emma, Alisdair and Stephen.

CONTENTS

The author Dr. Commins has had over 30 years experience in Environmental Pollution and has been involved in numerous assignments in this country, and overseas with Organizations such as W.H.O., C.E.C., O.E.C.D., I.U.P.A.C., N.A.T.O., U.S.P.H.S. He was 20 years in the Medical Research Council at the Air Pollution Research Unit, St. Bartholomew's Hospital, London, and 5 years with the Water Research Centre, U.K., where he was involved with air pollution and health, and drinking water and health, respectively. He has written numerous scientific papers and reports on environmental subjects, including on asbestos the well known 'Asbestos in Drinking Water; a Review', TR100 published by the Water Research Centre, U.K. in 1979, and an Independent Report which has had worldwide interest, 'Asbestos Fibres in Drinking Water' STR1, published in May 1983. He has had a very wide experience and is well known in many parts of the world, including Third World Countries.

He is now an Independent Consultant in Environmental Pollution and is a specialist in Air and Water contamination, Health Implications and Environmental Standards. As a Consultant, he can provide a useful independent view and has worked both in the U.K. and abroad on such topics as Air Quality and Drinking Water Quality Surveillance, Environmental Monitoring and Health, Environmental Impact Analysis, Environmental problems of various types including the topical issues of asbestos in environmental air and water. He is well qualified to write this Report on The Significance of Asbestos and Other Mineral Fibres in Environmental Ambient Air, a subject which is of worldwide interest.

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June 1985.

Interest in inhaled asbestos arose through the discovery of serious health effects associated with occupational exposure to these fibres early in the century. In recent years significant effort has been put into determining levels of asbestos in environmental air and into examining exposure situations where possible health effects might arise. Because of certain physical and some biological similarities between asbestos fibres and other mineral fibres, including some man-made mineral fibres, considerable interest has been expressed in environmental exposures to these fibres also. Concern has been expressed regarding the possible health implications of inhaling mineral fibres in environmental air. In the past, cases of mesothelioma cancers were reported to be associated with exposure to asbestos in environmental air and more recently with exposure to a natural non-asbestos fibrous mineral, erionite. In interpreting the significance of mineral fibres in environmental air, emotional attitudes have not been uncommon, causing in some cases unwarranted concern and even panic.

Because a considerable number of scientific and medical investigations have been carried out in recent years, it is now possible to appraise and draw some conclusions regarding the health implications of environmental levels of mineral fibres in environmental air.

The author, an Independent Scientist, has written and independently published this Report 'The Significance of Asbestos and Other Mineral Fibres in Environmental Ambient Air'. The readership is directed towards environmentalists, scientists, engineers, administrators, industrialists and even to the layman.

Where possible this Report attempts to define the technical, scientific and medical terms used. The subject covers the scene worldwide and considers some implications for different parts of the world. Where the possibility of a health risk might be defined, this is put into perspective with respect to some other 'rare-event' extremely low level day-to-day risks. The Report should help to allay some reported fears regarding the presence of asbestos in air in various environmental situations.

(Information contained in this Report is given in good faith but the author cannot accept any responsibility for actions taken as a result)

Few subjects have caused more scientific debate than the likely effects of exposure to very small amounts of a carcinogen. Until the discovery of the nature of DNA, it was commonly believed that the induction of cancer required intensive exposure, sufficient, for example, in the case of ionizing radiations to cause macroscopic damage to tissues, and the existence of a threshold dose below which no effects would be produced was taken for granted. Since then, the idea that mutations play an essential part in the production of cancer has been generally accepted and it is, consequently, presumed that the incidence of cancer that results from exposure to a very small amount of a carcinogen is likely to vary in direct linear proportion with the amount down to the ultimate level of a single unit. Newspaper headlines, in relation to asbestos, that one fibre kills cannot, therefore, be contradicted. There is, however, no reason to single out asbestos for public obloquy in this way as comparable statements also apply to most other carcinogens. The practical question, which is often evaded, is the extent of the associated risk.

Asbestos has been used extensively and for a long time and, in some respects, we are in a better position to make an informed guess at what the risk may be from exposure to a given amount for asbestos than for any other carcinogenic agent, other than ionizing radiations, as so many studies have been made of the health of workers exposed to it under industrial conditions. The position is, however, complicated by the fact that asbestos is not a unique chemical that owes its carcinogenicity solely to its chemical nature, but is a family of chemicals with important physical characteristics in common, the carcinogenicity of which is due both to their chemical identity and to the physical configuration of the fibres that they form. The hazard, therefore, depends partly on the type of asbestos involved and partly on the dimensions of the fibres which are modified by the way in which the asbestos is used. This greatly complicates the measurement of the "dose" to which anyone is exposed and Dr. Commins has done society a signal service in explaining the problem, taking both factors into account, and drawing what conclusions can reasonably be drawn from the existing evidence.

The implication of the very small risks which, it appears, are most likely to be produced by common environmental exposure is, however, difficult to appreciate. Risks of the order of one per million per year or per lifetime mean little to anyone other than an experienced statistician, and the interest of the Report has been greatly enhanced by the inclusion of the estimated risks of many other hazards of day-to-day life with which the general reader may be better acquainted. For it is only by a true appreciation of the meaning of the estimated risks and benefits that it is possible to make sensible decisions about the continued use of a material, its disposal, or its replacement by something else.

June 1985

Professor Sir Richard Doll, DM DSc FRCP FRS
Emeritus Professor of Medicine, University of Oxford
Honorary Member Imperial Cancer Research Fund's
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This Report appraises and draws conclusions regarding the worldwide health implications of exposure to asbestos and other mineral fibres in environmental ambient air. There has been and still is considerable misunderstanding regarding the health significance of environmental airborne asbestos, and to a lesser extent concerning other airborne mineral fibres. Because emotional attitudes are not uncommon, unwarranted concern and even panic has arisen in some cases in various parts of the world. However since a considerable number of scientific and medical investigations have been carried out in recent years, it is now possible to draw some conclusions regarding the situation worldwide; these conclusions should help to allay some reported fears about environmental asbestos in ambient air.

Asbestos and certain other mineral fibres are natural constituents of environmental air and will continue to be so. Airborne contamination by asbestos is widespread although it is at a low level. Until fairly recently other mineral fibres including man-made fibres had not been used as widely as asbestos; thus the extent of their contamination is less although it may perhaps increase. Some of the contamination arises from natural sources e.g. from naturally occurring fibrous materials but it also often results from human activities. Some of the asbestos and other mineral fibres are transmitted directly from sources to the air; a smaller amount will get into the air from the re-entrainment of deposited fibrous dusts. Apart from natural sources, mineral fibres become released to the air from such activities as mining, manufacturing, use and disposal of fibres and fibre containing products. Emissions to the air arise from industry, and from the abrasion and the deliberate destruction and disposal of mineral-fibre containing products. These emissions were greater in the past than nowadays because of the less effective control measures in use then. One emission which has been publicized is the use of mineral fibres (mainly asbestos) for vehicle brake linings. However the process of braking involves high frictional temperatures, which degrade virtually all the asbestos present in the brake material; consequently mainly non-biologically-active material is released to the air. The weathering and abrasion of panels etc. containing asbestos and other mineral fibres used for building products is another source of fibre release to the air. For outdoor air this release of fibre seems nowadays to be of minor consequence. In some cases the indoor levels of asbestos fibres in air could be somewhat raised compared with outside and a problem existed from asbestos sprayed surfaces in the past, especially where the 'dry' spraying of asbestos had occurred which allowed more substantial quantities of asbestos to be released from the rather friable surfaces produced. Other internal sources such as asbestos for electrical and thermal insulation, flue pipes, ironing boards, hairdryers, floor tiles, panels, etc. generally make very minor contributions; the exception is when the products are severely tampered with, for example by seriously damaging, sawing or strongly abreding them. Non-asbestos mineral fibres used in various products may also contribute to indoor air levels of fibrous materials. In many cases the fibre products contain a very high proportion of other materials like cement, plastic, rubber or resinous substances which bind the fibres (the fibres are essentially 'locked in') making it very much more difficult if not impossible for them to be released to the air than in the case of unbonded fibres. Chrysotile being the most used form of asbestos is much more commonly found in environmental air by comparison with crocidolite, amosite and tremolite. Man-made mineral fibres such as mineral wools and glass wool which are widely used, may fairly often contaminate the air to some small extent. Natural fibres such as aluminium silicate, calcium sulphate, attapulgite and erionite may also be found in the air in some places; a large number of different fibrous minerals at very low concentrations are likely to be present in air.

In order to detect and measure mineral fibres in environmental air, sophisticated equipment is required. Both the sampling and analysis of mineral fibres are highly specialized. For environmental air, transmission electron microscopy is needed to detect and identify all types and sizes of mineral fibres. Scanning electron microscopy which is cheaper and easier to use, is usually quite adequate to define the level of various mineral fibres which relate to a relative index of possible health risk; it cannot identify fibres less than about 0.2 μm diameter however. Fibres longer than 5 μm and in the range about 0.25 to 3 μm diameter are normally measured and used as a relative health risk index. However a small proportion of fibres in air is less than 0.25 μm diameter and the fibres may have some biological significance. Phase-contrast optical microscopy although very much cheaper than electron microscopy is totally unsuitable for measuring mineral fibres in environmental air; however, it has been satisfactory for occupational monitoring. To allow a comparison to be made between occupational and environmental exposures, the measurements by electron microscopy are transformed where appropriate into results which are equivalent to those recorded by optical microscopy. In order to obtain a meaningful result, the numbers of fibres in a sampled volume of air are recorded; mass concentration results are not regarded as a suitable index of possible health risk. In some cases mass concentration results have been converted to number concentrations and used for assessing the exposure to asbestos fibres. Unfortunately the conversion factors are very variable since they depend on the nature and precise dimensions of the fibres present (which are not always known) and in many cases this will lead to inaccuracies.

In order to define concentrations of mineral fibres in environmental air which are meaningful in terms of health risk, considerable care has to be taken in interpreting published results. Some studies provide little or no information on sampling positions and methods, or analytical techniques; some give no indication of how representative the samples are or over what period the samples were collected. In assessing environmental exposure to asbestos it is necessary to pay greater attention to long-term concentrations. Taking account of these factors, a typical population lifelong exposure (indoors plus outdoors) to asbestos (fibres greater than 5 μm long and 0.25-3 μm diameter, aspect ratio greater than 3:1) might be about 0.0005 f/ml. However there is some uncertainty regarding the precise figure for typical exposure. In countries or in situations where relatively little asbestos has been used the value might be lower. In some cases a typical lifetime figure of 0.001 f/ml or even perhaps higher might apply. For non-asbestos fibres there is insufficient data to estimate exposures in environmental air. Specific non-asbestos mineral fibres may be within an order of magnitude of asbestos levels; total non-asbestos fibres would seem to be often higher than for asbestos itself, perhaps even as much as ten times higher in some cases.

For a typical environmental asbestos level of 0.0005 f/ml, several thousands of fibres will be inhaled by a person into their lungs every day; only a fraction of the fibres will remain for long periods in the lung however. Although several thousands might suggest a high dose, in fact in mass terms it might represent only 0.2 μg per day which is a minute fraction of the total particulate matter we typically inhale every day from the general air. In contrast with the general environmental air, the exposure for the modern day asbestos worker could be well over a million fibres inhaled per day at work. This would compare with perhaps even a thousand million or more fibres inhaled per day in the past where certain workers were exposed to very high concentrations of asbestos.

No definite risk to the general public from environmental ambient asbestos exposure seems to exist nowadays; however, in order to assess the extent of any risk, theoretical mathematical predictions of the level of possible risk have been made and published. These predictions have been made by extrapolation of past heavy occupational exposures (where the incidence of human disease has been recorded) to the known low levels of exposure for the general public inhaling environmental air. Industrial diseases associated with asbestos exposure are in all probability more likely to be related to inhaling extremely high levels of asbestos over prolonged periods. Although very precise levels of exposure are not known for the relevant exposure periods years ago, it is anticipated that long-term typical levels could have been as high as several hundreds of fibres/ml air in areas where men were working. The exposure to asbestos for the general public is minute by comparison. In the mathematical model referred to above, predictions were made of possible levels of lung cancer and mesothelioma risk from inhaling environmental asbestos; asbestosis and other cancers were considered rather improbable. Also any human cancer risk from ingesting amounts of environmental asbestos following the inhalation of airborne fibres was considered to be at most, exceedingly low; such a conclusion has been based on the evaluation of human epidemiological studies and animal feeding studies. Taking account of the useable published predicted risk estimates, a critical evaluation suggests that if any risk exists from inhaling asbestos in environmental air it is at an extremely low level. A reasonable estimate for a lifetime cancer risk due to asbestos itself which might arise from a lifelong environmental exposure of 0.0005 f/ml would appear to be about one in 100,000 or lower. Even for teachers and children exposed in school buildings containing asbestos, the predicted lifetime risk is only marginally greater in relation to other comparable groups of people. For brief periods of exposure which might arise for the general public where they or others have occasionally sawn or sanded asbestos materials, this would again appear to provide only a marginally increased possible lifetime risk. Since crocidolite and/or amosite might be more hazardous than chrysotile, the theoretical risk from their exposure could be higher than that for chrysotile. However by far the commonest form of asbestos in environmental air is chrysotile and it is anticipated that it would be rare, if ever, these days for individuals to be exposed to lifetime concentrations of amphibole asbestos as high as 0.0005 f/ml. Thus the effective population risk (i.e. the number of any possible cancer cases) from exposure to environmental levels of amphibole asbestos should be exceedingly low. A lifetime risk level of around one in 100,000 for environmental asbestos exposure would seem to be an acceptable figure. It would appear to be lower than day to day 'rare-event' extremely low level risks, such as the cancer risk, from cosmic radiation when flying across the Atlantic, or from eating charcoal broiled meat, or the risk of being killed by lightning. Even if the typical lifetime exposure to asbestos (predominantly chrysotile) is as high as 0.001 or even perhaps 0.002 f/ml, the risk would still seem to be within, or lower than, the range of these 'rare-event' situations. It is anticipated that the opportunities for lifetime exposures greater than these levels would be rare and in consequence the number of possible cancer cases (if any) should be very small indeed. The World Health Organization regards a level of 1 in 100,000 for lifetime risk as acceptable in relation to defining guidelines for carcinogenic substances in drinking water.

One should not overlook the fact that any possible risk of lung cancer from asbestos exposure appears to be greatly multiplied by tobacco smoking; non-smokers will therefore avoid this additional risk. Greater possible risks could be associated with certain workmen dealing regularly with asbestos products where the processes are dusty; such exposures are however regarded as occupational and are outside the scope of this Report.

Any possibility of a risk associated with environmental asbestos exposure

in the future should decrease even further as improved control measures and changes in fibre use occur. The anticipated decline means that the health implications for the future will probably be of even lower significance. A decline already seems to be evident in that cases of mesotheliomas found in the past in members of the public seem not to be reported nowadays. Also the fairly sharp decline in recent years in the use of crocidolite and amosite in relation to chrysotile could decrease any risk since the amphibole forms appear to be more hazardous than chrysotile.

For inhaled non-asbestos mineral fibres including man-made mineral fibres (other than in the case of exposure to naturally occurring fibrous erionite), there seems to be no risk from cancer. This is supported by industrial experience where exposure to various mineral fibres has not definitely been shown to be associated with the diseases which can arise from heavy asbestos exposure. However occupational exposures have been lower than for asbestos. Also the fibres in industry are often larger and consequently are less readily inhaled. Nevertheless what is of importance is the fact that in a number of cases the workers have not perhaps been exposed for long enough to enable long latent period diseases such as mesothelioma and lung cancer to develop. There are in fact some suspicions regarding lung cancer risk for occupational exposure to certain man-made mineral fibres. Thus for the present, one should regard the health implications of exposure to non-asbestos mineral fibres as a little uncertain. It is of interest to note too that in some exposure situations e.g. in city air, there can be a preponderance of non-asbestos fibres over asbestos ones. Animal testing suggests that all mineral fibres of dimensions comparable to asbestos may have somewhat similar biological properties. However some fibres e.g. glass, are less durable and can be dissolved by lung fluids and could therefore be less hazardous. Non-asbestos mineral fibres in environmental air can be of similar dimensions to asbestos although in a number of cases they may be much larger and therefore not so readily inhaled. The presence of non-asbestos mineral fibres in environmental air should not be overlooked, especially in light of the fact that there is anticipated to be an increased usage of such fibres with time; in a number of cases they are used as asbestos substitutes. However it is uncertain whether any possible health significance relating to exposure for the general public will alter in the future. The probability is that any risk will remain at a very low level. If any future concern regarding environmental asbestos is expressed then one should at least consider the significance of other mineral fibres at the same time.

Setting aside the natural erionite exposure in some villages in Turkey where mesotheliomas have arisen, it is perhaps not impossible that unacceptable levels of exposure to asbestos and possibly other mineral fibres could exist in certain parts of the world today. One would anticipate that the chances of finding such undesirable conditions regarding asbestos exposure would be very remote now, at least in developed countries. For parts of the developing world however, it would seem that particular vigilance should be exercised to ensure that asbestos risk situations such as those found elsewhere 20 to 30 years ago are controlled if they happen to exist. The exposure to the natural fibrous mineral erionite is perhaps a warning that there might be other exposure situations in the world in relation to this or other comparable minerals. The dimensions of erionite fibres are not dissimilar to those for some amphibole forms of asbestos and both have been associated with a definite risk of mesothelioma when substantial quantities of fibres are inhaled. Thus efforts should be made to identify any possible risk situations where the general public might perhaps be exposed to excessive levels of mineral fibres of different types.

RESUMÉ OF THE HEALTH SIGNIFICANCE OF ASBESTOS AND OTHER MINERAL FIBRES IN ENVIRONMENTAL AIR

There has been, and still is, considerable misunderstanding regarding the health significance of environmental airborne asbestos and to a lesser extent other airborne mineral fibres. Emotional attitudes are not uncommon, causing in some cases unwarranted concern and even panic. Because a considerable number of scientific and medical investigations have been carried out in recent years, it is now possible to appraise and draw some conclusions regarding the worldwide health implications of environmental levels of asbestos and other mineral fibres in air; it is with this background that this Health Resumé has been compiled.

There would seem to be no firm evidence that the general population is currently at risk from developing cancer or other diseases as a result of their exposure to present day levels of asbestos or other mineral fibres in air, apart from one special case of localized exposure to the non-asbestos fibrous mineral, erionite, in some Turkish villages. In this special situation in Turkey, there is a very strong indication that the inhalation of erionite where it occurs quite naturally, has caused, and still is causing, cases of mesothelioma and also possibly lung cancer in the general population living in certain villages there. Elsewhere in the past, about 20 years ago, a few cases of mesothelioma in the general public living in some mining areas were associated with exposure to crocidolite asbestos. Also about 20 years ago, cases of mesothelioma were recorded in the general population who were exposed to presumably rather excessive levels of asbestos near factories, etc., or inside people's homes; the home environment being probably heavily contaminated as a result of asbestos workers bringing the dust home on their workclothes. The general workplace risk of mesothelioma however seems to be far less associated with the much more commonly used chrysotile asbestos, in comparison with amosite or crocidolite asbestos which are now both declining in use.

Although there seems to be no real demonstrable risk to the general public from exposure to asbestos nowadays, some mathematical predictions have been made of the possible level of health risk by extrapolation using occupational data. These predictions have been made on the basis of the very significant occupational health risk from asbestos in relation to the workers' heavy exposure in the past and the comparatively minute exposure for the general public. Risk models for both lung cancer and mesothelioma have been used and the predicted risk of asbestos exposure allowing for factors such as smoking has been determined. The public's cancer risk (if any) arising from the ingestion of asbestos and any other mineral fibres following the inhalation of asbestos is considered to be at most, exceedingly low. In the case of the fallout of asbestos and other mineral fibres from the general air, where they might ultimately contaminate water supplies and food crops and thereby become directly ingested, this contribution appears to be a trivial source of exposure; the health risk associated with such fallout is considered quite insignificant.

The critical evaluation of the published data from mathematically derived risk estimates for inhaled environmental asbestos suggests that if a risk exists, then it is at an extremely low level. As a result of the current exposure to asbestos itself in environmental air, the possible lifetime cancer risk (lung cancer and mesothelioma combined) would appear to be about one in 100,000 or lower. Past exposure levels of asbestos in special cases may have been associated with a somewhat higher level of risk; future environmental exposure risks will almost certainly be even lower still. Other than cancer, no other health risks (e.g. asbestosis) from asbestos exposure in environmental air appear

to be at all probable. The predicted possible risk from asbestos in air would appear to be at an acceptable level and seems to be within the range or even lower than some other 'rare-event' extremely low level risks which society faces, e.g. the cancer risk, from cosmic radiation when flying across the Atlantic, or from eating charcoal broiled meat, or the risk of being killed by lightning. The World Health Organization too, regards a level of lifetime risk of one in 100,000 as quite acceptable in relation to defining environmental guidelines worldwide for the quality of drinking water. In relation to asbestos exposure, any possible risk from lung cancer would appear to be greatly multiplied by smoking habits. Thus non-smokers avoid this major additional impact and their possible lung cancer risk from asbestos could be as much as one tenth that for smokers also inhaling asbestos in environmental air.

It should be stressed that in the above overall assessment of health risk, particular account was taken of possible higher risks for certain people e.g. teachers and children who might be inhaling additional asbestos fibres in some schools or other buildings where elevated levels of fibres in the indoor air have been reported. It would appear that the possible cancer risk is only marginally greater and still well within, or lower than, the range of other very low-level day-to-day risks society faces; a possible lifetime total cancer risk from asbestos exposure alone of around one in 100,000 or lower would still seem to apply for such groups. Similarly, for brief higher levels of asbestos exposure that might arise for the general public where they or others have sawn or sanded asbestos material, would appear to provide only a marginally increased possible lifetime risk. Greater possible risks could be associated with workmen dealing regularly with asbestos products where the processes are dusty; however such exposures are regarded as occupational exposures and are outside the scope of this Report. Since the amphibole forms, crocidolite and/or amosite, might be more hazardous than chrysotile, the theoretical risk from exposure to them could be higher than for the latter. However, by far the commonest form of asbestos in environmental air is chrysotile and it is anticipated that it would be rare, if ever, these days for individuals to be exposed to significant lifetime concentrations of amphibole asbestos. Thus the effective population risk from exposure to environmental levels of amphibole asbestos should be exceedingly low.

Apart from the present known risk of mesothelioma to certain Turkish villagers arising from the inhalation of natural erionite fibres, there is no firm evidence of any public health risk from current exposures to other natural or man-made mineral fibres. No models for predicting a level of possible risk to non-asbestos mineral fibres have been proposed. Even in industrial situations where the exposures, although very modest in comparison with past asbestos levels, are considerably higher than in the general environmental air, there is to date no definite evidence that workers contract asbestos-type diseases; however further occupational studies are needed to quantify any possible risk. Nevertheless it is of interest that in some environmental exposure situations (e.g. in city air) there would appear to be a preponderance of non-asbestos fibres over asbestos ones; a proportion of these non-asbestos fibres will be of natural origin. Also animal testing suggests that various mineral fibres can have similar biological properties to asbestos, where the fibre dimensions are comparable. Thus the significance of the presence of such non-asbestos fibres should not be overlooked, especially since their use is increasing. However although there is a little uncertainty regarding their precise possible health significance for the general public, the probability is that the environmental risk, if any, is at an extremely low level and it will continue to remain so, except perhaps in the case of erionite.

Although in general, the health risk from exposure to environmental

asbestos and other mineral fibres would appear to be extremely low, it may not in fact be zero and consequently certain precautions are prudent. However if the currently available control measures and codes of practice are correctly followed, no further drastic general measures would normally seem to be necessary for the public's protection. The one isolated exception seems to be natural erionite contamination, e.g. in some village situations in Turkey where a definite health risk exists, and further controls could be required.

It is not perhaps impossible that unacceptable levels of exposure to some mineral fibres, including erionite and asbestos could occasionally still exist in certain other parts of the world. In developed countries, the chances these days of discovering really undesirable conditions regarding asbestos exposure, should be very remote; however in parts of the developing world, particular vigilance should be exercised to ensure that some of the asbestos risk situations which were experienced elsewhere, 20 or so years ago, are controlled if they happen to exist. Similarly, it is important to try to identify situations where the exposure of natural non-asbestos mineral fibres may be undesirably high. Thus one could anticipate that in the future, the health risk from exposure to asbestos and other mineral fibres in the environmental air worldwide, will be at an acceptable very low level. In the case of the naturally occurring minerals like erionite the situation could be different however, in that it may be difficult to apply control measures to protect fully people living nearby.

1. INTRODUCTION

In order to evaluate the significance of asbestos and other mineral fibres in air it is essential to review a range of aspects; these include the types, uses and potential sources, sampling and analysis, concentrations found in air, as well as the health implications. In this introductory chapter, the types, uses and potential sources of asbestos and other mineral fibres which can contaminate environmental air are considered. Other aspects are dealt with in subsequent chapters.

There have been numerous reviews of the properties, types and uses of asbestos, and some on other mineral fibres, including man-made mineral fibres (1-10); only a brief review of these particular aspects is given here. More emphasis is given to asbestos because of its relevance within the context of this Report and also since more is known about asbestos than other mineral fibres.

1.1. Asbestos

1.1.1. Types of asbestos

Asbestos exists as a class of naturally occurring fibrous silicates (1, 3, 9). Asbestos deposits are found in many parts of the world. Russia and Canada mine considerable quantities but South Africa, Zimbabwe, China, Italy, Brazil, United States of America and Australia are also noted for their production (11). Small deposits often quite uneconomical to mine will be found in many countries. Asbestos or products containing it are manufactured or imported by practically all countries.

There are two main groups of asbestos: the serpentines and the amphiboles, comprising a total of six main types of fibre (1,3). The technological importance of asbestos relates to its resistance to fire, its thermal and electrical insulation properties and its special binding capacity when incorporated into cement products, etc. This binding property provides strength and stability (9,11) when it is used in cement products, and also when asbestos is mixed with various other materials such as occurs in the fabrication of brake linings and floor tiles, etc. The names of the six main types of asbestos are (a) Serpentine group: Chrysotile ('white asbestos'), (b) Amphibole group: amosite, crocidolite ('blue asbestos'), anthophyllite, tremolite, actinolite.

Different asbestos types as mined may be contaminated with other minerals including fibrous ones; some of these minerals may be removed in processing raw asbestos (4). Also different asbestos types may exist together; for example chrysotile is not uncommonly associated with small quantities of an amphibole, tremolite (4, 8).

The properties of the different fibres vary. Chrysotile is rather different from the amphibole group: it tends to be attacked by acids (9) because of the magnesium hydroxide within its lattice structure. The amphiboles tend to be more resistant to such attack (1). Chrysotile is usually a flexible, silky and tough fibre, whereas the amphibole types are usually somewhat brittle by comparison (1). Chrysotile is composed of minute fibrils which are curled silicate sheets spiralled as helices around a central fine capillary; the fibrils (the individual ultimate fibres) can be as narrow as 0.01 μm in diameter (2) but typically they are 0.02 to 0.03 μm (2). The amphiboles in contrast are solid lath-like fibrils generally having a larger cross sectional area than chrysotile; they can be around 0.1 μm in equivalent diameter or larger. When heated to temperatures in excess of 500°C chemical changes will occur and at 750°C the physical strength of asbestos will decrease (13).

Because of the different properties of the various fibres, they are used for a variety of purposes (1). The consumption of asbestos has greatly increased during this century (9, 14). Approximately 95% of all asbestos produced is chrysotile; the remainder consists mainly of amosite and crocidolite. In recent years somewhat less asbestos has been produced; the use of crocidolite and amosite has declined in particular (15).

1.1.2. General uses of asbestos

Its range of characteristics of flexibility, strength and durability have allowed more than 3,000 uses to be made of this unique substance (16). Some of the more common uses (listed in typical order of amounts produced) are asbestos-cement building products, asbestos-cement pipes, floor tiles, sheets, friction materials, fire-resistant insulation boards, jointings and packings, textile products, fillers, reinforcement, insulation and coating materials, etc. (1). More then 80% of the world's usage of asbestos is as asbestos-cement products (2). The proportion of the asbestos incorporated varies widely, i.e. between about 5 to almost 100%, according to the type of product. Mixtures of different asbestos types are used to provide optimum properties for certain products.

1.1.3. Potential sources of asbestos in environmental air

Because of the widespread use of asbestos and products containing it, inevitably some contamination of environmental air has arisen; the problem of environmental contamination was greater in the past because of the existence of fewer control measures. In addition to man-made sources, some natural sources of asbestos (weathering of soils and rocks) have contaminated environmental air (6).

Airborne fibres will ultimately be deposited on to various surfaces as a result of natural fallout mechanisms often accelerated by rainfall. Many of these deposited fibres will become embedded in soil and some will fall or get washed into water sources. A limited quantity of deposited fibres may become re-entrained into environmental air. Some potential sources of asbestos fibres released to air are asbestos boarding, guttering, drainpipes, roofing, felting, insulation materials, tubs and pots, brake linings for motor vehicles, and in the home or inside various buildings from a variety of sources. In many cases, at most only tiny quantities of fibres are released from these particular uses of asbestos; this is due to the fact that the products are often sealed with paints, etc. or the fibres are so firmly bound (i.e. locked into a matrix), or are left otherwise undisturbed. Only unless such products are sanded or sawn, etc., will there be the possibility for significant quantities of fibres to be released. In addition there is a range of minor possible sources of asbestos; these have been considered and appraised elsewhere (6, 9, 17, 18). Many potential sources of asbestos have been investigated but in most cases there would seem to be little evidence of significant release of asbestos fibres (6, 9, 19). However there are certain sources where some people have expressed particular concern regarding possible fibre release to the general environmental air; these sources are evaluated below. They are:-

(a) asbestos brake linings; (b) asbestos waste tips; (c) industrial emissions and mining activities, including tailings dumps; (d) use of asbestos roofing and other outdoor asbestos construction materials; (e) asbestos in the home and in other buildings (especially insulation materials); (f) shipyard activities; (g) use of asbestos tailings and asphalt-asbestos mixtures for road surfacing; (h) asbestos removal and demolition activities; (i) do-it-yourself activities involving asbestos products.

Where very extensive construction work, etc. is carried out using asbestos materials the exposure may be higher to workmen, but this situation can be regarded as occupational exposure and is therefore outside the scope of this Report. In many cases it is not possible to determine the precise contribution which various sources make to the general environmental air. Thus in this Report much greater reliance is placed on the overall levels of total 'respirable' asbestos fibres actually measured in outdoor and indoor situations. (see Chapters 2 and 3).

(a) Asbestos brake linings as a source of asbestos in environmental air.

For many years brake linings used in motor cars and some other forms of transportation and in machinery, have contained asbestos; up to 60% of the final product used can contain asbestos (20, 21). When braking, the linings gradually wear away releasing particles to the air. It has been suggested that in urban areas the wear of motor car brake linings may possibly be a significant source of asbestos air pollution (6). However as a result of the frictional processes which occur during braking, very high temperatures are produced which are sufficient to cause a physical and chemical degradation of the fibrous properties of the asbestos (6, 9, 21-23). The temperatures are sufficiently high to cause chrysotile asbestos to degrade to the non-fibrous amorphous mineral forsterite (20); forsterite has been reported to be a harmless non-carcinogenic material (6, 22, 23). Various studies have been carried out to determine the proportion and amounts of the asbestos fibres in the brake linings which may be released to the general air (6, 25-28). A study reported in 1978 suggested that braking caused 99.7% of the asbestos in the brake linings to be converted into inert and harmless particles (6, 23). In another study reported in 1982 (21), over 99.9% of the asbestos was found to be chemically or physically altered so that it could no longer be identified as asbestos; furthermore less than 1% of any asbestos fibres released were longer than 5 μm (i.e. few were of dimensions which are considered to be of particular biological significance; see Chapter 4). In another study reported in 1976 (6, 29), only 3-6% of the debris released from brakes seemed to be asbestos; again few of the asbestos fibres were longer than 5 μm. Various other studies reported that very little asbestos as such is released from brake linings (6, 20-23, 231). In a more recent study (21) it was found that only 2 to 6 μg of asbestos/km/vehicle was emitted to the air. Even measurements made very close to test vehicles indicated concentrations of less than 0.0004 to a maximum of 0.007 f/ml air (19); at cross roads in a large city concentrations up to 0.0004 f/ml air were observed (19). Thus it would appear that the emissions of asbestos from the use of asbestos brake linings are not of major consequence (see Chapter 3, for comparison with information on general levels in environmental air).

(b) Asbestos waste tips.

Clearly such tips can be a potential source of windblown asbestos dust. These days such tips are better controlled (6, 8) and a minimum of dust will be released to the air. Near one asbestos waste dump (19), levels of 0.0001 to 0.00045 f/ml air were recorded. In the past some measurements made in the U.K. provided higher figures and the majority of results seemed to be in the concentration range 0.01 to 0.2 f/ml (8). The method of analysis used however was optical microscopy and the results are likely to be in error because of the presence of non-asbestos fibres which will have been present and recorded as asbestos (see comments, Chapters 2 and 3).

Insufficient data is available to draw firm conclusions, but if the normal control practices are carried out asbestos waste tips should not now be

significant contributors of asbestos to environmental air (6, 232). Any problem is normally minimized anyway because such tips are usually remote from where people live.

(c) Industrial emissions and mining activities, including mining tailing dumps.

In the past some industrial sources have been reported to be very significant contributors of airborne asbestos levels; eye witness accounts (30) have referred to snow-like films of asbestos dust in the communities of some asbestos mining areas in years gone by. These days with the practice of improved controls for mining activities, the emissions to environmental air are much lower. Probably even today certain activities (especially in some parts of the less developed world) release some asbestos to environmental air; potentially they are probably one of the larger sources of human exposure although they are quite local to such mining areas. Recently in South Africa, concentrations of asbestos in the range 0.0002 to 0.6 f/ml air have been reported close to mining areas (31). In Canada, concentrations in the range 0.0002 to 0.0018 f/ml have been reported (31). In Italy a level of 0.009 f/ml has been recorded (32). In the past levels of even up to over 1 f/ml have been reported (33, 34), but these were probably short duration measurements and thus are in no way representative. Factory emissions on the other hand these days should be relatively minor sources where proper controls are implemented; most developed countries have introduced adequate means of control. In some cases in certain developing parts of the world the controls may not yet be very effective. Levels as low as 0.0005 f/ml to 0.002 f/ml air near manufacturing plants have been recorded in recent years (19, 32).

Transportation of asbestos these days is not considered to be a potential source of asbestos since the material should be conveyed in adequate packaging (19); the situation was very different some years ago however (268).

(d) The use of asbestos roofing and other outdoor asbestos construction materials.

Such materials have been used extensively in the construction of various types of buildings; they are still used widely in some parts of the world. In studies carried out in Germany, the concentrations were below 0.00015 f/ml in a village where 'claddings' and roofs were made of asbestos products (19). Samples taken on a very large heavily weathered roof showed a maximum of 0.0004 f/ml (19). In South Africa in urban Soweto, an area with almost exclusive asbestos-cement roofing, the concentration of asbestos was only 0.0002 f/ml (31). In Austria, levels were reported to average less than 0.0001 f/ml in an area of asbestos roofing (32). Thus in general the levels in areas where asbestos roofing and other construction material have been used would appear to be low (for comparison with general environmental levels, see Chapter 3).

(e) Asbestos in the home and other buildings.

There is a wide range of potential sources within homes and other buildings, e.g. asbestos flue pipes, electric toasters, electric heaters and hairdryers, ironing board pads, oven gloves, cooker and boiler seals, cooker simmer mats, ceiling and floor tiles, some clothes dryers, packing materials boarding, lagging and for some other insulation purposes (more especially sprayed-on insulation). One common misconception is that the different products containing asbestos all release fibres. Many asbestos products consist of asbestos fibres which are 'locked into' cementitious or similar binding materials which makes it very difficult (if not impossible in some cases) for

fibres to become released to the air. One rather different situation however exists where asbestos has been in the past sprayed onto surfaces (often for insulation purposes). In the United States it has been reported (76) that where a dry mixture of asbestos and binders was applied through a water spray, much more loose and friable surfaces occur compared with cementitious or plaster-like material applied as a wet slurry with asbestos (see Chapter 3, section 3.2). In a number of cases asbestos fibres could be readily released from surfaces where asbestos had been sprayed on; the spraying of asbestos has only been carried out to a rather limited extent worldwide and the practice may not have occurred at all in some countries; it has now been abandoned (75). Probably where this practice has occurred it is potentially one of the more notable sources of asbestos fibres being released to the air inside buildings. However even in this case the average concentrations are not very high (see Chapter 3 and also below).

The surface of any asbestos-containing article that becomes damaged is a potential source of small quantities of asbestos fibre released to the air. In the home or in other buildings many asbestos products are sealed however (as a result of being painted or they are inside equipment, etc.), and the release of fibres is thus at an absolute minimum. Studies of airborne concentrations inside buildings have been made in order to assess the overall likely combined contribution from various sources there. Typical long term median concentration levels of around 0.0006 f/ml have been suggested for indoor air where asbestos products are present (9). Higher levels have been reported (see Chapter 3) but in many cases these results are not representative of long-term exposure conditions. Probably the commonest source of asbestos exposure to the general public, albeit at a low level, is from sources within buildings (9). One particular source that has been investigated are hand-held hair-dryers since a few years ago it was suggested that they were a possible source of undesirable quantities of asbestos. However extensive studies (35, 36) indicated that the maximum level of exposure was only 0.002 f/ml even under very extreme conditions; this is trivial (see Chapter 3). A comparison between the levels of asbestos inside different buildings, including school buildings where some higher levels have been reported, is given in Chapter 3.

(f) Shipyard activities.

Few actual measurements have been made of the general environmental air adjacent to shipyards where asbestos products for insulation and other purposes were used. Elevated levels may have occurred in the past (37, 39); however these days, the possibilities for significant fibre release to the general air are anticipated to be rather remote.

(g) Use of asbestos 'tailings' and asphalt-asbestos mixtures for road surfacing.

In the U.S.A., the use of 'tailings' for this purpose is prohibited now (6); at one time this source could have represented a very substantial source of emission to the general air in some situations in certain countries. The release of asbestos from the use of asphalt-asbestos mixtures for road surfacing has been investigated but it seems unlikely that fibres could become airborne in significant quantities (6).

(h) Asbestos removal, demolition and disposal activities.

It is now recognized that this can create a potential hazard for workers involved in removal and demolition and disposal practices (118). These days, codes of practice should be followed to minimize worker exposure (6). For the

general public, these activities are potential sources of only brief exposures to asbestos. In the past undoubtedly the levels would have been higher. Nowadays codes of practice are laid down which will minimize the exposure for the general public (6, 232). In some cases unwarranted removal and demolition rather than 'sealing in' asbestos products in situ could have caused unneccessary exposure to the general public. Demolition of asbestos-cement claddings has been reported to give rise to a maximum of 0.001 f/ml air (19); 100 m away the concentration was less than 0.0001 f/ml (19).

(i) Do-it-yourself activities involving asbestos products.

This is a potential source of exposure for the general public. These days recommended procedures are suggested (17, 18) to minimize exposure to asbestos fibres. Unless care is taken this source may perhaps represent a substantial source of exposure for members of the public. Particular care needs to be taken when sanding surfaces such as floors, walls and ceilings, etc., and also when cutting or drilling asbestos products; codes of practice have been published (17).

1.2. Non-asbestos fibres

1.2.1. Types, uses and potential sources of non-asbestos mineral fibres

There are numerous known types of non-asbestos mineral fibre; it has been estimated that over 150 asbestiform minerals exist (40). In addition, a number of man-made mineral fibres exist (7). Some of the commonest non-asbestos mineral fibres are:- attapulgite, erionite, rock wool, slagwool, carbon, glass, ceramic, sepiolite, aluminium silicate, meerschaum, wollastonite, talc, graphite, alumina, boron, mica, halloysite, dawsonite, calcium sulphate, potassium octatitinate, vermiculite, pigmentary potassium titinate, brucite, pyrolusite, rutile (7, 9, 41, 231).

Non-asbestos fibres are used for a variety of purposes, some are put to the same use as asbestos itself. Their detailed uses and properties have been reported elsewhere (7, 9, 10, 42). Little is known about the contribution which various uses of non-asbestos mineral fibres make to the general environmental air; certain mineral fibres can often be rather large and therefore do not always come within the definition of 'respirable' fibres which usually is the case with asbestos (7). The available data (see Chapter 3) suggests that the levels of non-mineral fibres in environmental air are usually very low. Although little is known about general environmental levels, one fibrous mineral of special concern is erionite. Erionite is found naturally in some villages in Turkey; levels of over 1 f/ml have been reported during the cleaning of caves where some villagers live (9, 43). The exposure to this natural mineral erionite is associated with cases of mesothelioma in the village population (see Chapter 4). This mineral seems to have had very limited commercial applications however (9).

A recent study (31) has indicated that in many cases relatively high proportions of the total fibres detected in environmental air are non-asbestos mineral fibres; for example in street air it has been reported that perhaps 90% of the mineral fibres are non-asbestos (19). Recently it has been shown that in some places in South Africa, up to well over 90% of the mineral fibres in some samples were non-asbestos (31). Some of these non-asbestos fibres will be of natural origin and some could be man-made. Natural calcium sulphate and aluminium silicate fibres are fairly common in environmental air (275).

2. SAMPLING AND ANALYSIS OF ASBESTOS AND OTHER MINERAL FIBRES IN ENVIRONMENTAL AIR

It is not the intention here to provide extensive details of the sampling and analytical methods for measuring mineral fibres in air. There have been many articles published on this subject (2, 8, 9, 44-57). A few special points however will be highlighted in relation to measuring mineral fibres in environmental air; these are: (a) in the past, the sampling procedures were not standardized which led to considerable variations in results, (b) in the past especially, a variety of analytical methods have been used which also led to a wide range of results, (c) there are particular difficulties in comparing some past and even some recent measurements with results obtained with acceptable modern methods, (d) for consistency and relevance it is useful to refer to one type of measurement for assessing possible health risk. In this Report all relevant measurements for environmental air are expressed as if they had been measured by detecting fibres using phase-contrast optical microscopy. (It will be seen later however that for environmental air optical microscopy per se is not satisfactory for detecting and measuring mineral fibres; measurements have to be carried out with electron microscopy techniques and the results then expressed as if measured by optical microscopy). Practically all the information in this chapter relates to the sampling and analysis of asbestos fibres, but much of it is also relevant to the measurement of non-asbestos mineral fibres.

2.1. General aspects

In the occupational field, the sampling and analysis of asbestos fibres have become standardized (44, 45, 48, 49, 50-55, 58), although research into possible improvements is still being carried out (49, 59). In contrast, as yet no internationally accepted standard method for measuring asbestos in environmental air has been published (6, 46). The standardized occupational methods used for the workplace situation are based on phase-contrast optical microscopical examination of specially collected filter samples. In this method the 'respirable' fibres (6, 44, 48, 50, 55) are the ones which are counted and recorded as fibre number concentrations. The 'respirable' fibres are regarded as those which are not less than 5 μm long and less than 3 μm diameter, and having an aspect ratio of length to diameter of greater than 3:1 (6, 44, 48, 50, 55). This method is satisfactory in that it provides results which are regarded as suitable for a relative index of possible health risk of exposure to mineral fibres. The method using optical microscopy however is not capable of distinguishing between different types of mineral fibre or different types of asbestos (6); it gives a result for total 'respirable' fibres whether the sample contains asbestos or other mineral fibres or a mixture of both. In general it is quite adequate for occupational measurements since the specific type of fibre to which the industrial workers are exposed, is usually known (6). For the general environmental air it is important to use a method which also records 'respirable' fibres so that a satisfactory index of possible health risk to the exposed population can be obtained (48). The method needs to be capable of readily distinguishing between 'respirable' and 'non-respirable' mineral fibres in the presence of a very large proportion of general particles of various types in environmental air. Unfortunately, as referred to above, it is not possible to use optical microscopy (a relatively simple and inexpensive method) to detect say specific fibres like asbestos in the general environmental air. This is because the method cannot identify the asbestos fibres which are frequently only perhaps 10% or even less of the total mineral fibres present (19). Also optical microscopy may not be capable of distinguishing between various mineral fibres and organic fibres present in environmental air (35, 46, 60, 61). It has been reported that only about 0.3% of the total airborne fibres of all types and sizes

in environmental air may be detected by phase-contrast optical microscopy (35, 61). Either transmission electron microscopy (a complex and expensive method) or scanning electron microscopy (a relatively cheaper and quicker method) are adequate to measure the relevant fibres in environmental air, i.e. those which have been used as an index of possible health risk (2).

For full environmental air measurements (often used for research purposes), it is necessary to use transmission electron microscopy; this is the only procedure which can identify specific types of mineral fibres of all sizes (2, 9, 35, 46, 49). When using the transmission electron microscopical method for the general environmental air, the procedure can nevertheless be arranged so that the results can be made comperable with those obtained for the workplace atmosphere (where standard phase-contrast optical microscopy is used). In both methods the 'respirable' fibres (i.e. those greater than 5 μm long and less than 3 μm diameter) are recorded. Thus by comparing such results for the general environmental air with those measured for the workplace atmosphere, the relative health risk may be assessed; however there is an important factor which needs to be taken into account. This factor relates to the much better resolution of fibres with transmission electron microscopy, i.e. fibres down to 0.01 μm can be detected, compared with optical microscopy where the narrowest fibres detectable are usually 0.25 μm (2). Due to this feature it has been reported that only between 2 and 50% of fibres longer than 5 μm are detected by optical microscopy (6, 49), although all sizes of mineral fibres are capable of being detected by transmission electron microscopy. Because of this it has been suggested that a transmission electron microscopical count for fibres longer than 5 μm should be divided by a factor of 10 (an average value) to provide the equivalent optical microscope fibre count (6). This factor however can vary considerably from the average value of 10 depending on the type of sample (6). This adds to considerable uncertainty in results obtained by this means. In certain cases (49, 62) measurements by means of transmission electron microscopy can be so arranged to measure specifically those 'respirable' fibres greater than about 0.25 μm diameter (i.e. similar to the criteria for determination by phase-contrast microscopy); where this is the case the factor of 10 referred to above is not applicable. The valuable use of scanning electron microscopy for analyzing general environmental air has been recently described (45). This convenient method (45) permits measurement of asbestos fibres in about the same size range as measured by phase-contrast optical microscopy (45); the results are directly comparable with each other and no special factor is required as in the case of certain transmission microscopy measurements. Only a small fraction (perhaps 10%) of environmental asbestos fibres greater than 5 μm long seem to be below the detection limit of scanning electron microscopy (275).

For special research purposes it may be necessary to measure all sizes of fibres for some situations in environmental air (62). This will include many fibres less than 5 μm long (9). For an index of health risk however, those fibres which are specifically greater than 5 μm are considered the more important; these are the ones measured in the workplace environment (2, 44) and of greatest interest in the environmental air.

The details of the procedures used to measure environmental levels of mineral fibre in air have been described elsewhere (6, 46, 52, 57). An outline of the modern procedures is given below.

2.2. Outline of current procedures for the measurement of asbestos and other mineral fibres in environmental air

Transmission electron microscopy is the only analytical method which can

detect and identify all sizes of mineral fibres present in environmental air (46). The biologically more important fibres i.e. those specifically greater than 5 μm long can also be measured by this technique (6). Scanning electron microscopy also measures these more biologically important fibres (9, 10, 45) but it is not adequate for detecting all sizes of fibre in environmental air samples. This is because its resolution (about 0.1-0.2 μm) is not sufficient to detect and allow the identification of the very finest fibres (19, 45, 62). In order to identify fibres, it is necessary to use selected area electron diffraction (SAED) and/or energy dispersive X-ray diffraction analysers (XRD) attached to a transmission or scanning electron microscope (46). Air samples are collected on membrane filters and special transfer procedures are used to prepare specimens for electron microscopical examination (46, 62). In some measurements made with transmission electron microscopy, collected fibre bundles may be broken up into individual fibres when preparing sample specimens for analysis (6); this can seriously distort the true concentration of 'respirable' particles present in environmental air. Considerable expertise is required in the analysis and not all laboratories can carry it out. By means of the SAED and XRD attachments, the types of each individual fibre may be identified. In the case of asbestos fibres, the identification of amphiboles is a particularly complex procedure (46). Various sampling techniques for collecting airborne mineral fibres have been used (2, 44-46); nevertheless improvements in both sampling design and analysis continue to be made (49, 62).

3. CONCENTRATIONS OF ASBESTOS AND OTHER MINERAL FIBRES IN ENVIRONMENTAL AIR

In this chapter the concentrations of mineral fibres in the general environmental air are discussed; the workplace environment is referred to in Chapter 4. Only the concentrations in air are considered in this chapter; aspects of actual human exposure to mineral fibres are considered in detail in Chapter 4. Both levels in the outside and the indoor air (including various buildings, offices and schools, etc.) are dealt with and the values evaluated. The majority of study results relate to asbestos levels; relatively little is known about the levels of non-asbestos fibres.

There are many publications where concentrations of asbestos and certain mineral fibres in environmental air have been reported (1, 6, 8, 9, 19, 30-32, 34, 35, 49, 63-76). Some of the published measurements are rather old and in certain cases the results are quite unreliable (9, 77). An attempt has however been made wherever possible in this Report to avoid referring to those results which were considered by the author to be too unreliable or too unrepresentative. As discussed in Chapter 2, various methods of sampling and analysis (more especially for asbestos fibres) have been used; in recent years an attempt has been made to try to standardize these procedures.

A very important aspect of the measurement of mineral fibres in environmental air is the need to ensure that the results are meaningful in terms of defining any possible risk to health (see Chapter 4). In terms of 'respirable' fibres in the range of sizes regarded to be of biological importance in environmental air, the most reliable measurement methods are those obtained with electron microscopy. Both transmission and scanning electron microscopy can be used (19). Results reported where optical microscopy has been used are generally unreliable for specific mineral fibre such as asbestos in environmental air. Where the method has been used for asbestos, reported results are often too high because the technique is not capable of distinguishing between asbestos fibres and the generally much larger fraction of other fibres in environmental air (6, 35, 61, 78).

Because concentrations expressed in number terms are regarded as the most appropriate for assessing health risks to mineral fibres, far less emphasis is given here to data where the concentrations have been reported in mass units (usually expressed as µg or ng per cubic metre or litre of air). The mass concentrations of fibres are obtained when fibre dimensions and the number of fibres in different size ranges are detected by electron microscopy, taking into account too, the density of identified fibres.

In general the proportion of fine fibres is greater in the environmental air than at the workplace (9); also very large fibres and fibre bundles (aggregates) may exist at the workplace which would be less usual in the general environmental air. However although there may be a larger proportion of fine fibres in the general environmental air, the mass of these fine particles does not necessarily make a very major contribution to the total mass loading of airborne fibres; this is simply because the mass of fibres is dependent on a squared function of fibre diameters. At the present time the more relevant and now accepted index of potential health risks to fibres in environmental air (2, 35, 44) is based on numbers of fibres greater then 5 µm long, disregarding the very finest fibres, i.e. those below 0.25 µm diameter. It is not an absolute index since some inhaled finer fibres which could be deposited in the lung may be carcinogenic; the proportion of such fibres in environmental samples analysed by scanning electon microscopy is low however (275).

Various authors have suggested factors to use when converting mass measurement concentrations of asbestos fibre in environmental air to the more useful number concentrations (6, 8, 9, 76). In many although not in all cases, care has been taken in reported studies to provide estimates of number concentrations of environmental exposures which are as comparable as possible to those as if measured by optical microscopy. However, it needs to be recognized that where a conversion factor is used the value is critically dependent on the fibre size distribution; it is also dependent on fibre type (6, 9). A relatively small change particularly in fibre dimensions, can make a large change in a conversion factor (9, 79). In consequence, there is not a constant factor which can be used to convert mass to number concentrations in units which are equivalent to those for optical microscopy (8). Most factors reported for asbestos are in the range 0.00002 to 0.0004 f/ml per ng/m^3 air (6, 8, 9, 74, 76, 80-82). In some cases, the particle size distribution is not known or recorded. In these circumstances, it is generally impossible with any reliability to convert mass to fibre number concentrations. In this chapter the results given are where the calculated fibre number concentrations for environmental air are as quoted in the original publication rather than attempting to make fresh calculations using different factors. However such results are of rather limited value by comparison with measurements of number concentrations made directly by counting particles.

The fibre dimensions for environmental air vary over a wide range; the dimensions depend on the type of fibres and the nearness to sources. For asbestos the finest fibril for chrysotile might be 0.01 μm diameter and perhaps 0.2 μm long (83). A typical asbestos fibre in air remote from sources might be 0.1 μm diameter and about 1 μm long (9, 84). Environmental studies carried out in the U.K. suggest an average fibre of chrysotile to be 0.04 μm diameter, 0.74 μm long (85). Environmental studies carried out in Japan indicated that fibres less than 1 μm long predominate; the average fibre length was 0.5 μm in the air near highways (231). Larger fibres of various minerals including asbestos will also exist in environmental air. Fibre size in industrial situations for comparison have been extensively studied (86). In the case of asbestos sampled well away from sources, relatively few fibres will be longer than 5 μm (9). Much less is known about the sizes of other mineral fibres in environmental air; many however are likely to be of dimensions within the range normally found for asbestos (see section 3.3.). Some will be much larger however.

The results of reported concentrations of mineral fibres in air are now discussed. In this chapter much greater consideration has been given to results of long-term sampling for mineral fibres in air; short-term sampling results are likely to be far less representative of relevant human exposure. A longer term overall concentration is considered to be a more relevant parameter for relating to any possible health risk for meaningful exposures covering many years. In some reported studies it is uncertain what period of time the concentrations refer to; also precise sampling details especially where they could be relevant to human exposure conditions, are often lacking. Relatively little emphasis is given here to those less well documented results.

Only in a few cases were specific types of asbestos reported for environmental air measurements. In most cases the predominant fibre is chrysotile since this is by far the commonest type of asbestos used (275). Only rarely would the proportion of crocidolite and/or amosite fibres in environmental air samples be significant.

A number of investigations (see below) have been carried out where various levels of mineral fibres (almost exclusively asbestos) have been reported; most

studies particularly the earlier ones give results as mass concentration levels, rather than number concentrations.

3.1. Outdoor air concentrations of asbestos

3.1.(a) Outdoor mass concentrations of asbestos expressed as $\mu g/m^3$ air

Mass concentration measurements have been reported elsewhere as various units but for reasons of consistency and convenience, all values here are expressed in the one unit of $\mu g/m^3$ (published values have been recalculated where necessary). As mentioned earlier less emphasis is given here to mass concentration results, since those expressed in numbers of fibres in a given value of air (usually fibre/ml air nowadays) are recognized to be the most appropriate as an index of exposure which defines possible health effects.

In Paris, mean concentrations of asbestos of approximately 0.001 $\mu g/m^3$ air have been reported for outdoor air (6, 69, 87); 99% of all observations were less than 0.007 $\mu g/m^3$ air. In the U.S.A. (70), most average levels were in the range up to about 0.002 $\mu g/m^3$.

In Connecticut, U.S.A., the general levels some years ago were reported to be less than 0.010 $\mu g/m^3$ air in both urban and rural locations (6, 74). Levels were sometimes higher (6) in road tunnels.

For the U.S.A. as a whole however, it has been estimated that the average level is about 0.0015 $\mu g/m^3$; for urban areas the average is 0.003 $\mu g/m^3$ and for rural areas 0.0001 $\mu g/m^3$ (65). In Holland (6), levels of between 0.0005 and 0.002 $\mu g/m^3$ have been reported for industrial towns and 0.0001 to 0.0005 $\mu g/m^3$ for rural towns. In Canada, median levels were generally less than 0.001 $\mu g/m^3$ (6). Some higher median levels were reported (up to 0.036 $\mu g/m^3$) in some areas of mining activity in Canada where there were mining activities in the past and in areas of natural asbestos erosion (6). Past levels of chrysotile asbestos in a mining town in Canada were reported to average 80 $\mu g/m^3$-140 $\mu g/m^3$ (88); they are much lower nowadays (88). In the U.K., near industrial emissions, mean levels up to 3.4 $\mu g/m^3$ have been reported (85). More recent measurements in Canada (expressways, suburbs, small cities) indicated concentrations of asbestos to be substantially lower than 0.001 $\mu g/m^3$ (6). In the U.K., mean levels in the range less than 0.001 to 0.004 $\mu g/m^3$ have been recorded (85). For past situations near emission sources in various countries a wide range of values has been reported (6, 9, 34, 85), i.e. from 0.0001 to over 8 $\mu g/m^3$; the higher values represent short duration levels and are thus not representative of long term human exposure.

Recently a comprehensive evaluation of concentrations for outdoor air has been made taking account various studies from several different countries (9). Median values of 0.0007 to 0.007 $\mu g/m^3$ were reported (9). Measurements carried out in the last 5 years provided median values of less than 0.001 $\mu g/m^3$ (9). Median levels as high as 0.014 $\mu g/m^3$ were reported for samples taken in New York over 15 years ago (9).

3.1.(b) Outdoor number concentrations of asbestos expressed as fibres/ml air

Some reported values are given as fibres/l, fibres/m^3, fibres/cc or fibre/ml; for consistency and convenience the one unit, fibres/ml (f/ml) is used here (reported values have been recalculated where necessary). Only values

measured by electron microscopy are seriously considered here, since those measured directly by optical microscopy can be too high; this is due to the fact that the latter technique cannot differentiate between asbestos and the high proportion of non-asbestos fibres usually present in environmental air (6, 19, 31).

In Canada, median concentrations in 1982 (6) were reported to be in the range less than 0.0004 f/ml to less than 0.0033 f/ml for asbestos fibres over 5 μm; the situations studied covered an expressway (less than 0.0033), suburbs (0.0007), a small city (less than 0.001) and a rural area (less than 0.0004).

In Austria (32), average levels of airborne asbestos ranged from less than 0.0001 to 0.005 f/ml (fibres greater than 5 μm); the areas studied included asbestos mining and manufacturing, areas of natural asbestos sources, urban areas, and areas where weathering of asbestos-cement roofing sheets had occurred.

In Germany and Austria, various studies have been carried out (19). Electron microscopic measurement of fibres greater than 5 μm was used. Examples of the results (19) are as follows: average level of less than 0.00015 f/ml in a village with considerable asbestos products usage; a maximum value of 0.0004 f/ml was reported in an area of heavily weathered corrugated asbestos sheets; at a crossroads in a large city, concentrations were in the range 0.00026 to 0.0004 f/ml: in areas of demolition of asbestos-cement claddings up to 0.00096 f/ml occurred near to sources, falling to 0.0001 f/ml at 100 m. away: near an asbestos waste dump up to 0.00045 f/ml was recorded (19). It has been reported (19) that the air in certain towns might contain around 0.0046 f/ml, near areas of mining 0.0024 f/ml, near asbestos cement plants 0.0005 f/ml, near natural asbestos deposits 0.0005 f/ml and in rural areas less than 0.0001 f/ml. On average the results (for fibres longer than 5 μm and narrower than 3 μm) were considered to be below 0.001 f/ml (19).

In some towns in South Africa, asbestos levels ranged from less than 0.0001 to 0.0002 f/ml (31); scanning electron microscopy measuring the fibres more than 5 μm long was used.

In a very recent review (9), the median outdoor concentration of asbestos fibres for general population exposure is suggested to be in the range 0.00002 to 0.0005 f/ml (values were measured as mass concentrations and converted to number concentrations equivalent to optical microscopy measurements). (9, 82, 87, 90-92). Another review (6) suggests an average concentration of 0.00003 f/ml to about 0.0006 f/ml for city air. Some higher values even over 1 f/ml have been reported (33, 34) but these were associated with places near asbestos mills and mines in the past; apart from the fact that the measurement methods are not properly documented, the results are not considered to be in any way representative of long-term exposures. More recently near a hostel in an asbestos mining area of South Africa, levels of 0.003 to 0.01 f/ml (8 hour samples) were recorded (31). In a recent review of the general population in the U.S.A. (65), an average concentration of 0.00006 f/ml was suggested.

In a very recent and very comprehensive review (9), an expert committee considered that a reasonable long-term outdoor median concentration of asbestos was in the range 0.00002 to 0.00075 f/ml; an overall median of approximately 0.00007 f/ml was quoted for fibres greater than 5 μm in length as if measured by optical microscopy.

In some Canadian studies (6); the quoted median values for fibres greater than 5 μm long ranged from less than 0.0004 f/ml (rural situations) to less than

0.001 f/ml for a city. These are not dissimilar to the above when divided by a factor of 10 (a factor suggested by the investigators (6) to obtain the equivalent concentration in terms of optical microscopic measurements).

Typical long-term outdoor average concentrations (representative of perhaps many years of exposure) could be in the range of approximately 0.0001 f/ml to 0.001 f/ml. A typical very long-term value of perhaps around 0.0005 f/ml for outdoor air could be realistic for the general population; in countries or situations where relatively little asbestos has been used the typical level could be lower. In some cases a level of 0.001 f/ml or perhaps more may apply. (These figures refer to concentrations of fibres greater than 5 μm long and in the equivalent units to those as if measured by optical microscopy).

3.2. Indoor concentrations of asbestos

In a number of circumstances because of internal sources of mineral fibres, the levels might be higher in indoor air compared with outside. This is not always so however because a number of fibres, particularly the larger ones in outside air, can be trapped in window and door crevices as the air flows into a building; also a number of air conditioning systems will filter out many particles including mineral fibres from the source of air entering a building.

3.2.(a) Indoor mass concentrations of asbestos expressed as $\mu g/m^3$ air

Mass concentration measurements have been reported elsewhere in various units but for reasons of consistency and convenience, all values here are expressed as the one unit, $\mu g/m^3$ air (published values have been recalculated where necessary). As mentioned earlier less emphasis is given here to mass concentration results, since those expressed in numbers of fibres in a given volume of air are recognized to be the most appropriate as an index of exposure which defines possible health effects.

Higher asbestos fibre concentrations for inside air compared with outside air have been observed in Paris (69). An average concentration of 0.002 $\mu g/m^3$ was found inside buildings (e.g. schools and offices) with a maximum single value of 0.012 $\mu g/m^3$ (6, 87). In buildings which had been insulated by spraying asbestos, the maximim range of average concentrations of asbestos in 21 buildings was in the range 0.001 to 0.070 $\mu g/m^3$ with a maximum single value of 0.75 $\mu g/m^3$ (6). Further studies carried out more recently by the same laboratories (68), indicated average results roughly within the same range as before. In comparable studies carried out in the U.S.A. (6), 83% of a total of 23 air samples showed values below 0.020 $\mu g/m^3$; 96% were below 0.050 $\mu g/m^3$ with a maximum single measurement of 0.087 $\mu g/m^3$. Of a further 28 samples (6, 93), 93% contained less than 0.020 $\mu g/m^3$; the maximum single measurement was 0.18 $\mu g/m^3$. In contrast in buildings where dry spraying of asbestos rather than wet spraying (see section 1.1.3.(e)) had been used (6, 93), the concentrations were higher; i.e. of 53 samples, 53% contained less than 0.020 $\mu g/m^3$ with a single maximum reading of 0.83 $\mu g/m^3$ (in an isolated generator room). Also in the U.S.A. average concentrations of 0.079 $\mu g/m^3$ were recorded in some buildings containing sprayed asbestos surfaces (6, 95); a maximum of 0.64 $\mu g/m^3$ was recorded. In another study carried out in the U.S.A., concentrations in schools were reported to be 0.005 to 0.040 $\mu g/m^3$ (67). In a recent review of some past measurements, average concentrations of between 0.050 to 0.25 $\mu g/m^3$ were claimed for various buildings including schools (76). These particular results seem to be quite out of line with results reported elsewhere; the methods of analysis are not necessarily identical with those used in other studies

and for various reasons it would appear that these particularly high results are not representative of the general picture. In a recent study carried out in Canada (35), it was concluded that in buildings containing sprayed asbestos insulation, the concentrations inside buildings were not statistically significantly different from the general outside air. Inside various buildings, including schools in the U.K., where asbestos-containing construction materials had been used, concentrations did not exceed 0.01 $\mu g/m^3$ asbestos (71); the main method of analysis used in the study was scanning electron microscopy. A few samples analysed by transmission electron microscopy suggested that the concentrations may not have exceeded 0.001 $\mu g/m^3$ (71).

3.2.(b) Indoor number concentrations of asbestos expressed as fibres/ml air

Some published values have been reported as f/l, f/m^3, f/cc (or f/ml); for consistency and convenience the one unit of f/ml air is used here (values have been recalculated where necessary).

In a study of airborne asbestos carried out in buildings in Canada, the maximum concentration of fibres reported was 0.003 f/ml, although in most samples in the 19 buildings studied, the concentrations for fibres longer than 5 μm were less than 0.001 f/ml (6, 94). In the more comprehensive of various studies carried out in the U.S.A., average concentrations appeared to be approximately in the range of less than 0.0006 to 0.0024 f/ml (6, 95). A typical mean value seemed to be about 0.001 f/ml (equivalent to optical microscopy measurements) although concentrations in the range less than 0.0001 up to 0.006 f/ml were reported (6, 93, 94).

In a recent evaluation of various studies the following median values were quoted for indoor air (9, 90, 91, 93, 96): 0.00054 f/ml (U.S.A. schoolrooms without asbestos; 31 samples); 0.00006 f/ml (buildings with asbestos surfaces in Paris; 135 samples); 0.00026 f/ml (U.S.A. buildings with cementitious asbestos; 28 samples); 0.00064 f/ml (U.S.A. buildings with friable asbestos; 54 samples); 0.00208 f/ml (U.S.A. schoolrooms with asbestos surfaces; 54 samples); 0.00405 f/ml (U.S.A. schools with damaged asbestos surfaces; 27 samples). A conversion factor of 30 $\mu g/m^3$ air per 1 f/ml was used to convert mass concentration values to equivalent optical microscopy measurements of fibres greater than 5 μm (9).

In Paris a median level inside buildings was reported to be less than 0.00015 f/ml (6, 87). It has been concluded that in most buildings with sprayed asbestos insulation the exposure to the occupants is less than 0.001 f/ml (6), even in the worst buildings. Ninety-four percent of all measurements seemed to be less than 0.003 f/ml (6). In the Federal Republic of Germany, indoor air levels are as follows:- sports centres 0.0001 to 0.0011 f/ml; swimming pools 0.0001 to 0.0012 f/ml; public buildings 0.0001 to 0.0002 f/ml (275). All these values are equivalent to optical microscope measurements. In some recent Canadian studies, the concentrations of asbestos fibres in indoor air were considered to be not statistically significantly different from outside air (61). Some years ago in a survey of levels of asbestos in various buildings in the U.K., 84% of over 1,100 samples collected, did not exceed a concentration of 0.005 f/ml (8); the details of the sampling and the analysis (optical microscopy was used) were not provided, and therefore because such a method can over-estimate the levels in environmental air (6), the results are of limited value.

Maintenance work in buildings, cleaning, repairing, etc., can provide very high although short period exposure conditions, e.g. up to 17.7 f/ml asbestos has

been reported (76, 95); these levels are in no way representative of average exposures however.

In a special study of U.S. schools, where insulation materials (5-20% asbestos) were being planned to be replaced by non-asbestos containing materials, air samples were collected and analysed by transmission electron microscopy (67). Asbestos concentrations for 9 samples ranged from 5 to 40 ng/m^3 air. This is equal to approximately 0.0002 to 0.001 f/ml (equivalent to optically measured fibres) (6), using a figure of 30 ng/m^3 equal to 0.001 f/ml (9). After replacing the asbestos materials, the airborne concentrations decreased; a reduction of over 50% up to 90% was observed (67).

In the hearings on health for the Royal Commission related to asbestos for Ontario, Canada, it was assessed that 'except in a few extreme situations where badly damaged friable asbestos had been allowed to persist, average exposures will be less than 0.0002 f/ml, (equivalent to optical microscopy measurements) and in fact are likely to be much less.' (75).

In underground public train systems, fibres can be found in the air (6, 63, 97). Only a small fraction of the total respirable fibres were found to be asbestos in a London tube survey (63); the remainder of the fibres were other inorganic or organic fibrous materials. Total fibrous material ranged from 0.02 to 0.32 f/ml; the investigators suggested an asbestos concentration range of 0.0004 to 0.006 f/ml (63). The levels to which people are exposed in such systems are generally for short periods, and it was reported that the human exposure conditions in relation to asbestos were 'completely safe' (63). In a study of the Toronto, Canada, train subway system where non-asbestos brake linings are now used, the levels of asbestos were measured; they did not however exceed the Ministry of the Environment Air Quality Guideline of 0.04 f/ml (6, 97). Again because of the short duration of exposure to the general public there, any brief exposure to asbestos would seem probably to be of little consequence.

A few years ago it was suggested that certain types of hairdryers were a possible source of undesirable quantities of asbestos. However extensive studies (35, 98) indicated that the maximum level of exposure was 0.002 f/ml even under very extreme conditions; this exposure level which might exist for very brief periods only must be considered to be negligible in terms of overall human exposure to asbestos. It has been estimated that if a hairdryer is used for 15 minutes each day then the incremental overall level in a room would be only 0.000037 f/ml for fibres greater than 5 μm long (106).

Another potential source of airborne asbestos fibres is the use of water containing elevated levels of asbestos in home humidifiers; however even where the water was very heavily contaminated with asbestos fibres, the levels of asbestos produced in room air were considered to be negligible (35, 99).

Taking account all the available information, it would appear that long-term overall indoor concentrations (representative of many years exposure) could be in the range of approximately 0.0002 to around 0.001 f/ml. A typical very long-term figure of 0.0005 f/ml for overall indoor air has been selected for the general population exposure. In countries or situations where relatively little asbestos has been used the typical level could be lower. In some cases a value of 0.001 f/ml or more perhaps could apply. (These figures are representative of equivalent optical microscopy measurements of fibres over 5 μm long).

3.3. Concentrations of other mineral fibres in environmental air

Relatively little is known about the concentrations in environmental air of mineral fibres other than asbestos. Some studies have indicated (19, 31, 46) that there are a number of fibrous minerals besides asbestos in air. It has been suggested that in some cases (e.g. in street air) there can be an order of magnitude (or more) higher concentrations of non-asbestos mineral fibres compared with asbestos itself (19, 46). Very little is known as to the identity or the size of such fibres. The following mineral fibres are some of those which have been reported to have been identified or are very likely to be present in environmental air: erionite (9, 100, 101); attapulgite (6, 9); glass fibre (9, 102); slag wool, rock wool, ceramic fibres, fibrous carbon, graphite, alumina, boron, potassium titinate, silicon carbide, wallastonite, fibrous sepiolite, halloysite, talc (9); brucite, calcium sulphate, alumino silicate fibres, (19). Some of these fibres if present will occur at rather low concentrations. Other than glass fibres, practically nothing seems to have been published on results of investigations of levels of specific mineral fibres in environmental air; a figure of 0.002 f/ml for glass fibre has been reported (9, 102) but it is totally unknown how representative this is for environmental air. In some villages in Turkey the total dust levels have been reported to be about 1 mg/m^3 air and most samples indicated that the levels of fibres including erionite were less than 0.01 f/ml (43). However in various samples taken during cleaning of the caves where some villagers lived, fibre concentrations of up to 1.38 f/ml were indicated (9, 43).

Recently an informative study using scanning electron microscopy has provided levels of total 'respirable' fibres in environmental air at the same time as measuring asbestos (31). In asbestos mining areas in Canada and South Africa near where people were living, total mineral fibre counts (excluding asbestos fibres present) ranged from 0.0002 to 0.0022 f/ml (31). In some towns in South Africa and Germany, total mineral fibre counts (excluding asbestos fibres present) ranged from 0.0001 to 0.003 f/ml (31). In areas where there were asbestos factories or in regions where asbestos building products had been used, concentrations between 0.0003 to 0.005 f/ml have been reported for total mineral fibres, excluding asbestos (31). In areas away from mining activities up to over 40 times more non-asbestos mineral fibres were detected in comparison with asbestos fibres; typically a ratio of 10 to 1 appeared to apply (19, 31). Thus in a number of cases the levels of total mineral fibres in environmental air could readily exceed those for asbestos alone.

The sizes of environmental fibres have not been reported elsewhere in any detail. However the sizes of certain non-asbestos mineral fibres commercially available are given here, since it is likely that at least some of them will exist in environmental air in approximately the range of dimensions indicated. Possible sizes of non-asbestos fibres are considered to be as follows: attapulgite (0.5-1 μm long, 0.03 μm diameter); erionite (up to 50 μm long, 0.01 to 5 μm diameter); glass (from 1 μm to 15 μm in diameter); mineral wool (1-20 μm in diameter); ceramic fibre (1-12 μm in diameter); carbon (up to 2-3 μm long, 3-7 μm in diameter) (7, 9, 100, 103-105).

4. HUMAN EXPOSURE TO INHALED ASBESTOS AND OTHER MINERAL FIBRES AND HEALTH IMPLICATIONS

This chapter considers the exposures to inhaled mineral fibres from various sources, including those arising naturally and those occurring as a result of human activities. Firstly, the exposure due to inhaling asbestos and other mineral fibres in occupational situations is considered. The much lower exposures to asbestos and other mineral fibres in the general environment is then discussed in relation to some of the past heavy asbestos occupational exposures. The human health implications of inhaling asbestos and other mineral fibres in occupational locations in relation to general environmental situations are evaluated. In this appraisal of the health implications, account is taken of animal testing data, general toxicological considerations, and data from human epidemiological studies carried out both at the workplace and in the general environment. Finally, some estimates of the possible human risk of inhaling general environmental asbestos are provided; the values for the possible risk are compared with published data on risks associated with various day-to-day hazards including exposure to various environmental factors.

4.1. Exposure to inhaled mineral fibres

4.1.1. General considerations

Asbestos and other mineral fibres (whether they are from natural sources or occur as a result of human activities), including man-made mineral fibres, can frequently be of such a size that they can be inhaled (2, 7). The precise dimensions of inhaled particles whether they are fibrous or not governs whether they are deposited in the upper respiratory tract (e.g. nose and tracheobronchial region), the bronchial regions or in the depths of the lung (down to the alveolar regions), or not inhaled at all (if very large) (2, 107). The dimensions of particles and fibres govern also the clearance from the respiratory tract (2, 9, 108, 109). In general only very fine fibres can penetrate to the depths of the lung; many of the extremely fine fibres however are immediately exhaled again (2). Very large fibres on the other hand, if they are inhaled at all, may simply be trapped in the human nose or mouth (2). Many of the common types of mineral fibres if inhaled, are likely to be trapped in the bronchial regions (9, 109). Some absorbed fibres may remain in the body for very long periods (9). Certain absorbed fibres may be translocated to different parts of the body (6, 7, 110). The actual dimensions of inhaled fibres in relation to deposition, clearance and retention in the respiratory tract are discussed in more detail later (see section 4.1.4.).

In addition to exposure via the pulmonary tract, some airborne fibres may enter the body via the mouth to become directly swallowed (83). Also many fibres deposited mainly in the bronchial regions ('finer' fibres) and the upper respiratory tract ('coarser' fibres) will be cleared and become swallowed due to mucociliary clearance (9, 111, 268). These swallowed fibres will enter the gastrointestinal tract (9, 112). The ingestion of asbestos and other mineral fibres is discussed in greater detail later (see section 4.2.2.(b)).

Finally, some fibrous materials, e.g. asbestos, can penetrate the human skin; under certain conditions, asbestos 'warts' in occupational situations have been produced (1, 6). There appears to be no firm record of such 'warts' arising in the general population, i.e. in persons not occupationally exposed to asbestos. Also, the exposure to asbestos by skin penetration would be expected to be minute by comparison with that arising from inhaling and ingesting asbestos; such 'warts' are considered to be of little health significance (6, 113).

It is well known that there are very marked differences between the exposure levels to asbestos (and other mineral fibres) in the occupational situation compared with the general environmental scene; the differences were particularly marked in the past, especially in the case of asbestos. The exposures in these situations and the means of quantifying them and the difficulties of doing this precisely, are considered later (see sections 4.1.2. and 4.1.3.). The health implications of occupational and non-occupational exposures to asbestos and to other mineral fibres (the exposures to these have been generally significantly lower than for asbestos) are reflected in these exposure differences; however from occupational experience it has been observed that certain other factors in addition, such as smoking also affect the risk of developing lung cancer (6, 9, 114).

4.1.2. Industrial exposure to inhaled mineral fibres

More occupational studies have been carried out where workers have been exposed to asbestos in comparison with exposure to other mineral fibres. This is mainly because asbestos started to be used many years before the extent of the interest in other mineral fibres began. In the early years, the control measures for dusts in general were rather ineffective, and this often led to high levels of asbestos dust being created in the occupational situation at the time. In more recent years, the controls have improved greatly and consequently nowadays the occupational levels of asbestos and non-asbestos fibres are much lower (6, 7). In some less well developed parts of the world however, the full use of the more effective control methods has yet to be achieved.

Only in the last 20 years or so has there been some reasonably reliable monitoring of asbestos and other mineral fibres for assessing the exposure of workers in occupational situations (2, 6, 9). Airborne mineral fibres and especially asbestos are notoriously difficult to sample and to measure (2, 6, 9). Various methods have been used in the past using a range of sampling and analytical procedures. For comparison purposes, it is particularly difficult to convert with any accuracy the past results using the older methods to those obtainable with the more acceptable methods used nowadays (6, 8, 9, 44, 45, 48, 49, 50-55, 62).

Workplace atmospheres in the case of asbestos fibres, were first estimated using various pieces of sampling equipment including a konimeter, a thermal precipitator and an impinger system, where the collected particles were examined by light microscopy (2, 9, 62). Often all visible particles were counted whether they were definitely fibrous or not and the results expressed as numbers of fibres in a given volume of air. The methods were subject to a number of errors (8, 9, 62). In the early 1960's, a membrane filter sampling technique became available (9, 51, 62). The membrane filter was examined by phase-contrast light microscopy and visible fibres were counted with an aspect ratio of 3:1 (length to diameter), (2, 44). Since the introduction of the membrane filter method, various publications have appeared on certain refinements of both the sampling and analysis of fibres (6, 8, 9, 44-46, 48, 49, 50-55, 59, 62, 85). Reviews of various methods and refinements have been published recently (6, 9, 44, 62). Some earlier methods provided a mass concentration of mineral fibres in air; nowadays however, results expressed in number terms are considered to be more relevant for defining human exposure in relation to any health effects (2, 7).

Currently the number of fibres greater than 5 μm long counted on membrane filters by phase-contrast light microscopy, is used as a relative index

of workplace exposure; fibres down to 0.25 μm diameter can be detected by light microscopy (44, 46, 62). Standardized methodology recommended for epidemiology and control purposes has been published (44, 62) and is now becoming widely used. Fibres shorter than 5 μm and narrower than 0.25 μm will also be present in workplace atmospheres but these smaller fibres can normally only be detected by electron microscope methods. However their routine measurement is not regarded to be necessary. This is justified since (a) many very narrow fibres are less likely to be trapped in the lung compared with larger ones (2); (b) relatively few fibres less than 0.25 μm diameter (and longer than 5 μm) seem to exist in workplace atmospheres (275); (c) the most biologically active mineral fibres appear to be the longer ones (2, 7, 9, 145) and are generally detectable by optical microscopy. Thus although very small fibres are not recorded by routine optical microscopy, the fibre count using this method is still relevant as a meaningful relative index of possible health risk in different occupational situations.

Because of the particular difficulties of accurately comparing past measurements of mineral fibres (especially for asbestos fibres) with those obtained with modern methods, certain investigators have made estimates of past exposures using various approaches (8, 9, 65, 106, 116). For the purposes of making estimates of health-risk (see section 4.3.) related to the inhalation of asbestos and other mineral fibres, approximations of concentrations of fibre levels for past occupational situations can be utilized. Taking account of various reports, (6, 9, 19, 75, 116-118) it appears likely that certain workplace atmospheres in the past were commonly averaging several hundreds of fibres per ml; maybe in some cases they were even over one thousand fibres per ml (118, 119). Maximum concentrations of even several thousands of fibres per ml have been quoted (19, 75, 119) but these conditions are unlikely to have persisted for long periods. The asbestos exposure varied widely depending on the industrial process. Textile production, removal and spraying of asbestos (insulation processes) particularly, seemed often in the past to have been associated with very dusty operations; asbestos-cement production, friction product manufacture and certain constructional work however were associated with much lower exposure levels (19, 20). These exposure levels have usually been reflected by the incidence of disease found in asbestos workers (19), although the type of fibre used is important too (2, 9). One difficulty with assessing exposure to mineral fibres is the problem of very localized pockets of fibres (due to the intrinsic nature of any rather dusty material) associated with certain industrial operations. For this reason, assumptions of the critical occupational exposures may often have been underestimated (62), and this is likely to be the case in a number of studies where the health effects of exposed workers have been studied in the past. In fact little work (except very recently) has been carried out on measuring the individual worker exposure, and this is quite essential for a proper assessment of actual exposure levels (8, 62). It is very likely that those workers who were the most heavily exposed in the past (in many cases to unmeasured pockets of extremely high levels of asbestos fibres), are the ones who would have a greater probability of contracting a disease. Thus one might anticipate that the more significant exposures in the past were perhaps at levels of many hundreds of asbestos fibres per ml as an average long-term airborne concentration for the workplace environment. Taking account of various factors and published reports on the subject (8, 62, 75, 116), very long period occupational exposures of often fifty up to several hundreds of asbestos fibres per ml air may well have existed in some occupations in the past. It is interesting to reflect on the very dusty conditions of the past where eye witness accounts (75, 118) would indicate that the conditions were often so bad that the workplace visibility was seriously restricted in a number of asbestos industries. The suggested values above for the levels of exposure in the hundreds of fibres per

ml would be compatible with such observations. Now with our knowledge of the diseases associated with very high levels of asbestos exposure (6, 8, 9), control measures have been introduced which have dramatically reduced the workplace airborne concentrations.

In order to compare occupational asbestos exposures with those reported for the general environment, it is necessary to take account of the differences in the exposure times. For example, an industrial worker may spend say 40 hours a week working for up to say 48 weeks per year; the general public of course will inhale the general air continuously for their lifetime. In some studies this exposure difference has been accounted for when comparing exposures; for example the National Research Council Committee in 1984 (9), used a factor of 4.56 for such comparison purposes. Also, industrial workers will often inhale at a significantly higher rate than the general population. This increased difference in volume of air inhaled will affect the relative exposure doses of these two groups; however it is very difficult to quantify this directly. In addition, humans whilst working have a concomitant increase in depth of respiration leading to increasing deposition in the deep lung (121); again this is difficult to quantify.

As has been mentioned earlier, the exposure to non-asbestos mineral fibres in industrial situations has on average been much lower than that for asbestos. Average levels of up to 2 f/ml have been recorded and occasionally levels up to 56 f/ml have been noted (7, 122). The higher exposure situations seem to be associated with ultra-fine fibres (7). Typical long-term average levels would seem to be well below 1 f/ml at the workplace (7).

4.1.3. Exposure to inhaled mineral fibres in the general environment (non-occupational)

This section relates primarily to the exposure to asbestos fibres, since practically nothing is known about the levels of exposure to non-asbestos mineral fibres in environmental air.

As indicated in section 3, there is a very wide range of reported concentrations of asbestos fibres in air. The concentrations may be somewhat higher in indoor air compared with those outside. Only concentrations expressed in number terms (i.e. f/ml) are considered here for the purposes of defining exposure; mass concentrations are not considered to represent very meaningful exposures in terms of health effects (35). Fibres longer than 5 μm, and of larger diameter than 0.25 μm and up to 3 μm detectable by optical microscopy are considered to be a relevant relative index of health risk (see earlier); the results given here relate to such fibres. The concentrations are expressed as equivalent to those as if measured by phase-contrast optical microscopy even though they have almost exclusively been measured by electron microscopy. In Chapter 3 relatively little interest was taken of reported concentrations in air which were not representative of human exposure or where the sampling times were too short to be relevant to the longer term human exposure. In most cases the predominant exposure is to chrysotile asbestos, since this is the commonest type used (275); it is considered that only in rare situations would long-term environmental exposures relate to significant proportions of crocidolite and/or amosite. The asbestos concentrations given in this Report as f/ml air refer to total asbestos exposure unless otherwise specified.

For outdoor air, typical long-term average concentrations of asbestos (representative of perhaps many years of exposure) are considered (see Chapter 3) to be in the range approximately 0.0001 f/ml to perhaps 0.001 f/ml. A typical

very long-term value of perhaps around 0.0005 f/ml was considered realistic for the general population inhaling asbestos in outdoor air. A value of 0.001 f/ml or perhaps higher may apply in some cases.

For indoor air, typical long-term average concentrations of asbestos (representative of perhaps many years of exposure) are considered (see Chapter 3) to be in the range approximately 0.0002 to around 0.001 f/ml. A typical very long-term value of perhaps around 0.0005 f/ml for overall indoor air could be realistic for the general population. A value of 0.001 f/ml or perhaps higher might apply in some cases.

In assessing the relevance of indoor exposures to asbestos and other mineral fibres in relation to overall exposure, it is necessary to consider what proportion of the time we spend indoors. In most cases we seem to spend more of our time inside a building rather than outside, the major portion of which is generally in our homes. Although few of the indoor asbestos sampling programmes described in the literature were specially directed towards examining the home environment, in certain cases the levels in the home may be taken to be representative of concentrations reported for the inside of selected buildings. In a very recent and very comprehensive examination of environmental asbestos (9), the indoor environmental level of asbestos was considered to be expressed by a median value of 0.00054 f/ml (for rooms without asbestos) and 0.0006 f/ml (for rooms with asbestos). These values are close to the typical long-term indoor exposure figure of 0.0005 f/ml suggested here in this Report. The U.S. National Research Council Committee who defined the median values above (9), suggested that a reasonable estimate for an overall (indoor plus outdoor) median population value was 0.0004 f/ml. The Committee based this on spending one quarter of our time out of doors, five-eighths of our time in 'non-asbestos' rooms and one-eighth in 'asbestos' rooms; the median value of 0.0004 f/ml was calculated by weighting the figures above according to the fractions provided and using their defined median value of 0.00007 f/ml for outdoor air (9).

Of particular interest however is the situation regarding levels of exposure in certain schools, e.g. in those where there could be friable asbestos. This is because children may spend say 10 or more years inside these school buildings (67); also teachers may perhaps spend 30 or more years where they could be exposed to elevated levels of asbestos. In some schools in the U.S.A. in particular, the airborne levels of asbestos have been measured (see Chapter 3). The school results have been recently evaluated (9) and the median values are as follows: 0.00054 f/ml (no asbestos); 0.00208 f/ml (asbestos present); 0.00405 f/ml (damaged asbestos surfaces). In other comparable buildings where asbestos was present, the median levels were in the range 0.00006 to 0.00064 f/ml. Although there have not been very extensive studies of asbestos levels in schools, the available reliable results suggest that the median values could lie in the range 0.0001 to 0.0040 f/ml. This could be compatible with long-term average exposures covering years, of perhaps 0.001 f/ml or even perhaps of 0.002 f/ml (all values are expressed as equivalent to optical microscopy measurements). Account is taken later (see section 4.3.) of these exposures in relation to the possible additional risk for asbestos exposure to children and teachers.

In this Report a typical overall long-term level for asbestos exposure is suggested to be 0.0005 f/ml. It is compatible with the median value of 0.0004 f/ml suggested by the U.S. National Research Council Committee (9) for population exposure. Again these levels are expressed as the equivalent for optical microscope measurements for fibres longer than 5 μm. A typical value of 0.0005 f/ml is suggested for countries where there has been extensive use

of asbestos; in other countries the level could be lower. In some cases a value of 0.001 f/ml or perhaps higher, may apply.

No formal measurements of time trends of outdoor or indoor measurements of asbestos in air have been made. However for outdoor measurements there would seem to be a tendency for some somewhat higher results to have been reported in the early 1970's (9) in contrast with the seemingly lower results for the last few years; these findings are not incompatible perhaps with some decline in environmental levels of asbestos fibres in air due to improved control measures for asbestos. Another reason for anticipating lower levels of asbestos nowadays is that general levels of air pollution have declined in many cities of the world due to the control of dark smoke emissions. The control of smoke levels has allowed more sunlight to enter leading to better dispersion of air contaminants generally. Although one study is not representative of general time trends, measurements made in the vicinity of asbestos mines in South Africa (residential areas and schools) show a significant decline during the last 20 years (123); these results are not inconsistent with various improvements in industrial control measures made over the years which is supported too by eye witness accounts in various situations.

Very little information is available on levels of non-asbestos fibres in the general environment and it is impossible at this point in time to give any representative information on general population exposure; isolated levels for glass fibres in air at 0.002 f/ml, and for erionite fibres at 0.01 f/ml, and up to 1.38 f/ml (inside caves being cleaned where some villagers lived) have been reported (see Chapter 3 for more details). In some situations it has been reported that the level of non-asbestos fibres in environmental air might typically be about 10 times that for asbestos (19, 31). Thus probably in a number of cases the levels of total mineral fibres in environmental air could exceed those for asbestos alone. The precise identity of the various individual fibres is not known, although aluminium silicate and calcium sulphate have been reported (19). In the absence of any better available information, it is probable that the concentrations of a number of specific non-asbestos fibres in air are within an order of magnitude of the levels reported for asbestos in environmental air.

4.1.4. Lung deposition, clearance and retention following the inhalation of mineral fibres

Many of the experimental studies on this subject have been carried out using asbestos fibres but the general principles given below apply broadly to all mineral fibres.

Although fibres covering a fairly wide range of sizes are capable of being inhaled in occupational situations, the geometry of the lower respiratory tract is such that only particles of aerodynamic equivalent diameter less than about 3 μm (2, 6, 9), can normally penetrate to the lower pulmonary regions (9, 108). The fibre diameter is the most critical parameter, although general shape, including length also governs respirability (9, 109, 124-26). Because fibres can travel longitudinally in an airstream, their length can be considerably greater than their diameter and it would not be uncommon to find particles perhaps 25-40 μm long entering the alveloar regions. Most fibres entering the lung are less than 50 μm (6) but fibres longer than 100-200 μm are unlikely to reach the terminal air spaces (6, 9). As far as fibre diameter is concerned, this critically governs deposition. Very narrow short fibres are less likely to be trapped in the lung due to the fact that some can be exhaled virtually immediately (2). Certain types of fibres, e.g. narrow chrysotile asbestos by comparison with amphibole asbestos, are rather flexible and their 'curly' nature means that some of the

longer ones may not reach the lowest regions of the respiratory tract (268), although they may be effectively trapped in the larger bronchioles (9, 127).

The rate of deposition of fibres higher up the respiratory tract (bronchial regions and above) is greater than in the alveolar regions because the larger fibres can be impacted onto various surfaces (2, 108). In these higher regions, several mechanisms are involved in the clearing of fibres from the site of deposition, i.e. mucociliary clearance, translocation of alveolar macrophages containing small fibres (9, 108, 128) and uptake by epithelial cells lining the airways (9, 108, 129). Mucociliary clearance is an effective and fairly rapid means of removing fibres from the bronchiolar regions (6); the fibres become transported up the respiratory tract and many of them are ultimately swallowed (the ingestion of mineral fibres is discussed in section 4.2.2.(b) of this Report). Some fibres may be expectorated (6, 108). Mucociliary clearance is impaired by smoking (9, 108, 130, 233). Also overloading at very high dust load concentrations may overwhelm the defence mechanisms which in turn affects lung clearance (6, 131). The analysis of lung tissue in post mortem samples has been used as some indication of the possible asbestos fibre exposure to asbestos workers and to members of the general population (9, 132, 133). Several orders of magnitude higher asbestos levels were detected in some heavily exposed workers compared with lightly exposed workers and 'non-exposed' groups (132, 133). The quantities of fibres found in lung tissue are not necessarily wholly suitable in terms of an index of exposure however; this is because the rates of deposition and absorption of inhaled asbestos vary. For example chrysotile asbestos is much more quickly removed from the body than the more stable amphibole forms of asbestos (6, 9, 134-37); also fibre size is of critical importance in terms of deposition (see above). Glass fibres seem to be particularly readily dissolved by body fluids (7, 138) and the examination of lung tissue for the presence of these fibres may be a very poor indication of such exposure. In contrast, rock and slag wool fibres are more durable (7). Various types of mineral fibres have been detected in lung tissue (9, 139).

Deposited fibres less than about 5-10 μm long may often be engulfed by a single macrophage and thereafter become translocated (6, 9, 108, 140-43). Some of the fibres which become translocated may ultimately be eliminated by mucociliary clearance mechanisms; others pass to the lymphatic system and descend to the lower regions of the lung (6). Longer fibres (20-25 μm or longer) are incompletely engulfed by one macrophage, although several macrophages may act together to inactivate the fibre (143, 144). From the results of occupational studies and some animal tests, it seems that the most biologically active mineral fibres tend to be the longer ones (2, 7, 145); see also sections 4.2.1.(a) and 4.2.1.(b).

4.2. Effects of inhaling mineral fibres

The details of the complex mechanisms causing various biological effects due to retained fibres in the animal and human body are not discussed here in this Report; they have however been reviewed fully elsewhere (6, 9, 146). Nevertheless the actual human health effects, taking account of appropriate animal data are discussed here; where relevant, an outline of the mechanisms of disease occurrence in humans is referred to e.g. the current theories of cancer being caused by mineral fibres. Reviews have been published of the findings of in-vitro studies explaining their use in interpreting aspects of some biological mechanisms in relation to mineral fibre exposure (9, 146).

This section examines first the results of animal experimentation and then the human epidemiological evidence later on. A comparison is made between

the effects of inhaling asbestos and inhaling other mineral fibres. The health aspects of inhaling mineral fibres in the occupational environment is evaluated and contrasted with the evidence of possible implications for general environmental exposure.

4.2.1. Animal studies

A very considerable amount of work has been carried out on animals exposed to asbestos; by comparison, a limited amount of testing data is available on various other mineral fibres. The salient features of the results of tests involving implantation (injection), inhalation and ingestion of fibres in animals are described in this section; depending on the route of administration, fibrosis (asbestosis), lung and other tumours including mesotheliomas, have been observed (7, 9, 139).

Although general animal testing of mineral fibres has formed an important part of the evaluation and significance of possible effects related to human exposure, it is recognized that certain of the animal experiments are only of limited value when the results are extrapolated to humans (139). Animal experiments are nevertheless most valuable as a qualitative (at best a semi-quantitative) indication of the potential human health effects in relation to mineral fibre exposure (6). A number of animal tests have been carried out with extremely high doses in order to try to demonstrate any effects. If in such tests no effects are detected, then it can in some cases be acceptable to regard the result as providing some possible reassurance as far as humans are concerned where their exposures are at lower equivalent doses. The general limitations of animal testing have been reviewed (273); also the limitations specifically in the case of tests with asbestos have been reported (6). In the overall evaluation of the health implications of inhaling asbestos and other mineral fibres presented in this Report, the results of animal experiments have been only a part of the process of drawing general conclusions as far as human exposure is concerned. Other data including human epidemiology, additional toxicological data and information on risk assessment have also been used (see later sections 4.2.2. and 4.3.).

4.2.1.(a) Animal implantation tests

Various studies have been carried out where mineral fibres have been implanted into the animal species (79, 120, 148-50); such tests however are artificial in the sense that the actual routes of exposure e.g. via inhalation or ingestion are excluded. Nevertheless the studies have been useful in demonstrating certain biological mechanisms involving various effects, including the development of cancer. In this Report, the results of implantation tests have been taken into account when evaluating possible overall effects of inhaling or ingesting mineral fibres.

In relation to the development of mesothelioma in animals, asbestos fibres longer than 8 μm and less or equal to 0.25 μm seem to be the most carcinogenic (2, 151-2), i.e. long thin fibres. However, there is not a sharp cut off in dimensions (145) and indeed some reports refer to fibres less than 1.5 μm as the more carcinogenic (8). Various non-asbestos mineral fibres have been reported to be carcinogenic; these include: glass, basalt, rock wool, slag wool, aluminium silicate, ceramic, attapulgite, dawsonite, silicon carbide, potassium titinate, and erionite (7, 9, 10, 145, 146). For a number of these fibres the maximum carcinogenic potential has been reported to occur when the fibres are long and thin, i.e. 20 μm long and less than 0.25 μm diameter (7, 145). The fibrous mineral erionite is particularly carcinogenic as demonstrated by intraperitoneal injection, and gives rise to mesothelioma (146, 153, 159).

4.2.1.(b) Animal inhalation experiments

These experiments have been carried out to investigate particular known effects or effects considered possible in human beings exposed occupationally to inhaled mineral fibres. The tests were generally associated with evaluating the following diseases:- asbestosis (fibrosis); lung cancer; mesothelioma, as well as some other possible cancers.

(i) Fibrosis due to the inhalation of mineral fibres

Using asbestos (both amphibole and chrysotile forms have been tested), fibrosis (an irreversible disease associated with the deposition of excess fibrous tissue) has been observed in some animal species when the fibre was inhaled (6, 9, 120). In humans this is the occupational disease known as asbestosis. With inhaled glass fibre however, minimal fibrosis was reported where fibres of similar dimensions to asbestos were used (6). Compared with shorter fibres, greater fibrogenic potential was observed with longer ones (i.e. greater than 10 μm) both for asbestos and for glass (6); this was demonstrated in both inhalation and injection studies (6). In contrast, inhaled alumina fibres seemed not to cause fibrosis (6, 154), although erionite, pigmentary potassium titinate (PKT) and potassium octatitinate (Fybex) fibres did cause some fibrosis (9, 105, 155).

It is possible that the fibrosis may be due to mineral fibre involvement with macrophages or the disruption of lung fibroblasts following fibre deposition, leading to acute inflammation (9, 156) in the terminal bronchioles and alveolar ducts (6, 9, 108).

(ii) Cancer of the lung due to the inhalation of mineral fibres

This is one of the most significant properties of certain mineral fibres and it has now been firmly established in numerous experiments that a range of different types of inhaled asbestos is associated with primary cancer of the lung in different animal species (9, 121). In the lung, both in the bronchial and alveolar regions, maglignant and other tumours may arise involving the cells in the epithelial layers. In some of the earlier experiments using asbestos fibres where certain tests were at the development stage, negative results were obtained (9, 148). Various techniques and the experimental design have improved with time and there are now many examples of lung cancer being demonstrated in animal species following the inhalation of asbestos. Where the appropriate animal is selected, certain other inhaled mineral fibres (e.g. glass, ceramic, rock wool and potassium octatitinate fibres) have also been shown to cause lung cancer (9, 148). However, it would appear that these non-asbestos fibres are generally less carcinogenic than asbestos fibres (9, 148); nevertheless erionite seems to be a particularly potent carcinogen (146, 153). Various experiments suggest that most, if not all appropriately sized mineral fibres are probably, in principle, capable of causing malignancy (120); their precise size, shape and hence their lung penetration and individual reactivity (durability) will govern their exact biological properties (120). Although as a result of animal experiments chrysotile asbestos was thought at one time to be more carcinogenic than amphibole asbestos (148, 157); taking account of all the most recent animal studies, the distinction between their pathogenic properties has become less clear (6, 120). A number of theories exist to try to account for the precise carcinogenic properties of various minerals, especially in relation to fibre lengths and fibre diameters (148). In contrast with some of the animal experiments, human epidemiological studies seem to suggest that exposure to chrysotile is more likely to be less important in terms of lung cancer than the amphibole forms (120) (see also section 4.2.2.(a)). If this is really so it could

perhaps be partly explained in terms of the less dusty nature of chrysotile (leading to lower exposures at the workplace), in comparison with some amphibole forms, particularly crocidolite (2, 20).

In the case of bronchiogenic cancer the precise fibre dimensions in relation to carcinogenic potential are not directly definable; implantation tests with various mineral fibres suggests however that fibres greater than 8 μm and less than 0.25 μm are the most carcinogenic for mesothelioma development (2, 151, 152). There are however no sharp demarcations in dimensions in terms of carcinogenicity and diameters up to 1.5 μm may be implicated (2, 145); in the case of non-asbestos mineral fibres the maximum potency would appear to relate to fibres 20 μm long and less than 0.25 μm in diameter (7).

Just as occurred with asbestos animal testing in some of the earlier experiments, lung tumours were not found to occur when (selected) mineral fibres were inhaled (148). For example, glass fibres showed no carcinogenic effects in rats in early experiments (148, 155). In most recent studies however (7, 148), small numbers of pulmonary tumours were found not only with inhaled glass fibres but with several other fibrous minerals too e.g. slag and rock wool and ceramic fibres (148). In general the evidence would suggest that asbestos fibres could be somewhat more pathogenic than some other mineral fibres (9). However, this may be a function of the precise experiments used for testing, and variations in fibre dimensions, rather than due to the intrinsic mineralogical nature of fibres. Glass fibres seem to be especially capable of being dissolved by tissue fluids and this may limit their carcinogenic potential (148). The pathogenic properties of various non-asbestos mineral fibres have been recently and extensively reviewed (7, 9, 148); man-made mineral fibres have also been evaluated recently (7).

In summary it would appear that many mineral fibres may be carcinogenic when inhaled by animals. Some mineral fibres have not been adequately tested but it is probable that virtually all mineral fibres of dimensions similar to the range exhibited by typical respirable asbestos fibres could be pathogenic to some extent (120) when inhaled by animals.

(iii) Mesotheliomas arising from the inhalation of mineral fibres

Mesothelial tissue forms the membranes surrounding both the lung and the abdominal cavity of the body; pleural mesotheliomas and peritoneal mesotheliomas respectively arise when cancer originating in the serosal cells occurs in these regions (9, 83). Mesotheliomas are very readily produced when certain mineral fibres including asbestos are implanted or injected into the pleural or peritoneal tissue regions (9, 121). Although following inhalation of chrysotile, amosite and crocidolite, mesotheliomas are produced in animals, they are more readily produced by implantation or injection; this could be because when respired, various clearance mechanisms will be operative in the lung, reducing the number of pathogenic fibres. There is conflicting evidence as to whether mesothelial tumour response is dose related or not (9, 151, 161-63); it would however be most surprising if some form of dose-response relationship did not exist but it may not be a simple connection (164-66). Various implanted fibres (both longer than 10 μm and some shorter ones), produce mesotheliomas, although non-fibrous particles do not generally cause tumours (9, 146, 153). All forms of asbestos including several natural mineral fibres (e.g. erionite) and some man-made mineral fibres produce mesotheliomas when implanted (9, 121, 159, 234) (see section 4.2.1.(a)). Although in human epidemiological studies of industrial workers (108, 250), amphibole forms of asbestos appear to be more pathogenic than chrysotile, in animal tests this difference is not apparent (6, 9).

The precise mechanisms of mesothelioma response are uncertain (9, 146) but mesothelioma may occur as a result of a foreign body reaction. Such a reaction has occurred with metal and plastic films where they have been implanted into animals; it is known as the 'Oppenheimer effect' (146, 167). Although long thin fibres seem to be more carcinogenic in animals in relation to mesothelioma development (146), at present the situation regarding the precise particle size for brochiogenic carcinoma is less clear (146). For mesotheliomas, fairly precise data are however available for both asbestos and other mineral fibres (9). In experiments carried out using a variety of different sizes and types of asbestos fibre (146, 162, 168-71) the most carcinogenic fibres were longer than 8 μm and less than or equal to 0.25 μm diameter (2, 151-52). For non-asbestos mineral fibres the maximum carcinogenic potential seemed to relate to fibres 20 μm long and less than 0.25 μm diameter (7). There are however no sharp dividing lines for the dimensions of carcinogenic and non-carcinogenic fibres (2); fibres even greater than 20 μm will have some carcinogenic potential and fibres up to 1.5 μm diameter or larger may be implicated (2, 8). There appears to be no definable lower limit for the diameter of fibres which are carcinogenic (2).

4.2.1.(c) Carcinogenic mechanisms related to the inhalation of mineral fibres

The precise mechanisms which involve asbestos and other mineral fibres acting as carcinogens when inhaled (or implanted) are not well understood. In the case of asbestos and probably other mineral fibres too, it is thought that the cancer originates in cells which have been transformed by changes in, or damage to the DNA, or other genetic material (6, 108, 146). The target cells in the case of mineral fibre cancers are the epithelial cells of the bronchial tract and the serosal cells of the pleura and peritoneum (6). In the case of animal studies where mineral fibres have been implanted into tissue and tumours produced (7, 9), one could postulate that the mechanism might involve the fibres acting as carcinogenic initiators, i.e. the fibres acting as genotoxic carcinogens (146, 172, 173, 255). The same mechanism might also possibly account for mesotheliomas developed in the pleura and peritoneum of both humans and animals. In this case it may be that mineral fibres act as complete carcinogens (146) in the way implanted plastic and metal films act; i.e. the 'Oppenheimer effect' (146). However in the case of bronchial cancer, it is well documented that smoking and asbestos exposure act synergistically, i.e. more than just additively (9, 108, 120, 174-75) and it is probable that asbestos then acts as a promoter for the carcinogens present in tobacco smoke (174, 176); i.e. the asbestos acting as an epigenetic carcinogen (172-75). Even so, there are contrary suggestions that it is the promoting substances in tobacco smoke which might act with carcinogens like asbestos and other mineral fibres, the latter acting as initiators (108). It is likely that smoking enhances the lung cancer risk of exposure to environmental ambient levels of asbestos (9). It has even been suggested that 'passive' smoking (i.e. side-stream smoke which non-smokers can inhale) might act in combination with asbestos exposure (120). Smoking is known to affect the natural clearance mechanisms in the lung and this increases the residence time of asbestos there (6, 233).

In support of the promoting hypothesis for mineral fibres, the combination of asbestos and certain potent polycyclic aromatic hydrocarbons (as demonstrated in animal tests), can enhance tumour formation or can cause related biochemical changes (6, 173-4, 176-180). These results are consistent with mineral fibres acting as carcinogenic promoters and the polycyclic aromatic hydrocarbons acting as carcinogenic initiators. Asbestos has the property to adsorb carcinogenic and other organic substances, in part acting as a carrier (174) and behaving as a carcinogenic promoter (cocarcinogen) in the same way

as the mineral hematite reacts in certain animal tests (179). However, in the case of mesotheliomas caused by mineral fibres, there may be little combined effect of extraneous substances like the various organic substances (including carcinogens, present in tobacco smoke; this is because the latter will be expected to be present only to a very limited extent in the pleura and peritoneum since the tobacco smoke will readily condense out in the bronchial regions of the lung as it is inhaled. Asbestos nevertheless has very active surface properties and this may enable it to catalyze certain chemical reactions in various parts of the body (181). There are suggestions too that asbestos might possibly act not as a local carcinogen, but systemically via the immune system (182).

It is now well recognized that particle dimensions are very important in defining the carcinogenic properties of fibres (2, 9, 108, 183-85). In addition, durability and surface chemical properties may be important too (6, 108, 145, 186).

Suggestions have been made in some media articles that one single fibre of asbestos is enough to kill (incidentally one fibre is a minute quantity representing 10^{-16}g to perhaps 10^{-9}g, see Appendix). Against this, firstly a number of people believe in the multi-stage, multi-hit hypothesis (146, 187) for a tumour to develop and therefore a critical lethal hit by one single small fibre, although indeed a theoretical possibility, is extremely unlikely (274). Secondly, practically everyone on the planet in the course of breathing will have huge numbers of minute asbestos and other mineral fibres in their lungs (often many millions), as a result of normal environmental exposure (132, 139, 188); thus the risk from one additional fibre is evidently insignificant. Hence the hypothesis of being killed by one single fibre, in view of the extremely low risk involved, can be considered to be highly improbable. Indeed the statistical improbability of the one fibre argument has recently been discussed and reported (188-89, 274).

Depending on whether asbestos or other mineral fibres act as promoting agents or carcinogenic initiators (or indeed perhaps both), governs whether the concept of a low-dose no-effect threshold is realistic or not (172). In the case of carcinogenic promoters, any effect they may have (particularly at low doses) could be reversible (172, 175), and hence a threshold hypothesis has some validity (175). In the case of carcinogenic initiators the same argument may not apply, although it would seem likely (certainly in the case of multi-stage, multi-hit carcinogenic processes) that a very low dose might not have an effect; thus again a no-effect threshold may exist (172).

In summary, it is uncertain whether asbestos acts as a promoter or carcinogenic initiator. The probability is that the former is more likely but it is not perhaps impossible that both mechanisms apply in different circumstances. There have been various recent reviews of the carcinogenic mechanisms of asbestos and other mineral fibres (6, 9, 108, 146); these reviews should be consulted for further details. Further work on the mechanisms of carcinogenicity by asbestos and other fibrous materials would seem to be warranted.

4.2.1.(d) Animal ingestion experiments

Because when humans inhale asbestos and other mineral fibres some of the fibres can be ingested directly through the mouth and some indirectly following inhalation (83), it is relevant to refer here to the results of some animal ingestion experiments. The animal experiments which have been reported were primarily for the purpose of determining whether ingested asbestos in drinking water or food could cause a carcinogenic response (112). Despite a series of

studies involving huge numbers of animals in which rats and hamsters were fed massive doses of various forms of asbestos, essentially no significant carcinogenic response has been found which can be attributed to the ingestion of asbestos fibres (83, 112, 258). It is now becoming generally accepted that the ingestion of asbestos by the general population is not significantly related to gastrointestinal or other cancers (83, 112, 254, 258). It is considered that the risk (if any) to humans ingesting even several hundreds of millions of asbestos fibres per day (as a result of ingesting asbestos in certain drinking waters), is at most, exceedingly low (83, 112, 260).

The reason for a lack of response when asbestos is ingested is almost certainly related to the fact that very few, if any, fibres are capable of passing through the gastrointestinal tract wall to cause any effect; also stomach acidity can chemically degrade certain asbestos fibres rendering them less pathogenic (83, 112).

A human might be inhaling several thousands of fibres per day from the general air, and a portion of this number could be ingested; however there is no reason whatsoever to regard this as in anyway responsible for causing cancer or other diseases in man. In the case of occupational exposures, where in the past many millions of fibres could be ingested per day, the situation regarding the possibility of gastrointestinal cancer in asbestos workers is equivocal, although very recent work suggests it to be unlikely (279); this possibility is discussed later in section 4.2.2.(a).

Although little is known about the ingestion of non-asbestos fibres in animals, a lack of effects with ingested asbestos fibres will almost certainly apply to other mineral fibres too.

4.2.1.(e) Summary of animal study findings

It is clear that asbestos and a number of other mineral fibres including man-made mineral fibres can provoke a carcinogenic response when they are implanted or inhaled by animals. Fibrosis, lung cancer and mesotheliomas have been demonstrated in animals. No carcinogenic response has arisen where animals have ingested asbestos however. Asbestos is probably more pathogenic than most other mineral fibres; glass fibre is probably one of the least pathogenic fibres although erionite (a fibrous zeolite) is a particularly potent carcinogen. The maximum carcinogenic potential is associated with asbestos fibres which are longer than 8 μm and narrower in diameter than 0.25 μm, although no sharp demarcation in dimensions exists and fibres up to 1.5 μm may be implicated. For non-asbestos mineral fibres, a length of 20 μm and a diameter 0.25 μm seems to be associated with the optimum carcinogenic response. It would appear that all mineral fibres may be pathogenic if they are of the appropriate size.

4.2.2. Human studies

The studies on humans exposed to mineral fibres have been essentially part of numerous epidemiological surveys carried out on groups of industrially exposed workers together with some investigations related to the general population. Epidemiological surveys are often fraught with difficulties in terms of inadequate exposure data, limited population data, limited population size, and precise details of the causes of morbidity and mortality. Moreover, numerous confounding factors exist in epidemiology; for example factors such as smoking, dietary habits, exposure to different occupational carcinogens, age, sex, race, social habits, social class, population density, population mobility,

etc., can frequently confuse the interpretation of the study results. In essence, epidemiology attempts to describe the distribution and determinants of disease frequency in human populations. The eminent Statistician, Sir Austin Bradford Hill considered that the following nine points (190) need to be taken into account in order to establish whether a certain defined factor is related to the causation of an identified disease. The points are (i) the strength of the link between disease and the factor in question, (ii) the consistency of the observation in relation to other studies, (iii) the specificity of the association, i.e. specific diseases related to specific persons or groups, (iv) the temporality, i.e. is there a trend with time linking disease and causative factor, (v) the biological gradient, i.e. establishing whether there is a dose-effect relationship, (vi) the plausibility, i.e. does the cause-effect relationship seem biologically plausible, (vii) the coherence, i.e. does the relationship conflict with the natural history and biology of the disease, (viii) experimental, i.e. can the association be tested by experiments and (ix) analogy, i.e. establishing whether analagous relationships have been proven elsewhere. Epidemiology can usually be applied to points (i) to (v) above, but points (vi) to (ix) are important in giving weight to establish whether there is a definite cause and effect relationship. Some of the important criteria for human epidemiology in relation to asbestos exposure have been evaluated (6). This preamble to epidemiology is included so that the reader may understand better the difficulties and limitations of studies where certain definite effects and some possible effects have been found to be associated with exposure to asbestos and other mineral fibres.

The human epidemiological studies include (a) occupational exposure situations and (b) general environmental exposures. In both categories the routes of exposure involve the inhalation and ingestion of fibres. Occupationally and in the general environment, fibres may be ingested either directly (through the mouth) or indirectly (as cleared lung fibres which are subsequently swallowed). The inhalation and ingestion of mineral fibres are treated separately in this Report.

4.2.2.(a) Health effects of occupational exposures to mineral fibres in air

As a result of various occupational studies, only the exposure to asbestos fibres has been definitely associated with human diseases (7, 237, 239, 248, 256, 267). There are however some (unproven) suggestions of possible effects associated with the inhalation of certain non-asbestos mineral fibres in the occupational situation (7, 120, 236, 250, 252, 253, 263). Because of the effects observed, this section is mainly directed towards the exposure to asbestos fibres.

Health effects of inhaling asbestos have usually been associated with prolonged exposures to very high concentrations of fibres in workplace air. Associated with occupational asbestos inhalation are three well defined and serious diseases; these are (i) asbestosis, (ii) lung cancer (bronchiogenic cancer) and (iii) mesothelioma (cancer of the pleura and of the peritoneum). It is now widely accepted that these diseases have been caused by occupational asbestos exposure; however many heavily exposed workers have not developed these diseases even after a lifetime of inhaling asbestos occupationally. Because there is generally a very long latency period before asbestos diseases manifest themselves, workers who began their heavy exposures say even 20-30 years ago may not succumb to the effects of the asbestos disease until into the next century (238, 264). Apart from asbestosis, both lung cancer and mesothelioma are not specific to asbestos exposure; they can both be caused by certain non-asbestos occupational exposures and other environmental factors (191).

In some asbestos occupational studies there are suggestions that certain other cancers (e.g. gastrointestinal, kidney, ovarian and laryngeal) could be associated with exposure to asbestos (9, 120); these cancers have not been firmly and definitely established to be due to asbestos exposure per se (120); see comments in section 4.2.2.(a), (iv). Finally, asbestos fibres can produce pleural plaques and pleural calcification of the lung (shown by X-ray examination); such an effect per se is not generally thought to be disabling to an exposed worker (9). In order that the reader can better understand the various human diseases indisputably associated with past very heavy occupational exposures to asbestos dust, they are described below (see (i) to (iii)).

(i) Asbestosis. It is believed that this is caused only when workers are exposed to high concentrations of asbestos dust for prolonged periods (6); below a certain threshold of low exposure, clinically defined asbestosis is most unlikely to develop (6, 268). Both chrysotile and amphibole forms of asbestos seem to be implicated in the development of asbestosis in heavily exposed workers (6); it is unclear whether chrysotile is more or less hazardous than amphibole asbestos in the development of this disease (6). Asbestosis is a form of pneumoconiosis, the latter historically caused by excessive exposure to mineral dusts such as coal. Asbestosis is a severely incapacitating disease (108). Although not proven, other mineral fibres if inhaled in high enough concentrations for long periods may also cause fibrosis of the lung in a similar way to asbestos. There have been many reviews of asbestosis in relation to asbestos exposure, including several recent ones (6, 8, 9).

(ii) Lung cancer. This is also a very serious disease and can be caused by a number of factors including smoking, and is associated with occupational agents such as exposure to asbestos, arsenic, beryllium, bischloromethyl ether, chromium, ionizing radiations, nickel, polycyclic hydrocarbons in soots and tars (9, 121, 192-94). The cancerous growths develop in the epithelial cells lining the bronchial tubes or the alveoli (9). The malignant lung tumours which develop often also invade into surrounding body tissues (9). Usually the latent period for the development of lung cancer is quite long (6, 120); for heavily exposed asbestos workers it is generally in excess of 10 years (268). All forms of asbestos seem to be associated with lung cancer where the occupational exposure has been large enough (6, 120); crocidolite and amosite may be more hazardous than chrysotile asbestos in relation to lung cancer (120). The establishment of the relationship between occupational lung cancer and asbestos exposure stems largely from the classical work carried out in the 1950's by Sir Richard Doll (195).

It has been suggested that asbestos bronchial cancers invariably occur in lungs which are the seat of fibrosis (278). Thus it could be argued that excess lung cancer might only occur if asbestosis has also occurred, and in fact this can be partly supported by some recent studies of low level industrial exposure to chrysotile which have shown no excess of lung cancer (268). This is an important point if true, since asbestosis is not considered to be significant at low asbestos exposures and most unlikely indeed at environmental levels (6, 8, 268). Thus it could be that asbestos-induced lung cancer occurs only in asbestos workers who develop asbestosis (where the exposure has been high enough) and would not arise in the general population since they are exposed only to very low levels of asbestos. However at this stage the hypothesis must be regarded as unproven.

It has been shown that industrial heavy exposure to asbestos increases the risk of lung cancer due to smoking (1, 6, 8, 108, 114, 196); however smoking does not seem to influence the incidence of mesothelioma in asbestos workers (8, 9, 108). For example, the increased risk has been demonstrated for some

asbestos insulation workers who had a lung cancer incidence rate of 8 to 9 times that of non-asbestos workers; if they smoked, the reported risk dramatically increased to 92 fold (8, 108, 197). The relative risk in heavily exposed asbestos workers is said to increase about ten times if they smoke (114).

(iii) Mesothelioma. This is a relatively rare form of cancer which can be produced by high occupational exposures to asbestos (6, 108). Malignant mesothelioma of the pleura (the pleura is a membrane surrounding the lung), and malignant mesothelioma of the peritoneum (the peritoneum is a membrane which lines the cavity of the abdomen), have both been associated with occupational asbestos dust exposure (198, 199, 241); the latter being normally less frequently found than the former. On balance it would appear that crocidolite and amosite are probably more hazardous than chrysotile (120, 211) in relation to occupational exposures to asbestos and the development of mesotheliomas (6). This human finding however is inconsistent with the results of animal experiments (see section 4.2.1.) (6), but this could perhaps be explained partly by the dustier nature of crocidolite and possibly amosite, in occupational situations (2, 120).

Mesothelioma is a particularly unfortunate form of cancer in that there is no known cure for the disease (8, 9, 108). It is somewhat unusual in that the disease may not develop until as long as 20-50 or even more years (average 38 years (268)) after the commencement of occupational exposure (6, 9, 108). Peritoneal mesotheliomas can be rather difficult to diagnose and because such tumours invade various tissue structures (6), including those of the gastrointestinal tract (9), confusion with gastrointestinal tumours and other carcinomas may occur (9, 279).

Unlike lung cancer, there appears to be no enhancement of mesothelioma development as a result of smoking (1, 9, 108). This could perhaps be explained by the fact that those specific translocated fibres (deposited initially in the lung) which are responsible for mesothelioma development in the pleura and peritoneum, are then remote from the tobacco tars condensed out in the lung.

At one time it was thought that mesothelioma was exclusively related to asbestos exposure, but there are now many examples of other factors including environmental forms of contamination which can also cause mesotheliomas (6, 200, 211); these other factors are discussed in more detail in section 4.2.2.(b). One particularly important non-asbestos situation relates to some villagers in Turkey exposed to the natural fibrous mineral erionite; mesotheliomas have been observed in this population (9). Although at low levels of occupational exposure to asbestos mesothelioma may not be observed, there is no firm evidence to prove that low doses of certain fibre types are without any effect. However, one might anticipate that if a threshold exists then the dose must represent numerous fibres rather than just a few (see section 4.2.1.(c) and 4.2.2.(b)).

(iv) Other possible effects. It is important to consider the possibility of other diseases that might be associated with asbestos exposure. However although statistical correlations have been observed relating for example gastrointestinal cancers (oesophageal, stomach, colon and rectal), and laryngeal, kidney and ovarian cancer to the inhalation of asbestos dust in occupational situations, the general evidence for a causal relationship is neither consistent nor firm (6, 9,). Very recently however it has been concluded that the evidence in relation to laryngeal cancer is quite strong (279). Recent critical evaluations of over 20 epidemiological studies suggests that the evidence for occupationally inhaled asbestos being able to cause gastrointestinal cancer in humans is rather weak (9). A very recent evaluation of associated gastrointestinal cancers in asbestos

workers (279) suggests that 'there are no grounds for believing that gastro-intestinal cancers in general are peculiarly likely to be caused by asbestos exposure'. The route of exposure may be direct ingestion when breathing through the mouth, or indirect as a result of inhaled fibres which have been deposited in the lung being cleared via ciliary mechanisms and then swallowed (83). However, the evidence for such directly ingested asbestos being of any health significance seems to be very weak indeed (83, 112); this has also been confirmed in animal experiments using massive doses of asbestos (83, 112); see section 4.2.1. Nevertheless since translocation of fibres deposited in the lung could arise, whereby fibre transportation occurs (possibly via the bloodstream) to various parts of the body (6, 9, 110, 128, 191), it would not perhaps seem impossible for occasional cancers, including perhaps gastrointestinal ones to arise from occupational exposure to asbestos. One problem with gastrointestinal cancers in humans is that they may get recorded as pleural, peritoneal or lung tumours (9, 279), the latter three being known to be caused by inhaling asbestos, see above. Thus the overall evidence for gastrointestinal cancers arising directly from the occupational inhalation of asbestos remains unproven; the probability of ingested asbestos being involved would nevertheless seem to be small (83, 112, 258, 260).

Non malignant pleural changes, e.g. pleural thickening, formation of plaques and calcification are also associated with occupational asbestos exposure (9). the changes are markers of asbestos and other mineral fibre exposure (6), although other environmental factors may also cause pleural changes (215); see also section 4.2.2.(b). These changes progress slowly. Few people in whom these changes occur actually complain of any ill effects (9); however, there have been occasional reports of certain individuals becoming incapacitated (6).

(v) Comparison between health implications of inhaled asbestos and non-asbestos mineral fibres. So far, effects in humans have only been described in relation to asbestos where it is inhaled occupationally. Although no firm evidence for effects caused by the occupational exposure to other natural mineral fibres or man-made mineral fibres have been described, an increasing amount of data is becoming reported which suggests that there may possibly be some undesirable effects (7, 120). For example the numbers of deaths from lung cancer in some occupational studies are somewhat higher than expected (7), although at this stage the data are far from firm to enable definite conclusions to be drawn (7). From the results of animal studies, (see section 4.2.1.) one might expect that where mineral fibres are of similar dimensions to asbestos fibres, then if they are inhaled in high enough concentrations for sufficiently long periods, similar diseases to those found for asbestos could perhaps arise (see also section 4.2.1.(b)). There are however some other differences between certain mineral fibres and asbestos, e.g. asbestos can in situ often more readily split longitudinally into finer fibres (2, 7) than many other mineral fibres, especially man-made ones; the exact significance of this splitting is unknown in terms of health implications but fibre dimensions can of course change and this may modify pathogenicity (7). Also in terms of durability some mineral fibres (e.g. glass) will more readily dissolve in body fluids than asbestos and this may decrease potency (6, 7). The exposures to asbestos in the past in industry were generally orders of magnitude higher than those for other mineral fibres, and this difference in dose could itself account for the lack of demonstrable effects with certain non-asbestos fibres. It has to be borne in mind that a number of diseases including lung cancer and mesothelioma can have extremely long latent periods before the disease manifests itself; thus one will need to wait some years yet before any possible effects from exposures to certain non-asbestos fibres have had a chance to show up.

It is not the intention here to evaluate in detail the various occupational epidemiological studies related to asbestos and other mineral fibre exposures. These have been described and fully evaluated elsewhere (6-9, 279). It is very firmly established in many studies that asbestos has caused serious effects in humans occupationally exposed in the past. The asbestos textile industry seems to have been particularly hazardous (6). Asbestos insulation workers seem generally to be at particular risk in comparison with miners, millers and most manufacturing workers (6, 9); asbestos cement and friction products manufacture seem to be associated with lower risks (19, 120). However, there are some exceptions to these general statements made above (6). Fibre type is also of particular importance (6). The precise levels of exposure related to these effects are not easy to define (see section 4.1.2); however it is very probable for reasons given in section 4.1.2. that the published exposure levels (116) as suggested and used in some health effects studies are underestimates of the relevant conditions for some exposed workers. The various diseases caused by past exposures to inhaled asbestos have been described earlier in this section. In contrast with asbestos, occupational exposure to other mineral fibres has not been proved to be associated with serious health effects; further work seems to be needed however to fully evaluate the situation.

The examination of lung tissue has been used in some case control epidemiological studies (132, 243). This is not considered as a wholly reliable means of quantifying exposure to asbestos and other mineral fibres, in that different forms of fibre will be retained and cleared at different rates over periods of time (6). Some of the limitations of using the analysis of fibres in lung tissue have been reported (6). However, very interesting comparisons between those fibres found in asbestos workers and the general 'unexposed' population can be made (276).

(vi) Summary of health effects of occupational exposures to inhaled mineral fibres. Various diseases including asbestosis, lung cancer and mesothelioma are indisputably associated with usually prolonged and very heavy exposures to asbestos which existed some years ago in certain industrial situations. At this point in time no definite such effects have been observed for occupational exposures to other mineral fibres, including man-made fibres; further work seems to be needed to fully evaluate this situation however. Asbestosis seems to be associated with all types of asbestos exposure, but in contrast, mesotheliomas would appear to be more particularly related to crocidolite and amosite exposures rather than to chrysotile; lung cancer seems perhaps also to be less associated with chrysotile exposures but the available evidence for this disease is not clear. Lung cancer and mesotheliomas are not specifically related to asbestos exposure; smoking and various types of different occupational exposures can also cause lung cancer and various non-asbestos associated factors can account for mesotheliomas. Smoking also strongly enhances the lung cancer incidence in workers heavily exposed to asbestos; mesothelioma incidence however does not seem to be associated with smoking habits. Other cancers such as laryngeal, gastrointestinal, kidney and ovarian do not seem to be consistently and firmly related to occupational asbestos exposure. Any possible effects of ingesting asbestos in occupational situations where airborne asbestos is present seem to be non existent or at most at low level; perhaps very occasionally, gastrointestinal tumours may arise where the inhaled asbestos could be translocated after being deposited in the lung to elsewhere in the body. Non malignant pleural changes are detected in some asbestos workers but these are not generally considered to be of special concern. It is likely that the predicted occupational levels of asbestos in air used in some health effects studies have been underestimated. Finally, although the evidence for non-asbestos fibres being a hazard to workers is weak, one might expect that where the fibres are

of comparable dimensions to asbestos and where the exposure is long and high enough, then in principle some similar problems found for asbestos may exist when workers are exposed to some of the more durable non-asbestos mineral fibres.

4.2.2.(b) Health effects of environmental exposure to asbestos and other mineral fibres in air

In this section any health effects that might be considered to arise from non-occupational exposures are evaluated. Exposures in the street, in the air near mineral fibre industries, at home, in the office or in other buildings (schools) etc. are appraised in relation to possible health effects.

In the case of inhaling fibres from the general environmental air, it is recognized that some will enter the respiratory tract and some will be ingested (either as a result of direct ingestion through fibres entering the mouth or indirectly as a result of lung clearance mechanisms). Consideration of the following possible diseases in relation to exposure are considered here:- fibrosis (asbestosis), lung cancer, mesothelioma, gastrointestinal cancers, certain other cancers.

Account is taken of human epidemiological studies where groups of people were studied in relation to their exposure to mineral fibres in environmental air. Such studies that exist, relate to asbestos fibre exposure rather than other mineral fibres; exposure to erionite has been studied however (see later). The actual published levels of environmental concentrations in different situations are provided in Chapter 3 of this Report; the risk estimates in relation to various possible diseases as a result of exposure to environmental mineral fibres are given in section 4.3.

Firstly it needs to be recognized that the exposure to mineral fibres in the general environment is generally many orders of magnitude lower than that experienced in the past in occupational situations; this is especially so in relation to asbestos dust exposure where in the past the workplace levels of asbestos were not infrequently enormously high. At least 1,000 to 10,000 times and even perhaps 100,000 times lower has been suggested (230, 257). Other than in very special past situations (see below) in relation to asbestos and for erionite exposure in some Turkish villages (see later), no adverse health effects have been definitely attributable to mineral fibre exposure in the general environment. In the studies examined here in relation to environmental exposures, particular emphasis is given to possible diseases such as cancer (including mesothelioma) rather than fibrosis (asbestosis). Fibrosis and asbestosis seem to be related to very heavy occupational exposures and in part could arise when the concentrations which are inhaled are so high that the pulmonary defence mechanisms are overridden (131). There are no serious references to fibrosis or asbestosis arising in the general population from environmental exposure to mineral fibres (8). There is thought to be a threshold level of exposure below which asbestosis does not occur (108, 268).

Next, various community epidemiological studies are evaluated where mineral fibres have been inhaled by the general public. Subsection 4.2.2.(b) (i) deals with asbestos and subsection 4.2.2.(b) (ii) deals with other mineral fibres.

4.2.2.(b)(i) Health studies in relation to environmental exposures to inhaled asbestos

General studies where no effects have been observed

In 1976 a study was published (201) in which various cancers were

contrasted between those counties in the United States where there were known natural deposits of asbestos, and those counties where there were no such deposits. Although this study did not include actual exposure data, it is very likely that the average person in the 'asbestos' counties inhaled more fibres there than in the other counties. No statistically significant difference in the incidence of cancers was found between the two groups of counties (201). Although the study was well planned, its sensitivity was such that it would not be capable of detecting any very low level of effects, if in fact they existed (6, 201). A somewhat analogous study (202) was carried out in Austria; districts and towns with asbestos deposits (tremolite asbestos) or asbestos processing were contrasted with control areas. The area of asbestos processing was one where a major asbestos-cement plant existed. A full evaluation of this study showed that no significant differences in lung and stomach cancer rates (both for males and females) could be attributed to environmental asbestos exposure. Although this study covered smaller populations than the above study (201), it was stated to be based on better data (202). Again however the sensitivity of the study was such that any very low level of effects (if they exist) would not have been detected. The same investigators (202) also looked at the distribution of mesotheliomas in Austria, but found no clustering of the tumour in areas associated with asbestos. Overall, taking account of some other studies too, the investigators considered that there was no indication of excess cancers due to environmental exposure (202).

A valuable study has been carried out at two mining townships in Quebec, Canada (30). This is an interesting study because the general air of these townships happened to be very heavily polluted with asbestos; a 'snow-like film' being a regular occurrence some 20 years or more ago, has been reported (30). Such a 'film' in itself suggests that a very high airborne-level of asbestos fibres existed at that time; levels as high as 140 $\mu g/m^3$ asbestos have been suggested (30). The utilization of environmental control measures has long since eliminated such conditions. The epidemiological study enabled various cancers including respiratory and digestive tract ones to be examined in relation to the asbestos townships; a comparison was made with the rest of the Province of Quebec acting as a control population (30). The results for females are more relevant, in that, other than for very few women, they were not occupationally involved like males; also many of the females were considered to be exposed since childhood (30). The mortality rates for females however were found not to be significant in excess of that which would be expected statistically (30). The results are compatible with the hypothesis of no excess risk, although because of the size of the study a very small excess cannot be completely ruled out. This negative result is of particular interest in that the environmental air pollution levels of asbestos were reckoned to be a hundred times greater than the air in some North America and European cities (30). In the study, males seemed to show some excess risk of respiratory cancer but this was readily accounted for by the fact that a significant number had histories of occupational exposures to asbestos (30).

In 1979 an investigation was reported (6) of a study of nearly 2,000 males living within 0.8 km of an amosite factory in New Jersey, U.S.A; none of the men worked at the factory. No excess mortality or excess lung cancers were detected in the group of men living near the factory compared with a control neighbourhood several kilometres away (6, 203).

Extensive studies of mesothelioma incidence in Canada, revealed no association between residence within 20 miles of intensive mining activity and this form of cancer (8, 204).

Thus these studies of general environmental exposure to asbestos did not demonstrate any undesirable health effects including cancer from inhaled asbestos in the general community air, even though in some cases the exposure must have been relatively high in the past; the sensitivity to detect small effects in these studies is low however.

Neighbourhood studies where effects have been observed

In contrast, there are some cases of neighbourhood exposure where effects in the general population have been alleged to be associated with non-occupational exposure to asbestos. For example, eleven cases of mesothelioma were reported in 1965 for non-occupationally exposed people living within half a mile of an asbestos factory in the east end of London where crocidolite, amosite and chrysotile were used (8, 37, 199). Some years ago neighbourhood cases of mesothelioma were reported nearby shipyards and near an asbestos factory in Hamburg, F.G.R. where mixtures of chrysotile and amphiboles were used (8). From studies carried out some time ago in South Africa, some neighbourhood cases of mesothelioma in a crocidolite mining area were reported (8, 205). Out of 33 cases of mesothelioma in the Northern Cape Province in South Africa, 32 seemed to be associated with histories of living near a crocidolite mine (37, 198); it is very probable that in the vicinity of the mining area it was very dusty. Thus in these particular studies there does seem to be some evidence that asbestos in the general environment in the past (especially perhaps for amphibole asbestos) was a contributing factor in the causation of some cases of mesothelioma in certain members of the general public. No firm information however is available on the levels of exposure; however, eye witness accounts of some environmental situations in the past (30) suggests that the exposures might have been fairly substantial in mining areas. Also mesotheliomas were not uniquely related to asbestos exposure (200) and thus it is possible that some recorded cases may have been caused by factors unrelated to asbestos.

Household-contact studies where health effects have been observed

In addition to these neighbourhood exposures to asbestos above, where some health effects have been observed, special cases of household contacts to asbestos exist with mesotheliomas being reported (8, 199, 206, 207). In these cases asbestos dust was presumably brought home on the workclothes of men working at an asbestos factory; the asbestos dust seems to have been the most likely cause of mesothelioma in some women at home (8, 199, 206, 207). In one of these studies carried out in New Jersey, U.S.A., cohabitants of 1,664 amosite asbestos workers employed from 1941-1954 were studied (8, 206). X-ray examination of 678 household contacts showed a significant number of lung abnormalities, e.g. pleural thickening, calcification and plaques (9, 206), compared with the incidence for the general public. According to the investigators (9, 206), 5 mesotheliomas were detected out of a cohort of 3,100 household contacts. This is a proportion much higher than is seen in the general population; the study has been brought up to date using further data (208). In another study (9, 207), carried out in New York State, U.S.A., cases of mesothelioma found in females between 1967-1977 were studied in relation to occupational exposure and household contact to asbestos. Six of the 52 cases of mesothelioma studied seemed to be associated with past occupational exposures, and 8 others had husbands or fathers who had been employed in asbestos industry. In a further study in England reported in 1965, 9 female cases of mesothelioma were investigated (8, 199); it seems that these could have resulted from husbands or relatives, etc. working at a local asbestos factory near London, U.K., bringing home dust on their clothes. Chrysotile, crocidolite and

amosite have been reported to have been used at the factory (8, 199). Also two cases of mesothelioma were reported in relatives of workers in a crocidolite mine in Western Australia (8. 209). These and other studies have been evaluated (6, 8, 9). It would appear that these household exposures to asbestos were sufficient to cause some mesotheliomas in non-asbestos workers; amosite and crocidolite seem to be more particularly implicated (8, 136). No reliable representative figures are available for the concentrations of asbestos dust at home to which people could be exposed (8), but in view of the very dusty nature of asbestos attached to clothing, the exposure may well have been substantial (75, 136). It has been reported (175) that several hundreds of fibres per ml air was measured in domestic situations where fine asbestos fibres can remain airborne for days before settling. Also once the dust has been brought home it is difficult to remove it, and asbestos fibres could be re-entrained and released again and again to the air (75). Home exposure is also significant in the fact that it can continue for the whole time one is at home, which for some people such as housewives, may represent a high proportion of their time each day. Another factor of some possible importance relates to the fact that some householders may be exposed to short duration peak exposure conditions from time to time in the cleaning of dusty workclothes, especially if the process is carried out in a small room. Such peak exposures are of some significance in that they could perhaps contribute to the possibility of overwhelming the lung's clearance mechanisms; overwhelming has the effect of making such exposures worse than an overall accumulated dose of the same magnitude, inhaled at lower concentrations for a longer period of time (6). Fortunately high household levels are a thing of the past; this is due to a number of factors, including the general awareness of a hazard, much lower workplace clothing contamination these days, adequate washing facilities at work before coming home, and dusty workclothes remaining at work rather than being brought home.

Exposures for special groups and possible health implications

Apart from asbestos dust brought home by asbestos workers, some people have expressed concern regarding indoor exposures to asbestos in general, with special concern in relation to possible effects in children (75, 76). If substantial quantities of asbestos dust are present inside buildings (perhaps in households, schools and certain other buildings) then on average a child's exposure to asbestos including their adult life later on will be greater. This may lead to the accumulated lifetime dose being higher than for those people not specially exposed. However, the increased exposure in comparison with other people is only slightly greater (6) as a result of such indoor asbestos, including school exposure (see Chapter 3 and elsewhere). Even so there is some extra concern for children in relation to mesothelioma since exposures in early childhood can theoretically be more significant in terms of the development of the disease (8, 9). Theoretically, for mesothelioma the risk is suggested to rise at a rate of between the 3rd and 4th power of time since first exposure (6, 9). However there is no really firm evidence that such early exposures do in fact lead to a very significant risk from mesothelioma later on in life (6, 8, 75, 210-11). Calculated estimates for any possible increased risk seem to be relatively small (see section 4.3.). Nevertheless, cases of childhood mesothelioma exist although as far as is known these are not asbestos related, or at least unproven to be asbestos related (6, 8, 210-11). A variety of factors unrelated to asbestos exposure appear to be causes of the disease both in children and in adults (191, 200, 211. 244). Factors such as viruses, certain organic chemicals, certain non-asbestos fibres e.g. erionite, radiation, hereditary factors, certain drugs, beryllium, chronic inflammation, seem to be implicated (191, 200, 211, 244). Children are of course less aware than adults of many hazards and there are examples in the past where children have been playing on sites contaminated

with asbestos dust, including dumps near factories and mines (8); however, although their exposure in the past may have been greater, there are no reported cases where it has been proved that such childhood exposures have led to the increased development of a disease later on in life. There have been suggestions that the lungs of young children are more susceptible but when various experts were questioned (6), no substantive support could be found for this proposition (6).

Other possible effects

In addition to the possibility of certain diseases which might perhaps be related to the environmental exposure to asbestos, the formation of pleural plaques and other changes are of interest. For example, pleural plaques were found to be endemic among agricultural workers of South Bulgaria (9, 212); Anthophyllite and tremolite asbestos present in the soils may have been responsible (9, 213). Similar pleural changes have been observed in New Jersey, U.S.A. amongst residents who in the past lived near an amosite asbestos factory (9, 206). These pleural changes seem simply to be indicators of exposure to asbestos and some other environmental dusts (6, 9); they have not been reported to have any significant health implications for the general population.

Pleural changes are also known to arise following exposures to agents such as talc, mica, kaolin and bakelite as well as certain mineral fibres (215). Other than lung cancer and mesothelioma, certain other cancers have been suggested as being associated with occupational exposures to asbestos; these are gastrointestinal, ovarian, laryngeal and kidney cancer. The evidence that there is a firm relationship between occupational asbestos and these cancers is weak (see section 4.2.2.(a)); thus in relation to environmental exposures to asbestos which are so much lower, the evidence of an association can be essentially dismissed. In drawing these conclusions it is recognized that where asbestos is inhaled, some of the fibres will subsequently be ingested (83) and thus there is direct exposure to ingested asbestos. However the evidence that directly ingested asbestos from whatever source is a health risk must be regarded as extremely weak (83, 112); for example, where relatively high concentrations of asbestos are ingested from certain drinking waters, the health risk (if any) can be considered to be sensibly zero or at the most exceedingly low (83). Also at the beginning of section 4.2.2.(b), various epidemiological community studies were evaluated in relation to asbestos exposure; there was however no firm evidence of gastrointestinal cancers in these studies.

Although there would appear to be no firm evidence of health risk from environmental levels of asbestos in air nowadays, risk estimations using mathematical formulae have been made. They have been made on the basis of exposures in the general environment in comparison with conditions in the past for occupational situations (see section 4.3.). Even for higher than average exposure conditions the predicted risks seem to be at an extremely low level (see section 4.4.).

4.2.2.(b)(ii) Health studies in relation to environmental exposures to inhaled non-asbestos mineral fibres

No studies have been reported which indicate any health effects in communities where exposures, including those arising from factory emissions of non-asbestos mineral fibres, or man-made mineral fibres have occurred; this contrasts with asbestos, where in the past health effects, e.g. cases of mesothelioma have been reported (see above) to be associated with environmental exposures to asbestos. However in the case of community exposures (for

villagers in Turkey) to the fibrous mineral erionite which occurs naturally, there seems to be a strong association between the inhalation of this mineral fibre and mesothelioma (9, 214, 215, 241, 251). In two villages in the Anatolia region of Turkey where some of the inhabitants live in type of cave, exposure to erionite which is a form of fibrous zeolite, occurs; very little asbestos has been found in the region (9). Both pleural and peritoneal mesotheliomas, some fibrosis, and the presence of pleural plaques have been reported in the population (9, 214, 215); it is possible that lung cancer may also be associated with the exposure to erionite (9). The various effects suggest that the route of critical exposure is via inhalation; erionite fibres have been detected in the lungs of villagers dying of mesothelioma (9, 216). Of particular concern is the rather high incidence of mesothelioma cases (9), and in view of the fact that some of the villager's dwellings are caves hollowed out of rock (9, 214-15), one must assume that the exposure to local mineral dusts and fibres is relatively high. Little is available on exposure, although in one study, up to 1.38 f/ml has been reported during the cleaning of some villager's caves (9, 214). Materials which happen to contain erionite are used for constructing some dwellings in this region (214); this could also probably cause increased exposure.

Turkey is not the only country where the population seem to be exposed to respirable erionite fibres. Recently in parts of Arizona, Nevada, Oregon and Utah in the U.S.A. and in New Zealand (9, 217, 234), erionite has been found, and pleural thickening and some pleural plaques (but no mesotheliomas) have been detected in some members of the population there; these plaques were thought to be possibly due to the inhalation of erionite. There are other geographical areas too in Finland, Eastern Europe and Greece where pleural calcification is reported to be prevalent in the general population (120, 214, 218-220). Although in a number of cases this may have been due to the inhalation of naturally occurring forms of asbestos, in others they are likely to have been caused by non-asbestos mineral fibres (9, 120). No symptoms of ill effects have been reported in the general population where cases of pleural calcification has arisen due to mineral fibres, whatever their source.

It is worth trying to determine why the exposure to erionite in the Turkish villages seems to be the cause of a relatively high rate of mesothelioma (9). Because such areas in which the erionite is found can be dry and dusty, the exposures may become relatively high. A particular factor of importance too is the fact that most of the villagers will have had a lifetime of exposure. It may be that erionite is a particularly hazardous substance to inhale over many years. Perhaps it is even more dangerous to humans than asbestos for a given dose; animal tests have demonstrated that it is a very potent carcinogen (9, 159) and no other mineral fibre, natural or man-made, has been stated to be as pathogenic in animals as erionite (120). There have been several recent reviews of the occurrence of mesothelioma in populations not known to be specially exposed to asbestos (9, 221-22). These studies are of particular significance in that they demonstrate that naturally occurring non-asbestos fibres can cause serious effects in non-occupationally exposed people; they show very clearly that mesothelioma is not uniquely related to asbestos exposure which was at one time thought to be the case. Various other factors such as viruses, radiation, specific chemicals and other factors (see section 4.2.2.(b)(i) are also considered to be strongly associated with mesothelioma in the general population (175, 191, 242, 244). It has been suggested that the risk of mineral fibre mesothelioma may be higher in areas where there is a greater incidence of benign pleurisy (261).

Silica fibres associated with areas where sugar cane is grown have been suggested to be possibly important in relation to mesotheliomas (245, 246). The evidence is however rather tenuous. The fibres seem to arise when the sugar

cane leaves are burnt prior to harvesting the cane; it has been shown that silica fibres of about 0.85 μm diameter and 10-300 μm long are produced when sugar cane leaves are ashed under laboratory conditions (277).

4.2.2.(b)(iii) Summary of the health effects of environmental exposures to inhaled mineral fibres

For the environmental conditions that exist nowadays there would appear to be no firm evidence that inhaling asbestos fibres causes diseases such as asbestosis, lung cancer, mesothelioma or other cancers. This contrasts with occupational exposures to asbestos which in the past were associated with an undesirably high incidence of asbestosis, lung cancer and mesothelioma. In the past too, in relation to environmental exposure to asbestos coming from factory emissions, etc., or from household exposure to dust brought home on workclothes from factories, cases of mesothelioma have been reported in people non-occupationally exposed to asbestos; the exposures seemed to be more associated with crocidolite and amosite although chrysotile could have been implicated too. For exposures in the general environment to non-asbestos mineral fibres including man-made fibres, there would appear to be no firm evidence of health effects being produced, except in the case of natural erionite fibres. Natural erionite fibres have been identified in a few parts of the world, and in two Turkish villages, cases of mesothelioma have been reported in villagers exposed to the fibre; it is thought that the cause of the mesotheliomas is the inhalation of the erionite. The risk of mesotheliomas from erionite exposure still exists today. Recently a number of other factors which seem to be related to the cause of mesothelioma have been reported; factors such as viruses, radiation, specific chemicals in the environment and other factors, appear to be important. Some pleural changes have occurred in members of the population exposed to asbestos and other mineral fibres in environmental air; these changes are not considered to be of any concern as far as health is concerned and they simply seem to indicate exposure to fibres, etc.

As a result of various community epidemiological studies, no firm evidence of a health risk from environmental asbestos seems to exist nowadays, but risk estimations based on mathematical predictions have been attempted (see section 4.3.). The risks have been predicted on the basis of concentrations of asbestos in the general environment including higher than average exposure situations in certain buildings like schools. Even for school children and teachers etc., the risks would appear to be at an extremely low level (see sections 4.3. and 4.4.).

4.3. Estimates of possible health risk associated with inhaling asbestos and other mineral fibres in environmental air

Since there is a definite and indeed sizeable health risk associated with past occupational exposures where high levels of asbestos were inhaled by workers, it is not inconceivable that a small risk might possibly exist for the general population where the latter inhale very much lower levels of asbestos. Some possible risk may also exist from the exposure to environmental levels of non-asbestos fibres, although unlike asbestos, no health risk has yet been definitely proven for occupational exposures to non-asbestos fibres. In this section the magnitude of any general population health risk possibly associated with exposure to inhaled mineral fibres (mainly referring to asbestos) is assessed.

One method of estimating human risk from various environmental substances is to take account of animal exposure data in which extrapolation of the animal risk to that for humans is calculated using various information (9). This can be a useful approach although where there is a considerable quantity of

relatively good human epidemiological data, the use of the latter is very much to be preferred (9). Because of the greater uncertainty associated with the use of study data where animals have been exposed to asbestos, approaches using the information from human epidemiological studies are referred to and used here. In interpreting and using the human epidemiological data, account is however taken of certain findings from various laboratory experiments with animals. Nevertheless it needs to be recognized that there are some limitations even with the use of human epidemiological data (235). In the approaches used here the prediction of human risk has been mainly based on extrapolation of occupational data to that for the general environment using health statistics and information about the different exposures. Reference is made to some health studies carried out directly on the general population exposed to low levels of asbestos; however, the sensitivity of such studies is generally not adequate to provide precise estimates of any very low risks which may be associated with environmental asbestos exposure. Although no firm evidence of a risk exists for current environmental levels of exposure to asbestos, in order to try to define the level of possible risk, special mathematically derived risk estimates have been calculated.

4.3.1. Some possible cancer risks

For environmental asbestos, predicted possible risk estimates related to lung cancer and mesothelioma are considered here. Asbestosis is not considered to be a health issue for the general public (8); also other cancers e.g. gastrointestinal cancer, laryngeal and kidney cancers are considered to be too improbable in relation to environmental asbestos exposure (see section 4.2.2.(b)). The risk estimates given here take account of the fact that the overall exposure to environmental mineral fibres includes exposure to inhaled fibres in indoor as well as in outdoor air. Special account is taken of the exposure to children (because they may possibly be more exposed at school than elsewhere) and of the exposure to the occupants of particular buildings where the levels of mineral fibres e.g. asbestos may be elevated. In making risk assessments it is important to consider special groups such as children because they just might be more sensitive than adults (9, 223-25). However in the case of the inhalation of asbestos there is no firm evidence that children compared with adults are intrinsically more prone to develop cancer when exposed to the same concentration of fibres, except in relation to a potentially longer period of exposure. The length of exposure and more particularly the date of onset of exposure seem to be of special importance (226) and these are fully taken into account here in the evaluation of children's exposure to mineral fibres.

By far the most comprehensive evaluation of possible health risks regarding exposure to mineral fibres in the non-occupational environment has been only very recently published; this was carried out under the auspices of the distinguished National Research Council in the U.S.A. The large Committee of Specialists (9) concluded that it is meaningful to make predictions of risk for both lung cancer and mesothelioma which could possibly be caused by environmental exposure to asbestos. The Committee also concluded that their information base, although not adequate for quantitative risk assessment to environmental non-asbestos mineral fibre exposure, was of some use for certain qualitative aspects of risk evaluation for such fibres (9). The Committee (9) adopted two equations for their risk assessment of exposure to asbestos. For lung cancer an equation derived by Professor J. Peto (9, 226) was used. This equation provided cumulative lung cancer mortality for a given dose of asbestos over a specified time period; the possibilities of lung cancer risk for smokers and non-smokers, and for males and females were assessed separately. For mesothelioma, another equation based on the multi-stage theory of carcino-

genesis was used where cumulative mesothelioma mortality for a given environmental asbestos dose could be predicted allowing for the time since first exposure i.e. onset of exposure (9, 227). No separate assessment for smoking habits or sex was made since mesotheliomas do not appear to depend on these factors (9). For these two equations, substantive supporting evidence for their justification in use has been reported (9, 116, 226, 228, 229).

4.3.2. Predicting possible cancer risks

4.3.2.(a) National Research Council 1984 Study

Using the two equations referred to above and incorporating carefully evaluated risk data from occupational studies for known levels of asbestos exposure, general environmental lifetime (based on 73 years) risk values were calculated and reported by the National Research Council Committee (9). A median value of 0.0004 f/ml asbestos was considered by the Committee to represent population exposure overall (i.e. including outdoor and indoor exposures). The details of the risk calculations (9) are too extensive to provide in detail here. The results as reported (9) are given in Table 1.

Because the equations used are based on a linear dose-effect relationship, the figures quoted in Table 1 can be increased or decreased in direct proportion to the exposure level. The Committee concluded the following two points (9).

1. 'For non-smokers, the lifetime risk for mesothelioma from non-occupational environmental exposure to asbestos is higher than for lung cancer. For smokers, however, the risks of lung cancer are substantially higher than for mesothelioma, because of the multiplicative interaction of smoking and asbestos exposure.'

2. 'Individual lifetime risk estimates for lung cancer from non-occupational environmental exposures to 0.0004 f/ml are much lower than the risks observed for smoking.'

The Committee (9) considered that the outdoor median concentration of asbestos fibres to be 0.00007 f/ml (range 0.00002 to 0.00075 f/ml; various studies). They reported median levels in rooms without asbestos as 0.00054 f/ml and in rooms with asbestos surfaces 0.0006 f/ml (range 0.00006 to 0.00405 f/ml; various studies). The Committee calculated the median population exposure to be 0.0004 f/ml by apportioning an individual's time spent in outdoor and indoor air (9).

4.3.2.(b) Other studies

Another risk study of non-occupational exposure to asbestos was reported in 1983 (65). An exposure to asbestos of 0.0015 $\mu g/m^3$ in outdoor air was estimated for the entire U.S. population and the possible risks for lung cancer and mesothelioma were calculated. For lung cancer, an extrapolation was made from workplace exposure levels and the incidence of occupational cancer. The investigator (65) estimated that the lifetime risk from lung cancer in the general population was 2 per million. For mesothelioma the risk was not however calculated from occupational risk data. For this disease it was considered that about one-third of the cases of malignant mesothelioma in the general population were caused by non-occupational exposure to asbestos. From this the investigator deduced that the general population lifetime risk for mesothelioma was 100 per million. The basic principle of the calculation method used for predicting possible total lung cancer incidence would appear to be reasonably

Table 1

Estimated individual lifetime risks from a continuous exposure to the median dose of 0.0004 f/ml asbestos in environmental air
(Table is adapted from National Research Council Committee 1984 report, (9))

Disease	Exposure Group	Estimated individual lifetime risk (per 100,000)
Lung cancer	male smoker **	6.4 (0-29) *
Lung cancer	female smoker **	2.3 (0-11) *
Lung cancer	male non-smoker **	0.6 (0-2.2) *
Lung cancer	female non-smoker **	0.3 (0-1.3) *
Mesothelioma	all	0.9 (0-35) *

* Range of estimated values; the lower value of zero was considered possible by the committee if the linear extrapolation used over-estimated the risk. The models used to produce these estimates of risk provide values which could be higher than for some other possible models (9).

** The sex differences for lung cancer are due to differences in lung cancer background rates associated with smoking patterns, occupational exposures and other factors (9).

sound, although for various reasons the actual values could be an over-estimation of the true level of risk (see later). In contrast, the principle of the calculation used for determining mesothelioma risk would appear to be open to criticism. This is because there is little firm justification for the assumption that one-third of the mesotheliomas found in the general population were caused by non-occupation exposure to asbestos; it is more likely to be a much smaller fraction simply because non-occupational exposures to asbestos are so very much lower (see Chapters 3 and 4) than occupational exposures (6, 9). Using a different set of data and assumptions from another study, the same investigator (65) reported a lifetime risk of 4-24 per million for mesothelioma (i.e. lower than above) and 3-30 per million for lung cancer (higher than above) in relation to general population exposure to asbestos (65, 116); this other study (116) is discussed further, later.

From the data provided in yet another study an estimated risk for lung cancer for an exposure to 0.0005 f/ml corresponds to perhaps 0.05-1.7 excess deaths per 100,000 births for 50 years 'continuous' 8 hours per day exposure to environmental asbestos (8). The basic data for this calculation made by the U.K. Asbestos Advisory Committee (1979) was drawn from several past occupational studies (8).

In an investigation reported in 1981 some rather different values for risk estimates were given for environmental exposure to asbestos (116); see also above. These estimates were based on extrapolation of lung cancer and mesothelioma risks from occupational studies. However, the selection of the occupational data for this purpose appeared to be biassed towards the higher risk studies (116). The investigator excluded the lowest risk occupational study data for reasons which are not clear. This exclusion of selected data seems to have introduced a bias in the reported risk estimates for environmental exposure, leading to a higher level of environmental risk than would have occurred if no data had been eliminated. The reported values are considerably greater than for example those much more precisely evaluated by the U.S. National Research Council Committee (9) mentioned above. In view of the unrepresentativeness of the risk data provided by this particular investigator (116) no further consideration is given here to the reported figures.

In 1983 some risk estimates were calculated by the Federal Health office of the F.R.G. (230). Special risk models for mesothelioma and lung cancer were used and the following information has been published: Total cancer risk in the general population, including smokers (mesothelioma and lung cancer combined) for an environmental asbestos exposure of 0.0001 to 0.001 f/ml (urban population) was reported to be in the range 0.02-0.24/100,000 persons/year. It would appear that the total predicted lifetime risk is not too dissimilar from that estimated by the U.S. National Research Council Committee referred to in this Report; however it is not possible to compare fully these two sets of data.

4.3.2.(c) Risk predictions for special groups exposed to asbestos in buildings

For special groups e.g. school children and their teachers, it is possible to estimate exposure on the basis of the increased levels of asbestos they might inhale compared with other less exposed groups. Using a median representative general population exposure level of 0.0004 f/ml calculated by the National Research Council Committee (9) it is possible to assess a composite exposure based on a proportion of a person's life spend in school buildings containing somewhat elevated levels of asbestos. (The general population value of 0.0004 f/ml above was based on spending one-eighth (12.5%) of one's life in an

'asbestos' building where the median level was 0.0006 f/ml, five-eighths (62.5%) of one's life in a non-asbestos building at 0.00054 f/ml, and one quarter (25%) of one's life outdoors at 0.00007 f/ml (9)).

In order to evaluate the possibility of increased exposure and its effects, it has been assumed that the long-term exposure actually at school was as high as 0.002 f/ml (9, 90) i.e. 3 to 4 times the reported median level for indoor air. As an example in the case of teachers, it has been assumed that they work 30 years inside a school building contaminated with 0.002 f/ml for an average of 1,560 hours per year (40 hours per week for 39 weeks a year). Thus the proportion of a teacher's say 73 year lifetime spent inside a school would be (30 x 1560)/(73 x 365 x 24) = 0.073 (= 7.3%). This can be shown to represent approximately a one-third increase in lifetime exposure to asbestos in comparison with the average general population exposed to 0.0004 f/ml. Thus for a male non-smoker the predicted lifetime lung cancer risk (using the U.S. National Research Council data) would theoretically increase from 0.6 to only 0.8 in 100,000, and for a female non-smoker the corresponding predicted lung cancer risk would rise from 0.3 to only 0.4 in 100,000. For mesothelioma the predicted risk would theoretically rise from 0.9 to 1.2 per 100,000. Thus even where a rather extreme level of 0.002 f/ml in schools is selected for teachers working inside buildings for many years the risk is expected to be only slightly greater in comparison with the general population.

For children at school an analogous calculation can be made. As an example, let us assume that from the age 6-16 years a child is inside a school for 6 hours per day for 200 days per year during the 10 year period (9). Thus the proportion of a pupil's say 73 year lifetime spent inside school would be (10 x 200 x 6)/(73 x 365 x 24), equals approximately 2%. This can be shown to increase the total lifetime exposure by about 8% where a rather very extreme value of 0.002 f/ml is considered for indoor school average exposure over 10 years. Adapting the approach used by the National Research Council Committee (9) it can be shown that this represents approximately a theoretical 10% increase in lung cancer risk and about a 20% increase in mesothelioma risk (a higher increased risk for mesothelioma is predicted because it depends critically on the age of onset of exposure). Thus again as with teachers, the increased possible risk compared with the general population is relatively small even where the pupil theoretically spends his or her time inside a classroom contaminated with what must be regarded as a rather extreme level for protracted exposure

In a very recent evaluation carried out by the Royal Commission on matters of health and safety arising from the use of asbestos in Ontario, Canada (6) it has been suggested that a ten year asbestos exposure in a building might be 0.001 f/ml. From this the Commission estimated (6) that the risk of death from asbestos exposure for a ten year period could be 0.029 per 100,000 population per year. The Royal Commission considered that such a risk is 'not significant' because it is orders of magnitude lower than other risks faced by the general population (6).

In the most recent study just published (279) it was considered that the level of asbestos above background level in asbestos buildings in Britain is seldom more than 0.0005 f/ml (optical microscopy equivalent). For an exposure to this level of chrysotile for the period of a working week in an office for 20 years in adult life or for 10 years or so at school, or to lower levels for prolonged times at home, a lifetime risk of death of one in 100,000 was calculated; exposure to crocidolite (and possibly amosite) was suggested to be associated with a greater risk.

In another separate evaluation it has been reported that the lifetime risk for mesothelioma is likely to be less than 1 in 100,000 exposed at school from age 12 to 18 (6 years of exposure), based on a level of asbestos of 0.003 f/ml (6, 9); this level for long-term exposure must be regarded as very extreme. The level of risk (even at this unlikely long-term level of exposure) has been described as 'negligible' (6).

In contrast however in another study, the lifetime risk of death per year from mesothelioma and lung cancer has been estimated to be perhaps as great as 10 in 100,000 for pupils spending their school life in the more contaminated schools. (76). The investigator (76) admits however that there is a large uncertainty in estimating his risk. He assumed a continuous exposure (outside air and indoor air in schools, combined) of 0.01 f/ml (0.3 $\mu g/m^3$) to obtain the risk level suggested. A continuous level of 0.01 f/ml seems to be based on an ultra extreme possibility for exposure to asbestos; adequate justification for the existence of such levels being maintained continuously during all the school years for overall exposure to asbestos is not provided in the publication (76); no other published data would seem to support this level. In fact it can be calculated that in order to achieve an average overall exposure of 0.01 f/ml with typical non-school long-term exposure levels of 0.0005 f/ml (see this Report) the pupil's exposure actually at school from age 6-16 years would often need to be approaching 0.1 f/ml asbestos. Such a figure for a continuous exposure inside a school building for 10 years is inordinately high and no published figures whatever are available anywhere to support such an excessive long-term level of exposure. In order to obtain lifetime risk estimates for continuous exposures to 0.01 f/ml, the investigator used a linear model for lung cancer and a power function for mesothelioma (76). The investigator considers that the mesothelioma risk is a function of the fifth power of time from the onset of exposure (76); although other investigators (226, 229, 279) have also suggested power relationships (for example the National Research Council Committee used a power index of 3.2 (9)), the fifth power is a very extreme value.

4.3.3. Comparison of predicted risks

In Table 2 some mathematically predicted figures for possible lifetime risk are given for long-term exposures to asbestos at typical environmental levels. Some risks are related to exposures expressed in mass units but much more attention will be paid here to exposures expressed in number terms (i.e. f/ml). In Chapter 3 it was deduced that a typical long-term level of exposure to asbestos accounting for indoor and outdoor exposure combined appeared to be about 0.0005 f/ml. For countries or situations where relatively little asbestos has been used the typical concentration may be lower. A higher value of 0.001 f/ml or even perhaps 0.002 f/ml may apply in some cases. Table 2 includes some risk values calculated for the typical level. The average predicted possible lifetime risk values for exposure to 0.0005 f/ml, ranges from 0.4 to 8 per 100,000 for lung cancer (including smokers) with a predicted value of 1.1 per 100,000 for mesothelioma (this latter risk is independent of both smoking habits and sex differences). For non-smokers specifically, the possible lung cancer lifetime risk is predicted to be 0.8 per 100,000 (males) and 0.4 per 100,000 for females; for smokers the risk due to asbestos exposure is 8 and 3 per 100,000 for males and females, respectively. Studies A and B in Table 2 have been excluded from further detailed discussion since the exposure levels are quoted in mass concentration units rather than number concentrations (see earlier comments..

The range of risk values extracted from Table 2 are based on occupational studies where workers were generally exposed to crocidolite, amosite or

Table 2

Estimates of possible lifetime risk associated with environmental long-term exposures to asbestos

Environmental exposure	Lifetime risk per 100,000		Reference
	Lung cancer	Mesothelioma	
A Average population exposure of 0.0015 µg per m^3 air in USA * (Enterline, 1983)	0.2	10 ‡‡	65
B Average population exposure of 0.0015 µg per m^3 air in USA * (Schneiderman, 1981, Enterline, 1983)	0.3-3	0.4-2.4 ‡‡	65, 116
C Population exposure of 0.0004 f/ml (median value) ‡ (National Research Council, 1984) - Male smoker	6.4	0.9	9
Female smoker	2.3	0.9	
Male non-smoker	0.6	0.9	
Female non-smoker	0.3	0.9	
D Population exposure of 0.0005 f/ml (calculated risk from data given by National Research Council, 1984)			
Male smoker	8 **	1.1 **	9
Female smoker	3 **	1.1 **	
Male non-smoker	0.8 **	1.1 **	
Female non-smoker	0.4 **	1.1 **	

‡ Where additional exposure in schools etc. occurs at levels above 0.0004 f/ml the theoretically increased risk can be calculated (9). For 0.002 f/ml exposure in schools the predicted risks for teachers and pupils have been calculated (see this Report); the risks are only slightly increased from the values given in C above.

‡‡ Based on an unsubstantiated method for deducing risk (see text).

* Excludes indoor asbestos pollution which may be higher than outdoors.

** Risk values are in proportion to exposure; for example if long-term exposure is 0.001 f/ml then the possible risk values would be doubled.

chrysotile or various mixtures. In general, the occupational risk seems to be higher for crocidolite and amosite in comparison with chrysotile. Extrapolations from various occupational to environmental levels of risk are likely to some extent to reflect the risk from the more hazardous forms of asbestos i.e. crocidolite and amosite rather than chrysotile. Thus one might expect that the predicted environmental risk value for chrysotile to be perhaps somewhat smaller than the figures given in Table 2; for crocidolite and amosite the environmental risk values might be expected to be somewhat higher than the figures in Table 2. Thus the possible overall environmental risk from a given dose of inhaled crocidolite or amosite may be higher than that for chrysotile. However, by far the commonest form of asbestos in environmental air is chrysotile with amphiboles being detected far less frequently (275). Thus the effective possible population risk (i.e. the numbers of possible deaths from cancer) from exposure to environmental levels of amphibole asbestos should be exceedingly low.

In various parts of this Report in relation to predicted risk estimates, reference has been made to the certain difficulties involved in (a) sampling and analysis in relation to exposure estimation for both occupational and environmental conditions, (b) determining health risk from occupational exposures in relation to defined exposure levels, (c) confounding effects of smoking, (d) possible existence of a threshold level at which no health risk may be associated with very low exposures, (e) use of unrealistic factors to convert mass concentrations of fibres to number concentrations, etc. A number of the difficulties will result in errors when predicting risks based on environmental levels of exposure to asbestos. Rarely will these factors provide an underestimate of general environmental risk; in general they will tend to overestimate risks to give exaggerated environmental risk values. The detailed reasoning for the environmental risks being capable of being over-estimated are as follows: (further references to several points raised are included elsewhere in this Report).

4.3.4. Reasons for predicted environmental risks being often exaggerated

(1) Estimates of the critical occupational exposures to asbestos in the past are often too low (62). This is partly due to only a few appropriate measurements having been made in the past, but also it is because the analytical procedures used then gave results which are now known to give low results (see section 4.1.2.). The accuracy of past estimates for occupational exposure is of particular importance; the exposure levels relate critically to occupational disease incidence recorded years later. Where the values for the past occupational exposure are too low this will cause the predicted estimate of environmental ambient risk to be exaggerated. Eye witness accounts (75) support higher occupational exposures for the past conditions; these eye witness accounts refer to a very marked reduction in visibility in certain factories years ago. Also in the past, the lack of individual asbestos worker-oriented exposure measurements would tend not to identify 'hot spot' situations. The few 'average' workplace measurements that were recorded in the past would not have reflected any high 'hot spot' individual worker exposures. One could expect that there is a greater probability that these high unrecorded concentrations of asbestos rather than 'average' (i.e. lower levels) were more likely to have reflected any asbestos disease found in workers.

(2) Even if some past general workplace asbestos levels could be defined accurately, they may not have reflected the true worker risk since very high dust exposures can disproportionately decrease the effect of the lung's natural

clearance mechanisms (131, 233). Thus in calculating general environmental risks from occupational exposure data, probably the very high occupational exposure figures should in effect be regarded as equivalent to even higher exposure levels; unless this is allowed for, the general environmental risks could be over-estimated.

(3) The asbestos workers of the past were also exposed to asbestos at home as demonstrated by the health risk of some workers' wives then (8, 199); thus in effect, the workers' exposure could have been somewhat greater than reflected by the workplace figures alone.

(4) If in the case of lung cancer and mesothelioma a threshold exposure level to asbestos exists below which any effect occurs, then for very low general environmental exposures, any risk could be smaller than suggested and perhaps in some cases even essentially zero. In the case of lung cancer specifically, it is perhaps possible that at very low exposures to asbestos, i.e. in the absence of asbestosis, no lung cancer whatsoever may occur (see section 4.2.2.(a)).

(5) Some published environmental risk estimates for lung cancer have not been fully corrected for the marked effect of tobacco smoking (1, 108, 196). Thus some published environmental risk values may be too high in relation to the effects of exposure to asbestos alone.

(6) In assessing environmental exposures in relation to occupational levels, the fact that industrially employed workers generally inhale at a higher rate and breathe more deeply than other people, should probably be taken into account. It is difficult to assess precisely the workers' effective exposure on this basis (see section 4.1.2.) and the net effect in the absence of taking this into account is to under-estimate the workers' exposure; this leads to an over-estimate of any general environmental risk.

(7) It has been suggested (86) that the result of not distinguishing in some occupational studies between the alleged lower health risk of chrysotile in comparison with the more severe health risks of crocidolite exposure, leads to an over-estimation of environmental risk to asbestos by 'a large factor'. There is some justification for this suggestion since chrysotile is by far the most common form of asbestos which is generally found in environmental air.

(8) In some publications the risk of mesothelioma associated with environmental exposures to asbestos has been based on attempting to apportion the total number of mesotheliomas in terms of exposure to occupational and environmental conditions respectively. In some cases the environmental proportion of total mesotheliomas due to asbestos has been suggested to be relatively high; the justification for this however would seem to be open to criticism in that the vast majority of exposures to the much higher levels of asbestos are occupationally based. Also in recent years a number of publications have indicated that asbestos is only one of several known causes of mesothelioma (43, 214, 215) in the general population.

(9) Some published environmental risk estimates have been made on the basis of air measurement data expressed in mass concentration units. Conversion factors have been used to derive fibre number concentrations from mass values. In some cases these factors may not be truly representative of the types and sizes of fibres in the environmental air and this could lead to errors. In a few cases the fibre number concentrations may be under-estimated but more frequently the values seem likely to be over-estimated, which in turn could lead to an exaggerated predicted risk of exposure to environmental asbestos in air.

(10) Some published environmental risk estimates have been made by using transmission electron microscopy to provide results which are not corrected or not fully corrected for the equivalent counts that are provided when using optical microscopy (see Chapter 3); not correcting for this effect can lead to an over-estimate of environmental exposure which in turn will exaggerate the environmental risk.

(11) Some published environmental risk values are based on environmental asbestos levels in air which are too high in relation to a lifelong average exposure level. For lifetime exposures it is necessary to use representative data which reflects long-term exposures over many years. Such an over-estimate in environmental levels leads to an exaggerated level of predicted risk.

Not all the comments 1-11 above, necessarily relate directly to the data provided in Table 2. Many of these comments are considered to be relevant however in relation to a number of reported studies. It is of course impossible to quantify precisely the extent of any over-estimation of environmental risk; nevertheless the over-estimation is often likely to be at least several-fold and in some cases it could even be exaggerated by an order of magnitude or more. It is very probable that the values for risk estimates given in Table 2 are somewhat exaggerated, possibly by several fold. Therefore it is suggested that the total cancer risk for non-smokers is about one in 100,000 or lower for an average long-term population exposure level of 0.0005 f/ml for the mixture of types of asbestos found commonly in environmental air (mainly chrysotile asbestos).

4.4. Risk estimates for environmental asbestos and other mineral fibres in perspective

In recent years a number of studies have been carried out in which the risk of death or injury associated with various environmental and other factors has been estimated. The methodology for estimating risk is a very involved subject and no attempt is made to describe here the procedures used. Actual values for risk estimates are provided however and these have been drawn from several highly reputable publications (269-72). The risk data given in this section are exactly comparable with those estimated earlier for environmental asbestos exposure, see Table 2. The various data are provided as lifetime risk estimates assuming a 73 year life-span. Where necessary lifetime estimates have been calculated from published risk data, when reported as annual rates of risk. It is recognized that the published data cannot be regarded as very precise risk figures; in some cases there may be deviations from the values given depending on a number of factors, e.g. due to variations associated with different parts of the world and the lack of perfect data from which to calculate risk. In Table 3 the lifetime risks from various causes are given; particular emphasis is given to cancer because this would appear to be a possible risk associated with environmental asbestos exposure. The data is given in various categories of defined risk level. For convenience and compatibility with other data, the lifetime risk is expressed per 100,000.

The table grades risks from the very high ones like smoking and motor vehicle accidents down to the extremely low level risks such as being killed by lightning, getting cancer from eating charcoal broiled meat, or getting cancer from the increased cosmic radiation if one flies at high altitude across the Atlantic; these 'rare-event' risks society seems to accept. What is evident from Table 3 is that the estimated risk from environmental asbestos alone of around one or less in 100,000 (see section 4.3.) appears to be within, or lower than, various 'rare-event' extremely low level risks, allowing for the uncertainty

Table 3 - Lifetime risk values for selected situations

Selected risk situations, mainly U.S. data (References 269-72)	Lifetime risk per 100,000
Extra High Risk	
Smoking (all causes of death)	21,900
Smoking (cancer only)	8,800
High Risk	
Motor vehicle, U.S.A., 1975 (deaths)	1,600
Elevated Risk	
Frequent airline passenger (deaths)	730
Cirrhosis of liver, moderate drinker (deaths)	290
Motor accidents, pedestrians, U.S.A., 1975 (deaths)	290
Skiing, 40 hours per year (deaths)	220
Moderate Risk	
Light drinker, one beer per day (cancer)	150
Drowning deaths, all recreational causes	140
Air pollution, U.S.A., Benzo(a)pyrene (cancer)	110
Natural background radiation, sea level (cancer)	110
Frequent airline passenger, cosmic rays (cancer)	110
Low Risk	
Home accidents, U.S.A., 1975 (deaths)	88
Cycling (deaths)	75
Person sharing room with smoker (cancer)	75
Diagnostic X-rays, U.S.A. (cancer)	75
(Risk level where few would commit their own resources to reduce risk; Royal Society, London, 1983), (270)	70
Very Low Risk	
Person living in brick building, additional natural radiation (cancer)	35
Vaccination for small pox, per occasion (death)	22
One transcontinental air flight per year (death)	22
Saccharin, average U.S.A. consumption (cancer)	15
Consuming Miami or New Orleans drinking water (cancer)	7
(Risk level where very few would consider action necessary, unless clear causal links with consumer products, Royal Society, London, 1983), (270)	7
Extremely Low 'Rare-Event' Risk	
One transcontinental air flight per year, natural radiation (cancer)	4
Lightning (deaths)	3
Hurricane (deaths)	3
Charcoal broiled steak, one per week (cancer)	3
ENVIRONMENTAL ASBESTOS RISK*, 1985, (cancer) ('around one per 100,000 or lower'; this Report)	1
('Acceptable' risk: World Health Organization for drinking water, 1984, (259) (cancer)	1
(Further control not justified, Royal Society, London, 1983, (270))	0.7

* Excludes possible effects of smoking

factor associated with published risk values (272). What is also interesting is that certain risks which are often perhaps overlooked, seem to be around two orders of magnitude more hazardous in terms of cancer than environmental asbestos exposure e.g. natural background radiation, tobacco smoke from sharing a room with a smoker, additional radiation from diagnostic X-rays, and additional cosmic radiation from being a frequent airline passenger.

A lifetime level of risk of 1 in 100,000 has been used as an 'acceptable' level by the World Health Organization in relation to guidelines for drinking water quality, applicable worldwide. The Canadian Royal Commission (6) suggests a level of risk for a protracted level of exposure to asbestos of 0.001 f/ml, to be not significant. At an asbestos level of 0.001 f/ml the cancer risk has been suggested to be equivalent to smoking 2 cigarettes per year (247) i.e. a very low risk indeed. According to the Royal Society London (270), very few people would take action at a risk level of 10^{-6} per annum (i.e. a lifetime risk of 7 in 100,000), except perhaps if clear causal links are established to be due to certain consumer products; in the case of environmental asbestos no definite causal links seem to have been established for very low levels in the general environment. At a risk level of 10^{-7} per annum (i.e. a lifetime risk of 0.7 in 100,000) the Royal Society, London (270) considers that further control would certainly not be justified. Thus a lifetime risk of around one in 100,000 or lower, estimated in this Report for the general population exposures to environmental asbestos, would seem to be at a satisfactory level (257, 259). Even if a person was theoretically exposed for a lifetime to a level of 0.001 f/ml or perhaps 0.002 f/ml, the risk would still seem to be well within the range or lower than the 'rare-event' extremely low level risks which society accepts (see above). Any risks for future exposures to asbestos are of course likely to be lower still because of improving control measures.

There is insufficient data to assess the environmental risk to non-asbestos mineral fibres. For the general man-made mineral fibres the probability of there being a significant risk is very low and it is likely to continue to be so. For specific natural mineral fibres the risk may be significant however, and in some villages in Turkey there is an undesirable level of risk associated with exposure to erionite fibres (9, 214, 215). It is possible that exposures to other non-asbestos mineral fibres may cause undesirable health effects; for example the burning of sugar cane leaves, where silica fibres could be inhaled by the general population living near some sugar cane plantations (see section 4.2.2.(b)(ii)).

It is of interest to note that in a number of situations there would seem to be perhaps ten times more non-asbestos mineral fibres in environmental air by comparison with asbestos (see Chapter 3); thus if any concern is to be expressed regarding asbestos in environmental air, perhaps at least as much concern should be directed towards non-asbestos fibres (see section 4.2. regarding health implications of non-asbestos fibres in relation to asbestos fibres).

4.5. General discussion in relation to the significance of human exposure to mineral fibres in environmental air

There appears to be no firm evidence that there is a definite health risk for the general population exposed to asbestos in environmental air. In the past however, cases of mesothelioma in the general public seemed to be associated with exposures to asbestos living near mining areas, near factories and near shipyards; cases even occurred in some women at home exposed presumably to asbestos brought there by husbands or relatives, etc. working at asbestos

factories. The effects appeared to be related more to exposures to crocidolite and amosite and less to chrysotile. Except for natural erionite fibres in some Turkish villages, there is no firm evidence that mesothelioma or other diseases result from environmental ambient exposure to mineral fibres these days. Non-malignant pleural changes can occur in the general population exposed to mineral fibres in environmental air; other non-fibrous minerals may also be implicated. These pleural changes are not considered to be of any health concern.

Mineral fibres exist in a range of sizes; natural ones like asbestos and erionite for example are quite often finer than certain man-made fibres. Some man-made mineral fibres can be rather large and often are not readily inhaled. Many mineral fibres however can wholly or partly exist in the same range of sizes exhibited by asbestos. Probably the potentially most hazardous fibres are the ones which are longer than about 5 μm and finer than perhaps 1.5 μm; asbestos fibres are very often within this range. Animal experiments and other considerations would suggest that where mineral fibres (whatever their type) are within this size range, they are very likely to be pathogenic if inhaled in sufficient quantities; the durability may also affect their pathogenicity. Some fibres may become ingested as a result of inhaling them but the evidence that they could then cause undesirable health effects is essentially non-existent.

In the absence of any demonstrable health effects from environmental exposure to asbestos, some risk estimations based on mathematical predictions have been made. Essentially the predictions have been made by comparing the exposures to asbestos in the general environmental air with those for past occupation conditions where the level of incidence of disease in workers has been recorded. Asbestosis is not considered to be a health issue for the general public; consequently only risk predictions for lung cancer and mesothelioma have been made. All other forms of cancer are considered to be too improbable in relation to inhaling asbestos at low levels.

Predicted possible risks have been made taking account of long-term exposures to a combination of outdoor and indoor exposures to asbestos. The higher-level risk for persons such as teachers etc. or children who might be exposed to somewhat elevated airborne concentrations of asbestos in schools has been considered. Also the predicted possible risk for the combination of asbestos exposures and tobacco smoke for smokers has been taken into account. There have been various publications where a wide range of values of predicted possible risks has been reported. Particular note has been taken of a very recent publication where risk predictions were made by a distinguished Committee under the auspices of the National Research Council in the U.S.A. Other data were also considered and the more reliable results taken into account. For an estimated overall long-term concentration of 0.0005 f/ml (see Table 2), the calculated predicted possible lifetime total cancer risk due to inhaled asbestos exposure alone is less than 2 in 100,000 for males (1.9 per 100,000 males; 1.5 per 100,000 females). For smokers the predicted possible lifetime cancer risk due to asbestos exposure (see Table 2) is less than 10 in 100,000 and less than 5 in 100,000 for females. However there are many reasons for regarding these various values as over-estimations of true risk (see this Report, section 4.3.). The expected possible lifetime risk (due to exposure from asbestos alone) appears to be about one in 100,000 or lower for the level of exposure defined above (see section 4.3.). Even for a possible higher level of exposure (e.g. teachers and children who could be exposed in certain schools to some additional asbestos), the predicted risk is only marginally greater. The estimated risk value of around one in 100,000 may somewhat exaggerate the risk for chrysotile asbestos exposure (the commonest form of asbestos exposure) and could somewhat underestimate the risk for crocidolite and amosite exposure (see section 4.3.).

However in view of the fact that exposure to much crocidolite or amosite in the general environment is expected to be very rare, the number of people in a given country possibly developing cancer would be extremely low indeed.

A level of lifetime risk of around one or less in 100,000 can be regarded to be at a perfectly acceptable level in that it is lower than 'rare-event' risks like being killed by lightning, getting cancer from eating charcoal broiled meat, or getting cancer from the increased cosmic radiation if one flies across the Atlantic. Even if the lifetime exposure to asbestos was as high as 0.001 f/ml or perhaps 0.002 f/ml, the risk will still be within the range or lower than these 'rare-event' risks. Also since it is anticipated to be very unusual for people to be exposed to levels as high as 0.002 f/ml, the numbers of people at risk would be low and hence the numbers of any possible cases of cancer would be expected to be exceedingly small. A level of lifetime risk of 1 in 100,000 has been utilized as an 'acceptable' level by the World Health Organization (1984) in relation to guidelines for drinking water quality worldwide (259). According to an assessment by the Royal Society of London (1983) at a general lifetime risk level of 0.7 in 100,000, it is considered that further control would not be justified (270). In Japan (1985) it has been reported that at the level of asbestos in the ambient environment there is little risk to the nation in general (266), and it is stated that 'the risk of other people, (non-occupationally exposed persons) if any, is very small' (231). For Britain it has been recently estimated that the exposure to chrysotile inside an asbestos containing building is seldom more than 0.0005 f/ml above background level; the exposure for a working week in an office for 20 years in adult life or for 10 years at school calculates to produce a lifetime risk of death of one in 100,000 (279). It is suggested that if 20% of the British population experienced such an exposure (so low is the anticipated population risk) that only one death a year in Britain would be caused by it (279).

Because of some concern regarding the biological properties of asbestos (and for other reasons too), mineral fibre substitutes for asbestos have been contemplated and indeed are now becoming fairly widely used. It should be noted however that mineral fibres of comparable dimensions to asbestos often have similar undesirable biological properties in animal tests (100) and some concern has been raised regarding the use of such substitutes (118, 240, 265). Any substitute for asbestos needs to be considered very carefully and various relevant factors have been very recently reviewed (10). In relation to health implications special thought needs to be given to substitutes and even apparently innocuous materials may be perhaps not wholly safe; for example the use of wood dust as a substitute may possibly be associated with nasal cancer if the exposure was very high (249). There is no firm evidence that occupationally exposed workers to non-asbestos mineral fibres definitely get fibrosis or cancer; however recent studies suggest the possibility of some effects. Thus the significance of non-asbestos fibres should not be overlooked, especially since their use is increasing; however the current levels of exposure seem to be very low. One non-asbestos mineral has given rise to particular concern; this is the naturally occurring mineral erionite where cases of mesothelioma have arisen in some villagers in Turkey.

The general health risk from exposure to environmental asbestos and other mineral fibres would appear to be very low indeed and probably will continue to remain so. However the risk may not be zero and consequently certain precautions are prudent. If the currently available control measures and codes of practice are strictly followed then no further drastic general measures would seem to be necessary for the public's protection.

It is possible perhaps in some less developed parts of the world that undesirable levels of exposure to asbestos and other mineral fibres such as erionite may occasionally still exist. Particular vigilance should be exercised to identify and control any such situations if they happen to exist.

5. APPENDIX

1. Mass of single asbestos fibres capable of being inhaled

(a)	Chrysotile (ultimate tiny fibril), 0.01 μm dia., 0.2 μm long	4×10^{-17}g
(b)	Amphibole (ultimate fibril), 0.1 μm cross section, 3 μm long	10^{-14}g
(c)	Chrysotile (largest normally entering lung), 3 μm dia., 50 μm long	1.5×10^{-9}g

2. Numbers of fibres inhaled per day (fibres 0.25-3 μm dia., longer than 5 mμ, aspect ratio greater than 3:1)

(a)	0.0005 f/ml suggested as typical exposure	7500*
(b)	0.5 f/ml suggested as possible worker exposure nowadays	4×10^{6}** (at work)
(c)	300 f/ml suggested worker exposure (very heavy exposure in the past)	2500×10^{6}** (at work)

3. Lifetime exposures to numbers of fibres inhaled (as in 2 above)

(a) 2×10^{8} based on 73 years

(b) 4×10^{10} based on 5 days per week, 48 weeks per year, 40 years at work

(c) 1×10^{13} based on 5 days per week, 48 weeks per year, 20 years at work

* based on $15 m^3$ air per day inhaled overall

** based on $8 m^3$ air per day inhaled at work

6. BIBLIOGRAPHY

1. Public Health Risks of Exposure to Asbestos. Commission of the European Communities. Rapporteur Professor R.L. ZIELHUIS (1977). Pergamon Press, Oxford, U.K.
2. WALTON, W.H. The Nature, Hazards and Assessment of Occupational Exposure to Airborne Asbestos Dust: a Review. Annals Occup. Hyg. (1982) 25, 117.
3. HODGSON, A.A. Fibrous Silicates. Royal Inst. Chem. London, Lecture Series No:4 (1965).
4. SINCLAIR, W.E. Asbestos. Mining Publications Ltd., London, (1959).
5. Asbestos: Properties, Application and Hazards. Vol 1, Ed. Michaels and Chissick, John Wiley, U.K. (1979).
6. Report of the Royal Commission on Matters of Health and Safety Arising from the use of Asbestos in Ontario. (1984). Ontario Government Bookstore, 880 Bay Street, Toronto, Canada.
7. Biological Effects of Man-Made Mineral Fibres. (1983). World Health Organization. Euro Reports and Studies 81.
8. Advisory Committee on Asbestos, Final Report. Vols. 1 and 2 H.M.S.O., London, (1979).
9. Asbestiform Fibres: Non Occupational Health Risks. Committee Chairman, Prof. L. Breslow, National Research Council, U.S.A. (1984). National Academy Press, Washington, D.C.
10. HODGSON, A.A. Alternatives to Asbestos and Asbestos Products. (1985) Anjalena Publications, Crowthorne, U.K.
11. Asbestos-cement: the facts. Asbestos Information Centre, London (1982).
12. WALKER, J.S. Asbestos and the Asbestiform habit of Minerals. (1981). M.Sc. Thesis Univ. Minnesota, U.S.A.
13. COMMINS, B.T. Asbestos in Drinking Water: a Review TR100. Water Research Centre, U.K. (1979).
14. SELIKOFF, I.J. and LEE, D.K. Asbestos and Disease. Acad. Press, New York (1978).
15. World Mineral Statistics. 1977-81.
16. TOFT, P. and WIGLE, D. Asbestos and Drinking Water in Canada. Sci. Total Envir. (1981) 18, 77.
17. Asbestos in the Home. Asbestos Information Centre, London, U.K. (1983).
18. Asbestos in Building. Asbestos Information Centre, London, U.K. (1983).
19. ROBOCK, K. Workplace and Environmental Situations: Measuring Techniques, Emission Sources, Results and Consequences. Asbestos International Association, 4th Biennial Conference, Paris (1983).
20. ROWSON, D.M. The Chrysotile Content of the Wear Debris of Brake Linings. Wear (1978) 47, 315.
21. WILLIAMS, R.L. and MUHLBAIER, J.L. Asbestos Brake Emissions. Environ. Res. (1982) 29, 70.
22. JACKO, M.G. and DUCHARME, R.T. Brake Emissions: Emission Measurements from Brake and Clutch Linings from Selected Mobile Sources. U.S. EPA Report 68-04-0020 (1968).
23. ANDERSON, A.E. and GEALER, R.L. Asbestos Emissions from Brake Dynamometer Tests. Paper presented at Soc. Auto. Engineers Meeting, Detroit, U.S.A., (May 1973).
24. HARBEN, P. What's new after asbestos. Ind. Mineral (1980) 51.
25. LYNCH, J.R. Brake Lining Decomposition Products. J. Air Poll. Contr. Assoc. (1968) 18, 824.
26. HATCH, D. Possible Alternatives to Asbestos as a Friction Material. Annals Occ. Hyg. (1970) 13, 25
27. HICKISH, D.E. and KNIGHT, K.L. Exposure to Asbestos During Brake Maintenance. Annals Occ. Hyg. (1970) 13, 17.

28. ALSTE, J. and WATSON, D. Airborne Asbestos in the Vicinity of a Freeway. Atmos. Environ. (1976) 10, 583.
29. ROHL, A.N. Asbestos Exposure During Brake Lining and Repair. Environ. Res. (1976) 12, 125.
30. SIEMIATYCKI, J. Mortality in the General Population in Asbestos Mining Areas. Proc. World Symposium on Asbestos, page 337, (May 1982), Montreal, Canada.
31. SELLES, D.J., ISSEROW, L.W. and ROBOCK, K. Results of Sampling in Mining and Non Mining Areas. Paper presented at International Conference on Air Pollution, Pretoria, South Africa, (Oct. 1984).
32. FELBERMAYER, W. and USSAR, M.B. Environmental Pollution by Weathering of Asbestos Cement Sheets. Research Report (1980). Institut fur Umweltschutz und Emissionsfragen A-8700, Leoben, Austria.
33. McDONALD, J.C. Mesothelioma as an Index of Asbestos Impact. From Banbury Report No:9, Quantification of Occupational Cancer, Cold Spring Harbor Laboratory (1981) 73.
34. LANTING, R.W. and den BOEFT, J. Atmospheric Pollution by Asbestos Fibres (1979). Commission of European Communities EUR 6768 EN.
35. TOFT, P. and MEEK, M.E. Human Exposure to Environmental Asbestos. Paper presented at International Conference on Environmental Contamination, Imperial College, London (July 1984).
36. Preliminary Study on the Possible Release of Asbestos During the Operation of Hand-held Hairdryers. Department of Nat. Health and Welfare, Ottawa, Canada (1979).
37. NEWHOUSE, M.L. Asbestos-Related Diseases. Pulse Beat (1983) 5.
38. HARRIES, P.G. Asbestos Hazards in Naval Dockyards. Annals Occ. Hyg. (1968) 11, 135.
39. HARRIES, P.G. Experience with Asbestos Disease and its Control in Great Britain's Naval Dockyards. Environ. Res. (1976) 11, 261.
40. BANK, W. Asbestiform and/or Fibrous Minerals in Mines, Mills and Quarries. Mines Safety and Health Administration Report IIII (1980) U.S. Dept. Labor.
41. DAVIS. J.M.G. The Biological Effects of Mineral Fibres. Annals Occ. Hyg. (1981) 24, 227.
42. Man-Made Mineral Fibres and Man. Seminar, Royal National Hotel, London, (February 1985).
43. BARIS, Y.I. and SIMONATO, L. Malignant Mesothelioma and Radiological Chest Abnormalities in two Villages in Central Turkey. Lancet (1981) 1, 984.
44. Reference Method for the Determination of Airborne Asbestos Fibre Concentrations at Workplaces by light microscopy. Asbestos International Association, London. Method No:1 RTM1 (1982).
45. Method for the Determination of Airborne Asbestos Fibres and other Inorganic Fibres by Scanning Electron Microscopy. Asbestos International Association, London. Method No:2 RTM2 (1984).
46. CHATFIELD, E.J. Analysis of Asbestos in Environmental Samples. Paper presented at International Conference on Environmental Contamination, Imperial College, London, (July 1984).
47. SAMUDRA, A.V. and HARWOOD, C.F. U.S. EPA Report EPA-600/2-77-178 (1978).
48. Size Definitions for Particle Sampling. TC 146. Air Quality of the International Standards Organization. Amer. Ind. Hyg. Assoc. J. (1981) 42, G-64/A-68.
49. ROBOCK, K., ISSEROW, L.W. and SELLES, D.J. Research on the Concentration and Identification of Dust Particles in Ambient Air by Electron Microscopy. Paper presented at International Conference on Air Pollution, Pretoria, South Africa (Oct. 1984).

50. Code of Practice on Safety in the Use of Asbestos. International Labour Office, Geneva (1983).
51. LEIDEL, N.A. USPHS/NIOSH Membrane Filter Method for Evaluation of Airborne Asbestos Fibres. Nat. Inst. Occ. Safety and Health, Cincinnati, U.S.A. (1979).
52. The Measurement of Airborne Asbestos Dust by the Membrane Filter Method. Technical note 1. Asbestos Research Council, Rochdale, U.K. (1971).
53. Membrane Filter Method for Airborne Asbestos Fibres. U.S. Dept. Health, Cincinnati, U.S.A. (1979).
54. Revised NIOSH Asbestos Counting Method. In Manual Analytical Methods, (May 1984). U.S. Govt. Printing Office, Washington, D.C., U.S.A.
55. Council Directive on the Protection of Workers from the Risks related to Exposure to Asbestos at Work. European Economic Communities, Brussels (1983).
56. Measurement of Inorganic Fibrous Particles in Ambient Air: Scanning Electron Microscopical Method. Verein Deutscher Ingenieure (1984), Dusseldorf, F.R.G.
57. U.S. National Institute for Occupational Safety and Health, Cincinnati, U.S.A. (1977).
58. STEEN, D. and GUILLEMIN, M.P. Determination of Asbestos Fibres in Air: Transmission Electron Microscopy as a Reference Method. Atmospheric Environ. (1983) 17, 2285.
59. MARCONI, A., MENICHINI, E. and PAOLETTI, L. A Comparison of Light Microscopy and Transmission Electron Microscopy Results in the Evaluation of the Occupational Exposure to Airborne Chrysotile Fibres. Annals Occ. Hyg. (1984) 28, 321.
60. SPURNY, K.R. and STOBER, W. Asbestos Measurements in Remote Ambient Air. In: Clean Air, the Continuing Challenge, Ann Arbor Publications, Michigan, U.S.A. (1978).
61. CHATFIELD, E.J. Measurement of Asbestos Fibre Concentrations in Ambient Atmospheres: Report prepared for the Royal Commission on Matters of Health arising from the use of Asbestos in Ontaria, Canada (1983).
62. ROBOCK, K. Analytical Methods for Airborne Asbestos. 6th Convegno di Igiene Industriale, Rome (Dec. 1983).
63. Asbestos in the Underground: no cause for alarm. Internat. Environ. and Safety (1978), 7.
64. LANTING, R.W. Levels of Exposure of the General Population from Industrial Activities. Proc. World Symposium on Asbestos, page 295, May 1982, Montreal, Canada.
65. ENTERLINE, P.E. Cancer Produced by Nonoccupational Asbestos Exposure in the United States. J. Air Poll. Control Assoc. (1983) 33, 318.
66. SPURNY, K.R. and STOBER, W. On the Evaluation of Fibrous Particles in Remote Ambient Air. The Science of the Total Environment (1979) 11, 1.
67. BOZZELLI, J.W. Airborne Asbestos Levels in Several School Buildings before and after Bulk Asbestos Removal. Int. J. Envir. Studies (1982) 20, 27.
68. SEBASTIEN, P., BIGNON, J. and MARTIN, M. Indoor Airborne Asbestos Pollution: from the Ceiling and the Floor. Science (1982) 216, 1410.
69. SEBASTIEN, P. and BILLON, M.A. Levels of Asbestos Air Pollution in some Environmental Situations. Annals New York Acad. Sciences (1979) 330, 401.
70. NICHOLSON, W.J., ROHL, A.N., WEISMAN, I. AND SELIKOFF, I.J. Environmental Asbestos Concentrations in the United States. From: Biological Effects of Mineral Fibres. IARC Publication No:30 (1980) 823.

71. Le GUEN, J.M. and BURDETT, G. Asbestos Concentrations in Public Buildings: a preliminary report. Annals Occ. Hyg. (1981) 24, 185.
72. AURAND, K. and KIERSKI, W.S. Health Hazards Posed by Asbestos. A position paper of the Federal Bureau of Health, F.R.G. (1981).
73. Indoor Pollutants. National Research Council (1981) Nat. Acad. Press, Washington, D.C.
74. BRUCKMAN, L. A Study of Airborne Asbestos Fibres in Connecticut. Proceedings of Workshop on Asbestos, Gaithersburg, M.D., U.S.A. (July 1977).
75. Summary of the Phase II Hearings on Health, Monitoring and Regulatory Issues. Royal Commission on Matters of Health Arising from Use of Asbestos in Ontario, Canada (Aug. 1982).
76. NICHOLSON, W.J. Environmental Asbestos Contamination: the Situation in the U.S.A. Paper presented at International Conference on Environmental Contamination, Imperial College, London (July 1984).
77. CHATFIELD, E.J. Asbestos Background Levels in Three Filter Media used for Environmental Monitoring. Proc. 33rd Annual Meeting Electron Microscopy Society of America, Las Vegas, U.S.A. (1975).
78. SPURNY, K.R. Asbestos Measurements in Remote Ambient Air. Ann Arbor Science Publications, U.S.A. (1978).
79. POTT, F. Some Aspects on the Dosimetry of the Carcinogenic Potency of Asbestos and other Fibrous Dusts. Staub-Reinhalt Luft (1978) 38, 486.
80 LYNCH, J.L. and AYER, H.E. The Interrelationship of Selected Asbestos Exposure Indices. Amer. Ind. Hyg. Assoc. J. (1970) 31, 598.
81. DEMENT, J.M. and ZUMWALDE, R.D. Asbestos Fibre Exposures in a Hard Rock Gold Mine. Ann. N.Y. Acad. Sci. (1976) 271, 345.
82. NICHOLSON, W.J., ROHL, A.N. and WIESMAN, I. (See National Institute of Occupation and Safety and Health, U.S.A. Report IV, 17a (1975)).
83. COMMINS, B.T. Asbestos Fibres in Drinking Water. STR1. Commins Associates, Altwood Close, Maidenhead, U.K. (1983).
84. SPURNY, K.R. and STROBER, W. Some Aspects of Analysis of Single Fibres in Environmental and Biological Samples. Int. J. Environ. Anal. Chem. (1981) 9, 265.
85. BURDETT, G.J., Le GUEN, J.M. and ROOD, A.P. Mass Concentrations of Airborne Asbestos in the Non-Occupational Environment: a Preliminary Report of U.K. Measurements. Ann. Occ. Hyg. (1984) 28, 31.
86. HWANG, C.Y. and GIBBS, G.W. The Dimensions of Airborne Asbestos Fibres: I. Crocidolite from Kuruman Area, Cape Province, South Africa. Ann. Occ. Hyg. (1981) 24, 23.
87. SEBASTIEN, P. Measurement of Asbestos Air Pollution Inside Buildings Sprayed with Asbestos. U.S. Environmental Protection Agency, Washington, D.C. EPA-560/13/80-026 (1980).
88. HARTFORD, W.H. Asbestos Exposure. J. Air Poll. Contr. Assoc. (1983) 33, 820.
89. SPURNY, K.R. Sci. Total Envir. (1983) 30, 147.
90. CONSTANT, P.C., BERGMAN, F.J. and ATKINSON, G.R. Airborne Asbestos Levels in Schools. Final Report U.S. Environmental Protection Agency. Midwest Research Institute (1982).
91. NICHOLSON, W.J. Measurement of Asbestos in Ambient Air. National Air Pollution Control Administration. Final Report (1971).
92. A Preliminary Report on Asbestos in the Duluth, Minnesota Area. Environmental Protection Agency, Washington, D.C. (1974).
93. NICHOLSON, W.J., ROHL, A.N. and WEISMAN, I. Asbestos Contamination of the Air in Public Buildings. U.S. Environmental Protection Agency, EPA-450/3-76-004 (1975).
94. PINCHIN, D.J. Asbestos in Buildings. Royal Commission on Asbestos. Study Series, No:8, Toronto (1982).

95. SAWYER, R.N. and SPOONER, C.M. Sprayed Asbestos-Containing Materials in Buildings: A Guidance Document. Part 2. U.S. Environmental Protection Agency, Washington, D.C. EPA-450/2-78-014 (1978).
96. NICHOLSON, W.J. Control of Sprayed Asbestos Surfaces in School Buildings: a feasibility study. National Institute of Environmental Health Sciences, North Carolina, U.S.A. (1978).
97. The 1980 Follow-up Report on Air Quality in the Toronto Subway System. Toronto: Ontario Ministry of the Environment, Report ARB-TDA-63-80 (1980).
98. Preliminary Study on the Possible release of Asbestos During the Operation of Hand-held Hairdryers, Environmental Health Directorate, Ottawa, Canada (1979).
99. MERANGER, J.C., REID, W.W. and DAVEY, A.B. The Transfer of Asbestos from Water to Air via a Portable Drum-type Home Humidifier. Can. J. Pub. Health (1979) 70, 276.
100. LILIS, R. Fibrous Zeolites and Endemic Mesothelioma in Cappadocia, Turkey. J. Occ. Med. (1981) 23, 548.
101. ROM, W.N. Health Implications of Natural Fibrous Zeolites for the Intermountain West. Envir. Res. (1983) 30, 1.
102. BALZAR, J.L. Environmental Data: Airborne Concentrations found in Various Operations. In: Occupational Exposure to Fibrous Glass. National Institute for Occupational Safety and Health, Cincinnati (1976).
103. NOLAN, J. Types, Uses and Methods of Manufacture of Man-Made Mineral Fibres. Man-Made Mineral Fibres and Man: Seminar, Royal National Hotel, London (February 1985).
104. SCHNEIDER, T. Size Distributions of Airborne Fibres Generated from Man-Made Mineral Fibre Products. Annals Occ. Hyg. (1983) 27, 157.
105. SIZUKI, Y. Carcinogenic and Fibrogenic Effects of Zeolites: preliminary observations. Environ. Res. (1982) 27, 433.
106. ENTERLINE, P.E. Extrapolation from Occupational Studies: A Substitute for Environmental Epidemiology. Envir. Health Perspectives (1981) 42, 39.
107. Size Definitions for Particle Counting. International Standards Organization, TC 146 Air Quality (1981).
108. CRAIGHEAD, J.E. and MOSSMAN, B.T. The Pathogenesis of Asbestos-Associated Diseases. The New England Journal of Medicine (1982) 306, 1446.
109. TIMBRELL, V. Deposition and Retention of Fibres in the Human Lung. Annals Occ. Hyg. (1982) 26, 347.
110. MONCHAUX, G. and BIGNON, J. Translocation of Mineral Fibres through the Respiratory System after Injection into the Pleural Cavity of Rats. Annals Occ. Hyg. (1982) 26, 309.
111. GROSS, P. et al. Ingested Mineral Fibres. Do they Penetrate Tissue or Cause Cancer. Arch. Envir. Health (1974) 29, 341.
112. Summary Workshop on Ingested Asbestos. Cincinnati, October 1982. Environmental Health Perspectives (1983) 53, 1-204.
113. ATHERLEY, G. A Survey of Four Studies on the Health Effects of Asbestos. Toronto: Royal Commission on Asbestos, October 31 (1980).
114. PETO, R. and DOLL, R. The Control of Lung Cancer. New Scientist (24th January 1985) p.26.
115. GIBBS, W.G. and La CHANCE, M. Dust/Fibre Relationships in the Quebec Chrysotile Industry. Arch. Envir. Health (1974) 28, 69.
116. SCHNEIDERMAN, M.S. Assessment of Risks Posed by Exposure to Low Levels of Asbestos in the General Environment. B.G.A.-Berichte (1981) 4, 3/1.
117. VAN DER REST, E. Industry's Viewpoint. Proceedings of the World Symposium on Asbestos, Montreal, p.164, (May 1982).

118. GRANT, S. Responsibilities of Management including Local Authorities in the Prevention and Control of Health Risks from Asbestos. Seminar on Asbestos Risks - Preventative Measures. National Industrial Safety Organization, Dublin (January 1985).
119. RAJHANS, G.S. and BRAGG, G.M. Engineering Aspects of Asbestos Dust Control. Ann Arbor Sci. Pub. (1978).
120. McDONALD, J.C. Mineral Fibres and Cancer. Annals Acad. Med. Singapore (1984) 13, 345.
121. PEPELKO, W.E. Experimental Respiratory Carcinogenesis in Small Laboratory Animals. Envir. Res. (1984) 33, 144.
122. ESMEN, N.A. and HAMMAD, Y.Y. The Environment in Ceramic Fibre Production. In: Biological Effects of Man-Made Mineral Fibres. WHO, Copenhagen (1982).
123. ISSEROW, L.W. and DU TOIT, R.S. Asbestos Fibres in the Outside Air of Asbestos Mines and Mills of South Africa. Paper presented at International Conference on Air Pollution, Pretoria, South Africa (October 1984).
124. TIMBRELL, V. The Inhalation of Fibrous Dusts. Ann. N.Y. Acad. Sci. (1965) 133, 255.
125. TIMBRELL, V. et al. Hollow Cast of Lungs for Experimental Purposes. Nature (1970) 22, 97.
126. HAMMAD, Y. et al. Deposition of Inhaled Man-Made Mineral Fibres in the lungs of Rats. Annals Occ. Hyg. (1982) 26, 179.
127. MORGAN, A. et al. Deposition and Clearance of Inhaled Fibrous Minerals in the Rat. Envir. Res. (1973) 6, 180.
128. LIPPMANN, M. et al. Deposition, Retention and Clearance of Inhaled Particles. Br. J. Ind. Med. (1980) 37, 337.
129. MOSSMAN, B.T. Interaction of Crocidolite Asbestos with Hamster Respiratory Mucosa. Lab. Invest. (1977) 36, 131.
130. SANCHIS, J.M. et al. Regional Deposition and Lung Clearance Mechanisms in Smokers and Non-Smokers. In: Inhaled Particles (1971) Unwin, England.
131. BOLTON, R.E. An Overload Hypothesis for Pulmonary Clearance of UICC Amosite Fibres Inhaled by Rats. Br. J. Ind. Med. (1983) 40, 264.
132. ROGERS, A.J. Determination of Mineral Fibre in Human Lung Tissue. Annals Occ. Hyg. (1984) 28, 1.
133. SEBASTIEN, P. et al. Topographic Distribution of Asbestos Fibres in Human Lung in Relation to Occupational and Non-Occupational Exposure. In: Inhaled Particles IV, Pergamon Press, Oxford (1977).
134. LANGER, A.M. et al. Chemical Characterization of Asbestos Body uses by Electon Microprobe Analysis. J. Histochem. Cytochem. (1972) 20, 723.
135. WAGNER, J.C. et al. The Effects of the Inhalation of Asbestos in Rats. Br. J. Cancer (1974) 29, 252.
136. BECKLAKE, M.R. Exposure to Asbestos and Human Disease. The New England J. Med. (1982) 306, 1481.
137. DAVIS, J.M.G. et al. Mass and Number of Fibres in the Pathogenesis of Asbestos-Related Lung Disease in Rats. Brit. J. Cancer (1978) 37, 673.
138. BERNSTEIN, D.M. et al. The Pathogenicity of MMMF in Contrast to Natural Fibres. Biological Effects of Man-Made Mineral Fibres, WHO, Copenhagen (1982).
139. CHURG, A. Non-Asbestos Pulmonary Mineral Fibres in the General Population. Envir. Res. (1983) 31, 189.
140. MORGAN, A. et al. Significance of Asbestos Fibres from Lung. Brit. J. Ind. Med. (1978) 35,146
141. MORGAN, R.W. et al. Mortality in Fibrous Glass Production Workers. In: Biological Effects of Man-Made Mineral Fibres, WHO, Copenhagen (1982).
142. LE BOUFFANT, L. et al. Distribution of Inhaled MMMF in the Rat Lung. In: Biological Effects of Man-Made Mineral Fibres, WHO, Copenhagen (1982).
143. ALLISON, A.C. Experimental Methods of Cell and Tissue Culture: Effects of Asbestos. IARC Publications No:8 (1973).

144. DAVIS, J.M.G. The Ultrastructural Changes that occur during the Transformation of Lung Macrophages to Giant Cells and Fibroblasts in Experimental Asbestosis. Brit. J. Exp. Path. (1963) 44, 568.
145. POTT, F. et al. Implantation Experiments with Mineral Fibres. In: Biological Effects of Man-Made Mineral Fibres, WHO, Copenhagen (1982).
146. MOSSMAN, B. et al. Asbestos: Mechanisms of Toxicity and Carcinogenicity in the Respiratory Tract. Ann. Rev. Pharm. Toxicol. (1983) 23, 595.
147. Principles and Methods for Evaluating the Toxicity of Chemicals. Environmental Health Criteria 6. WHO, Geneva (1978).
148. DAVIS, J.M.G. Carcinogenic Effect of Mineral Fibres in Inhalation Studies. VDI-Berichte Nr 475, p.241 (1983).
149. STANTON, M.F. et al. Relation of Particle Dimension to Carcinogenicity in Amphibole Asbestoses and other Fibrous Minerals. J. Nat. cancer Inst. (1981) 67, 965.
150. WAGNER, J.C. et al. Studies of the Carcinogenic Effects of Fibre Glass of Different Diameters following Intrapleural Inoculation in Experimental Animals. Symposium, Occupational Exposure to Fibrous Glass. NIOSH 76-151, Washington, D.C. (1976).
151. STANTON, M.F. and WRENCH, C. Mechanisms of Mesothelioma Induction with Asbestos and Fibrous Glass. J. Nat. Cancer Inst. (1972) 48, 797.
152. STANTON, M.F. Int. Agency Research on Cancer, Lyon. Scientific Publication No:8 (1973).
153. SUZUKI, Y. et al. Mesothelioma following Intraperitoneal Administration of Zeolite. Fed. Proc. (1980) 39, 640.
154. PIGGOTT, G.H. et al. Effects of Long Term Inhalation of Alumina Fibres in Rats. Br. J. Exp. Path (1981) 62, 323.
155. LEE, K. et al. Pulmonary Responses to Inhaled Inorganic Fibres with Asbestos and Fibreglass. Envir. Res. (1981) 24, 167.
156. GEE, J.B. Cellular Mechanisms in Occupational Lung Diseases. Chest (1980) 78, 384.
157. BOLTON, R.E. et al. Variations in the Carcinogenicity of Mineral Fibres. Annal Occ. Hyg. (1982) 26, 569.
158. GROSS, P. The Effects of Fibrous Glass Dust on the Lungs of Animals. Proc. Symposium Occupational Exposure to Fibrous Glass. NIOSH (1976).
159. WAGNER, J.C. Effects of Inhalation and Intrapleural Inoculation of Man-Made Mineral Fibres in Rats. WHO Conference on Biological Effects of Man-Made Mineral Fibres, Copenhagen (1982).
160. SMITH, D.M. et al. Chronic Exposure of Laboratory Animals to Inhaled Small Diameter Glass Fibres. WHO Conference on Biological Effects on Man-Made Mineral Fibres, Copenhagen (1982).
161. SMITH, W.E. and HUBERT, D.D. The Intrapleural Route as a means for estimating carcinogenicity. In: Experimental Lung Cancer, Springer, New York.
162. WAGNER, J.C. et al. Mesothelioma in Rats after inoculation with asbestos and other materials. Brit. J. Cancer (1973) 28, 173.
163. POTT, F. and FRIEDRICHS, K.H. Tumours in Rats after Intraperitoneal Injection of Fibrous Dusts. Naturwissenschaften (1972) 59, 318.
164. NEWHOUSE, M.L. and BERRY, G. Patterns of Mortality in Asbestos Factory Workers in London. Ann. N.Y. Acad. Sci. (1979) 330, 195.
165. HOBBS, M.S. et al. The Incidence of Pneumoconiosis Mesothelioma and other Respiratory Cancer in men engaged in Mining and Milling Crocidolite in Western Australia. In: Biological Effects of Mineral Fibres. IARC Lyon (1980).
166. SEIDMAN, H., SELIKOFF, I.J. and HAMMOND, E.C. Short-Term Asbestos Work Exposure and Long-Term Observation. Ann. N.Y. Acad. Sci. (1979) 330, 61.

167. BRAND, K. et al. Foreign Body Tumourigenesis Induced by Glass and Smooth and Rough Plastic. J. Nat. Cancer Inst. (1975) 55, 319.
168. WAGNER, J.C. and BERRY, G. Mesothelioma in Rats following Inoculation with Asbestos. Brit. J. Cancer (1968) 23, 567.
169. STANTON, M.F. et al. Carcinogenicity of Fibrous Glass: Pleural Response in the Rat in Relation to Fibre Dimensions. J. Nat. Cancer Inst. (1977) 58, 587.
170. STANTON, M.F. et al. Relation of Particle Dimension to Carcinogenicity in Amphibole Asbestoses and Other fibrous Minerals. J. Nat. Cancer Inst. (1981) 67, 965.
171. HARINGTON, J.S. Fibre Carcinogenesis. J. Nat. Cancer Inst. (1981) 67, 977.
172. WEISBURGER, J.H. and WILLIAMS, G.M. The Distinct Health Risk Analyses Required for Genotoxic Carcinogens and Promoting Agents. Envir. Health Perspectives (1983) 50, 233.
173. DANIEL, F.B. In Vitro Assessment of Asbestos Genotoxicity. Envir. Health Perspectives (1983) 53, 163.
174. NEWMAN, R.H. Asbestos-Like Fibres of Biogenic Silica in Sugar Cane. Lancet (1983) II, 857.
175. BROWNE, K. Asbestos-Related Mesothelioma: Epidemiological Evidence for Asbestos as a Promotor. Arch. Envir. Health (1983) 38, 261.
176. KANDASWAMI, C. et al. Effect of Chrysotile Asbestos Pretreatment of Rats on the Hepatic Microsomal Metabolism of Benzo(a)pyrene. International Symposium, Polynuclear Aromatic hydrocarbons (1982).
177. EASTMAN, A. et al. Influence of Asbestos on the Uptake of Benzo(a)-pyrene and DNA Alkylation in Hamster Tracheal Epithelial Cells. Cancer Research (1983) 43, 1251.
178. DI PAOLO, J.A. et el. Asbestos and Benzo(a)pyrene Synergism in the transformation of Syrian Hamster Embryo Cells. Pharmacology (1983) 27, 65.
179. MOSSMAN, B.T. and CRAIGHEAD, J.E. Comparative Cocarcinogenic Effects of Crocidolite Asbestos, Haematite, Kaolin and Carbon in Implanted Tracheal Organ Cultures. Ann. Occ. Hyg. (1982) 26, 553.
180. SZYBA, K. and LANGE, A. A Carrier Function of Asbestos Fibres in Benzo(a)pyrene Mutagenicity. Arch. Immun. Therapiae Exper. (1982) 30, 257.
181. COMMINS, B.T. and GIBBS, G.W. Contaminating Organic Material in Asbestos. Brit. J. Cancer (1969) 23, 358.
182. TURNER-WARWICK, M. and PARKES, W.R. Circulating Rheumatoid and Antinuclear Factors in Asbestos Workers. Brit. Med. J. (1970) 492.
183. HWANG, C.Y. and GIBBS, G.W. The Dimensions of Airborne Asbestos Fibres. Ann. Occ. Hyg. (1981) 24, 23.
184. POTT, F. Carcinogenicity of fibrous fine Dust. Arbeits. Sozial. Pravent. (1977) 12, 172.
185. STANTON, M.F. and LAYARD, M. The Carcinogenicity of Fibrous Minerals. In Proceedings of the Workshop on Asbestos, Gaithersburg (1977).
186. BIGNON, J. and JAURAND, M.C. Significance of the Chemical Composition of Fibres according to their carcinogenicity. Colloquium on Fibrous Dusts. Strasbourg (1982). VDI Report 475, Dusseldorf (1983).
187. BROWN, C.C. High to Low Dose Extrapolation in Animals. In: Assessment and Management of Chemical Risks. Ed. R. Tardiff. Amer. Chem. Soc., Washington (1984).
188. NEWHOUSE, M. Putting Asbestos into Perspective. Pulse p.2 (January 1985).
189. NEWHOUSE, M. Fear of Asbestos. Letter to Times Newspaper, London, (17th July 1984).

190. HILL, A.B. Proc. Roy. Soc. Med. (1965) 58, 295.
191. PELNAR, P.V. Non-Asbestos Related Malignant Mesothelioma. Canadian Asbestos Information Centre, Montreal (1983).
192 DOLL, R. and PETO, R. The Causes of Cancer: Quantitative Estimates of Avoidable Risks of Cancer in the United States Today. J. Nat. Cancer Inst. (1981) 66, 1193.
193. INFANTE, P.F. et al. Mortality Pattern from Lung Cancer and Non-neoplastic Respiratory Disease among White Males in Beryllium Case Registry. Envir. Res. (1980) 21, 35.
194. MANCUSO, T.F. Mortality Study of Beryllium Industry Workers Occupational Lung Cancer. Envir. Res. (1980) 21, 48.
195. DOLL, R. Mortality from lung cancer in Asbestos Workers. Brit. J. Ind. Med. (1955) 12, 81.
196 DOBBERTIN, S. Health Effects on the General Population. Proc. World Symposium on Asbestos, Montreal, (May 1982).
197. SELIKOFF, I.J. First Annual Report to National Institute of Environmental Health Sciences (1974).
198. WAGNER, J.C. et al. Diffuse Pleural Mesothelioma and Asbestos Exposure. Brit. J. Ind. Med. (1960) 17, 260.
199. NEWHOUSE, M.L. and THOMPSON, H. Mesothelioma of Pleura and Peritoneum following Exposure to Asbestos in the London Area. Brit. J. Ind. Med. (1965) 22, 261.
200. PETERSON, J.T. et al. Non-Asbestos-Related Malignant Mesothelioma. Cancer (1984) 54, 951.
201. FEARS, T.R. Cancer Mortality and Asbestos Deposits. Amer. J. Epid. (1976) 104, 523.
202. NEUBERGER, M. Environmental Asbestos Exposure and Cancer Mortality. Arch. Envir. Health (1984) 39, 261.
203. HAMMOND, E.C. et al. Asbestos Exposure, Cigarette Smoking and Death Rates. Ann. N.Y. Acad. Sci. (1979) 330, 473.
204. McDONALD, J.C. and BECKLAKE, M.R. Asbestos Related Disease in Canada. Paper presented at Zweiten Deutsch-Osterrichisch-Schweizerischen Untalltagung, Berlin (1975).
205. WEBSTER, I. Asbestos and Malignancy. S. Afr. Med. J. (1973) 47, 165.
206. ANDERSON, H.A. et al. Asbestosis among Household Contacts of Asbestos Factory Workers. Ann. N.Y. Acad. Sci. (1979) 330, 387.
207. MIANNA, N.J. and POLAN, A.K. Non-occupational Exposure to Asbestos and Malignant Mesothelioma in Females. Lancet (1978) 2, 1061.
208. ANDERSON, H.A. Family Contact Exposure. Proc. World Symposium on Asbestos, Montreal, p.349, (May 1982).
209. HOBBS, M.S. et al. Unpublished Data (1978). Referenced in Advisory Committee on Asbestos, HMSO (1979).
210. BRENNER, J. et al. Malignant Mesothelioma in Children. Medical Pediatric Oncology (1981) 9, 367.
211. BROWNE, K. The Epidemiology of Mesothelioma. J. Soc. Occ. Med. (1983) 33, 190.
212. ZOLOV, C. et al. Pleural Asbestosis in Agricultural Workers. Envir. Res. (1967) 1, 287.
213. BURILKOV, T. and MICHAILOVA, L. Asbestos Content of the Soil and Endemic Pleural Asbestosis. Envir. Res. (1970) 3, 443.
214. BARIS, Y.I. and ARTVINLI, M. Natural Mineral Fibre-Induced Chest Diseases in Turkey. Arch. Immu. Therapiae Exp. (1982) 30, 161.
215. ARTVINLI, M. and BARIS, Y.I. Environmental Fibre-Induced Pleuro-Pulmonary Diseases in an Anatolian Village. Arch. Envir. Health (1982) 37, 177.
216. SEBASTIEN, P. et al. Zeolite Bodies in Human Lungs from Turkey. Lab. Invest. (1981) 44, 420.

217. ROHL, A.N. et al. Endemic Pleural Disease Associated with Exposure to Mixed Fibrous Dust in Turkey. Science (1982) 216, 518.
218. KIVILUTO, R. et al. Pleural Plaques and Neoplasia in Finland. Ann. N.Y. Acad. Med. (1979) 330, 31.
219. BURILKOV, T. and MICHAELOVA, L. Uber den Sepiolitgehalt des Bodens in Gebieten mit Endemischen Pleuraverkalkungen. Int. Arch. fur Arbeitsmed (1972) 29, 95.
220. BAZAS, T. et al. Pleural Calcification in North-West Greece. Lancet (1981) 2, 254.
221. COFFIN, D.L. et al. Influence of Mineral Fibres from Noncommercial asbestos sources on the induction of neoplasia. Int. Conf. Environment and Lung Disease, Taormina, Italy (March 1983).
222. GLICKMAN, L.T. et al. Mesothelioma in Pet Dogs associated with Exposure of their owners to Asbestos. Envir. Res. (1983) 32, 305.
223. CALABRESE, E.J. Pollutants and High Risk Groups. Wiley-Interscience, New York (1980).
224. CALABRESE, E.J. Nutrition and Environmental Health Vol.I. Wiley-Interscience, New York (1980).
225. BABICH, H. and DAVIS, D.L. Food Tolerances and Action Levels. BioScience (1981) 31, 429.
226. PETO, J. Dose and Time Relationship for Lung Cancer and Mesothelioma in relation to Smoking and Asbestos Exposure. Symposium on Asbestos Carcinogenesis. West Berlin (Feb. 1982).
227. ARMITAGE, P. and DOLL, R. Stochastic Models for Carcinogenesis. Proc. Fourth Berkeley Symposium on Statistics and Probability. Univ. of California Press (1961).
228. NICHOLSON, W.J. Health Effects Update. Mount Sinai School of Medicine, New York (1983).
229. PETO, R. Carcinogenic Effects of Chronic Exposure to very low levels of Toxic Substances. Envir. Health Perspect. (1978) 22, 155.
230. FISCHER, M. and MEYER, E. The Assessment of the Health Risk from Asbestos Fibres by the Federal Health Office of the F.R.G. VDI-Berichte (1983) Nr 475, p. 325.
231. Report on Examination of Environmental Asbestos Levels (Japan). Japanese Environmental Agency on the Prevention of Atmospheric Pollution by Asbestos (1984).
232. SHEILS, A.K. The Disposal of Asbestos Wastes in the U.K. Paper presented to International Environmental Contamination Conference, Imperial College, London, (July 1984).
233. COHEN, D. et al. Smoking Impairs Long-Term Dust Clearance from the Lung. Science (1979) 204, 514.
234. WAGNER, J.C. Environmental and Occupational Exposure to Natural Mineral Fibres. IARC Scientific Publications No:30 (1980).
235. SCHNEIDERMAN, M.A. Extrapolation from Incomplete Data to Total or Lifetime Risks at Low Doses. Envir. Health Perspectives (1981) 42, 33.
236. ROBINSON, C.F. et al. Mortality Patterns of Rock and Slag Mineral Wool Production Workers. Brit. J. Ind. Med. (1982) 39, 45.
237. INDULSKI, J. et al. Occupational Exposure of Workers to Airborne MMMF in Poland. In: Biological Effects of Man-Made Mineral Fibres. WHO/IARC Euro Reports and Studies 81, Copenhagen (1982).
238. NICHOLSON, W.J. Occupational Exposure to Asbestos: Population at Risk and Projected Mortality - 1980 to 2030. Amer. J. Ind. Med. (1982) 3, 259.
239. ENTERLINE, P.E. and MARSH, G.M. Mortality of Workers in the MMMF Industry. In: Biological Effects of Man-Made Mineral Fibres. WHO/IARC Copenhagen (1982).
240. MAYER, P. Substitutes for Asbestos. Prophylaxe und Ergonomie (1983) 33, 282.

241. HILLERDAL, G. Malignant Mesothelioma 1982: Review of 4710 Published Cases. Brit. J. Dis. Chest (1983) 77, 321.
242. LAW, M.R. Evidence for Longer Survival of Patients with Pleural Mesothelioma without Asbestos Exposure. Thorax (1983) 38, 744.
243. CHURG, A. and WOOD, P. Observations on the Distribution of Asbestos in Human Lungs. Envir. Res. (1983) 31, 374.
244. ANTMAN, K.H. et al. Malignant Mesothelioma Following Radiation Exposure. J. Clin. Oncology (1983) 1, 695.
245. MALKER, H.R. Mesothelioma Among Sugar Refinery Workers. Lancet (1983) 2, 858.
246. CLARKE, G.D. Exposure to Asbestos Versus Organic Fibrous Dusts. Lancet (1983) 2, 1423.
247. Health Risks of Asbestos and Other Fibrous Fine Dust Pollutants in the Environment. Federal Newsheet on Public Health. German Federal Health Dept. October (1983). (Translation into English).
248. ENTERLINE, P.E. et al. Respiratory Disease Among Workers Exposed to MMMF. Amer. Rev. Resp. Diseases (1983) 128, 1.
249. HERNBERG, S. Nasal and Sinonasal Cancer. Scan. J. Work. Envir. Health (1983) 9, 315.
250. WEILL, H. Asbestos-Associated Diseases. Chest (1983) 84, 601.
251. POOLE, A. et al. In Vitro Genotoxic Activities of Fibrous Erionite. Brit. J. Cancer (1983) 47, 697.
252. HUUSKONEN, M.S. et al. Wollastonite Exposure and Lung Fibrosis. Envir. Res. (1983) 30, 291.
253. OLSEN, J.H. et al. Cancer and Production of Mineral Wool . Inst. Cancer Epid. Copenhagen (1983).
254. MITCHELL, J.W. Occupational medicine Forum. J. Occ. Med. (1983) 25, 361.
255. PERERA, F.P. The Genotoxic/Epigenetic Distinction. Envir. Res. (1984) 34, 175.
256. SHANNON, H.S. Mortality Experience of Glass Fibre Workers. Brit. J. Ind. Med. (1984) 41, 35.
257. COMMINS, B.T. Asbestos Contamination of Air, Soil and Water in Perspective. Proc. Int. Envir. Contamination Conf. (July 1984), Imperial College, London.
258. TOFT, P. et al. Asbestos in Drinking Water. CRC. Critical Reviews in Environmental Control (1984) 14, 151.
259. Guidelines for Drinking Water Quality. Vol.I Recommendations. World Health Organization, Geneva (1984).
260. COMMINS, B.T. Asbestos Fibres in Drinking Water with Special Reference to Asbestos-Cement Pipe Usage. Pipes and Pipelines Int. (1984) 29, 7.
261. HILLERDAL, G. Rarity of Mineral Fibre Pleurisy Among Persons Exposed to Finnish Anthophyllite and with Low Risk of Mesothelioma. Thorax (1984) 39, 608.
262. OLSEN, J.H. Cancer Incidence Among Employees in a Mineral Wool Production Plant in Denmark. Scand. J. Work. Env. Health (1984) 10, 17.
263. SARACCI, R. et al. The IARC Mortality and Cancer Incidence Study of MMMF Production Workers. In: Biological Effects of MMMF. WHO/IARC Meeting. Copenhagen 1982.
264. WALKER, A.M. et al. Projections of Asbestos-Related Disease 1980-2009. J. Occ. Med. (1983) 25, 409.
265. A Cautious Approach to Asbestos Substitution. Health and Safety 45. ENDS Report 121 (1985) p.9.
266. Prevention of Atmospheric Pollution by Asbestos. Letter from Chief of Air Pollution Control Agency, Japan, to Chairman of Japan Asbestos Association, (Feb. 21, 1985).

267. MORGAN, R.W. Mortality Among Fibrous Glass Production Workers. In: Biological Effects of MMMF. WHO/IARC. Copenhagen (1982).
268. Asbestos and Asbestos Related Diseases. Asbestos Information Centre. London (1985).
269. CROUCH, E.A. and WILSON, R. Inter-Risk Comparisons. In Assessment and Management of Chemical Risks. Ed. R.G. Tardiff. Amer. Chem. Soc. Washington (1984).
270. Risk Assessment: a Study Group Report. The Royal Society, London (1983).
271. HUTT, P.B. Unresolved Issues in the Conflict between Individual Freedom and Government Control of Food Safety. Ecotox. Envir. Safety (1978) 2, 447.
272. WILSON, R. Risk estimates. Ecotox. and Envir. Safety (1980) 4, 370.
273. Environmental Health Criteria No:6. WHO, Geneva (1978).
274. RUTSTEIN, M.S. Asbestos - Friend, Foe or Fraud. Geotimes (1982) p. 23.
275. ROBOCK, K. Inst. Applied Fibrous Dust Research, Neuss, F.R.G. (Personal Communication). (1985).
276. POOLEY, F.D. Biological Effects of Mineral Fibres. Brit. Occ. Hyg. Soc. Meeting, April 17 (1985).
277. NEWMAN, R.H. Asbestos-Like Fibres of Biogenic Silica Found in Sugar Cane. Brit. Occ. Hyg. Soc. Meeting, April 17 (1985).
278. SLUIS-CREMER, G.K. The Relationship Between Asbestosis and Bronchial Cancer. Chest (1980) 78, 380.
279. DOLL, R. and PETO, J. Effects on Health of Exposure to Asbestos. Health and Safety Commission, London. HMSO (1985).
280. SARACCI, R. et al. Mortality and Incidence of Cancer of Workers in the Man-Made Vitrous Fibres Producing Industry. Brit. J. Ind. Med. (1984) 41, 425.

STATE OF CALIFORNIA
GEORGE DEUKMEJIAN, Governor

AIR RESOURCES BOARD
1102 Q STREET
P.O. BOX 2815
SACRAMENTO, CA 95812

November 6, 1985

B. J. Pigg, President
Asbestos Information Association
1745 Jefferson Davis Highway
Crystal Square 4, Suite 509
Arlington, Virginia 22202

Dear Mr. Pigg:

Comments on the Draft Asbestos Report

Thank you for your comments on the Draft Asbestos Report. We have referred your comments on Part B to the Department of Health Services (DHS) for response. Your comments and this letter will be included in Part C of the Report to the Scientific Review Panel. The DHS response to your comments will be transmitted to the Panel and incorporated into Part C when they are completed. We will send you a copy of the report when it becomes available along with DHS' comments. I will be responding to your comments in the order in which they appear in your letter, followed by the footnote comments at the end.

Page 1, Paragraph 2: Public involvement is an important aspect of the Air Resources Board's toxic air contaminant program. The staff will communicate with your Association throughout the process of evaluating asbestos. With respect to the U.S. Environmental Protection Agency's (EPA) program to revise the NESHAPS regulations for asbestos, we have been in contact with EPA staff working on the revisions and intend to continue to follow closely EPA's efforts to revise the existing NESHAPS regulations for asbestos.

Page 3, Paragraph 4 to end of Page 4: The SAI study was a limited monitoring program of ten locations in California. At each location, two to five samples were collected for short periods of time (1 to 4 hours). Based on the limited sampling results, we believe that it is difficult to conclude that asbestos emission sources contribute very little or no emissions to ambient asbestos levels.

The monitored levels of asbestos at individual sites do vary considerably and this was pointed out in the draft report. SAI stated that comparison of asbestos data with simultaneously

collected meteorological data indicated that ambient asbestos concentrations are influenced by changes in meteorological parameters such as wind and humidity. (This rationale also applies when comparing asbestos results from different locations in that conditions from one location to another are not the same.)

In summary, we realize the limitations of the SAI study; however, the intent was to document asbestos levels in the ambient air. The study accomplished this goal from our point of view. I assure you that prior to proposing suggested control measures or making other risk management decisions, that causal relationships, when they exist, between sources and exposure levels will be investigated and documented.

Footnote #1: In the report, the ARB staff discussed the purpose of the averaging method that was used to estimate asbestos fibers which were not detected during laboratory analysis (refer to page III-15). In using this averaging method, we did not intend to imply that amphiboles are present at the mill in King City. It was stated earlier in the report that only chrysotile fibers were detected at this location.

In the revised report, we have made a note in Table III-3 that we do not expect to find amphiboles at the mill in King City. However, for consistency of applying the averaging method to all sampling results, we did not change the averaged values in Table III-3.

Footnote #2: Air Resources Board staff contacted representatives of both mining companies and requested that they submit their emission estimates or other information to staff for review. The information the companies provided included process rates but not emission factors or emission estimates. The new process rates were used in the calculations in the revised report.

The emission estimates for mining and milling were based on the best emission factors available. All estimates assume California companies use the best controls available and therefore, the lowest emission factors were used. Because the emission factors were based on the dry processing of asbestos, the emissions from the King City milling operation (wet process) are probably overestimated. However, the King City mill operator could not provide better emission factors for their wet process and therefore, the estimates are not adjusted at this time.

In order to compare monitoring data to emissions, one needs to know the emissions at the time the monitoring is conducted. ARB emission estimates are based on average process and emission rates. At any particular time, these average values may be different than the actual emissions coming from the plant and therefore should not be used for comparisons.

If you have any questions or comments, please contact Todd Wong at (916) 322-0289.

Sincerely,

William V. Loscutoff

William V. Loscutoff, Chief
Toxic Pollutants Branch
Stationary Source Division

cc: Peter D. Venturini
Michael Lipsett, DHS

III. Calaveras Asbestos, Ltd.

Calaveras
Asbestos Ltd.

October 21, 1985

Mr. William V. Loscutoff, Chief
Toxic Pollutants Branch
Air Resources Board
P.O. Box 2815
Sacramento, CA 95812

Attention Asbestos

Dear Mr. Loscutoff:

I am writing in response to your invitation to submit comments regarding the Air Resources Board's (ARB's) Draft Report on Asbestos.

As one of the largest asbestos producers in the United States and as a member of the Asbestos Information Association/North America (AIA/NA), we provided input to the AIA/NA's comments submitted to you.

Please be advised that Calaveras Asbestos, Ltd. concurs with AIA/NA's comments regarding ARB's Draft Report on Asbestos.

Of particular concern was the assumption that amphiboles are present at mines and the questionable amounts of fibre emissions indicated for mines and mills.

Thank you for the opportunity to comment on ARB's Draft Report on Asbestos.

Sincerely,

CALAVERAS ASBESTOS, LTD.

Joey E. Toney
Vice President
Environmental/Safety

JET/kf

P.O. Box 127 · Copperopolis, California 95228 · Telephone (209) 785-2201 · Telex 359458 CALACOPL

STATE OF CALIFORNIA GEORGE DEUKMEJIAN, Governor

AIR RESOURCES BOARD
1102 Q STREET
P.O. BOX 2815
SACRAMENTO, CA 95812

November 5, 1985

Joey E. Toney
Vice President
Environmental Safety
Calaveras Asbestos Ltd.
P. O. Box 127
Copperopolis, CA 95228

Dear Mr. Toney:

Comments on the Draft Asbestos Report

Thank you for your comments on the draft asbestos report.

We forwarded a copy of AIA's comments to the Department of Health Services so they can respond to the comments on Part B of the report, Health Effects of Asbestos. We will send you a copy of the Department's response to AIA's comments as soon as they are available.

Attached to this letter is our response to AIA's concerns regarding Part A of the asbestos report, A Review of Asbestos Uses, Emissions, and Public Exposure.

If you have any other questions or comments, please contact Todd Wong at (916) 322-0289.

Sincerely,

William V. Loscutoff

William V. Loscutoff, Chief
Toxic Pollutants Branch
Stationary Source Division

Attachment

cc: Peter D. Venturini
Michael Lipsett, DHS

STATE OF CALIFORNIA
GEORGE DEUKMEJIAN, Governor

AIR RESOURCES BOARD
1102 Q STREET
P.O. BOX 2815
SACRAMENTO, CA 95812

November 6, 1985

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Asbestos Information Association
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Arlington, Virginia 22202

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Sincerely,

William V. Loscutoff, Chief
Toxic Pollutants Branch
Stationary Source Division

cc: Peter D. Venturini
Michael Lipsett, DHS

IV. KING CITY ASBESTOS COMPANY

Calidria
ASBESTOS
A PRODUCT OF KCAC INC.

P.O. BOX K • KING CITY, CA 93930
TEL (408) 385-5961
TLX 510-600-1346

November 5, 1985

Mr. William V. Loscutoff, Chief
Toxic Pollutants Branch
Attention: Asbestos
Air Resources Board
P.O. Box 2815
Sacramento, CA 95812

Dear Mr. Loscutoff:

This is in response to your letter dated September 19, 1985, requesting comments on Parts A and B of the draft report on asbestos. Your Mr. Barham advised me that this response could be accepted even though after your October 21, 1985 deadline.

First of all, I would like to commend the ARB and DHS staff for the generally accurate, current, and complete nature of both reports.

KCAC mines, mills and markets "Calidria" Asbestos, which is short fiber chrysotile. We strongly concur with the comments sent to you on October 18, 1985 by the Asbestos Information Association of North America (AIA/NA) and encourage you and/or the Scientific Review Panel to carefully consider them.

Our chrysotile ore milling facility, located in Monterey County (not San Benito County as noted on p. I-7 of Part A), was visited on October 22, 1985 by your Mr. Gary Murchison, two members of his staff, and two representatives from the MBUAPCD. I assume that you will receive information from them to revise your section on "Mining and Milling," which starts on p. I-7 of Part A. Our mining operation does not involve drilling and blasting and our milling operation is a wet process, which is not described in your report.. The entire asbestos operation is now operated by KCAC, not Union Carbide Corporation.

Our main concern with Part A of your report involves the emission factors discussed on p. I-10. It is my understanding that these are based only on engineering estimates for Canadian operations and that no airborne fiber measurements were involved with any of your references. It does not seem appropriate to apply these "assumed" factors to California operations unless you have determined that the operations are similar. As stated earlier, our mining and milling operations are completely different than any other asbestos operation. Perhaps your have some justification, not included in the report, for your use of these emission factors for our operation.

It is unfortunate that your table I-1 on p. I-8 would indicate to the

public and others that we are emitting about one-half of 115 tons of asbestos per year from our mining operation and about one-half of 280 tons per year from our milling operation. Based on our current production and operating schedule, and assuming your mill emissions factor is correct, our mill emissions would be calculated as follows:

$$\frac{30{,}000 \text{ Tons ore}}{\text{year}} \times \frac{12 \text{ lbs.}}{\text{ton}} \times \frac{\text{year}}{200 \text{ days}} = \frac{1800 \text{ lbs/day}}{}$$

This is equivalent to 36 fifty-pound bags, almost one full pallet load. If we were actually emitting that much fiber, can you imagine the reaction from MBUAPCD or anyone in the area? I am sure the "dust cloud" would be visible for miles and the fields down wind from us would be white for miles around.

The North American asbestos industry has been severly damaged by the public release and/or misuse of information such as the above. We urge you to carefully reconsider the emission factors you have used and publish the revised information.

We have a total of six baghouses in our mill serving various dust collection systems. These are checked several times per day for visible emissions. The dust is automatically collected, slurried with water and returned to our system. Mr. Murchison has a description of our systems and has requested that we determine the amount of dust collected in our main baghouse. We will attempt to do this during the next several weeks and provide him with the information. This may enable you to determine a more accurate estimate of our emissions.

As mentioned earlier, Union Carbide Corporation, noted several times in your report, sold all of its assets in the asbestos operation to a private group of investors effective June 30, 1985; and KCAC, Inc., now owns and operates these assets.

Reference p. I-11: I am not aware of any floor tile manufacturers using asbestos in California.

Reference p. III-17 & III-20: This is in support of the AIA/NA letter and one sent to you by Mr. Toney of Calaveras Asbestos on October 21, 1985. Because amphiboles could not be detected at our chrysotile operation, you are arbitrarily saying that one-half the detectable limit was present. If you found that cyanide was not detectable (and I'm sure you would), would you say that we were emitting one-half the detectable level?

Reference p. III-23: I question the conversion and use of TEM measurements to PCM equivalents.

Thank you for the opportunity to comment on your draft report on asbestos. Please keep us advised and let me know if you would like additional information or have any questions.

Very truly yours,

John L. Myers

KCAC, Inc.
John L. Myers
President

cc: G.S. Murchison, P.E.
L.D. Odle, MBUAPCD
R.J. Kronkhyte
E.C. Madlangbayan

JLM/dat

STATE OF CALIFORNIA
GEORGE DEUKMEJIAN, Governor

AIR RESOURCES BOARD
1102 Q STREET
P.O. BOX 2815
SACRAMENTO, CA 95812

November 19, 1985

Mr. John L. Myers
KCAC, Inc.
P. O. Box K
King City, CA 93930

Dear Mr. Myers:

Thank you for your comments on the Draft Asbestos Report to the Scientific Review Panel (SRP). Your comments were received on November 8, 1985 which was too late to incorporate them into Part A or Part C of the Report to the SRP. However, copies of your comments and our response will be given to the SRP prior to the November 20th SRP meeting.

Parts A, B, and C were sent to the SRP for review on November 6th. These reports were also sent to you for review. The reports are not final by any means and revisions can be made before submittal to our Board. Your comments and our response will be incorporated into Part C at that time. I will now respond to your comments in the order they appear in your letter.

Page 1, Paragraph 3: The ARB staff has responded to the comments sent by the Asbestos Information Association of North America (AIA/NA). A copy of our response is attached for your information.

Page 1, Paragraph 4: In the Report to our Board, we will clarify that the KCAC milling facility is located in Monterey County. Also, we will include a brief description of the wet process used by KCAC.

Page 1, Paragraph 5 to Page 2, Paragraph 3: The emission factors for mining and milling were selected based on the best information available. The ARB staff assumed that California mines and mills use the best controls available; therefore, the lowest emission factors were used. Because these factors were based on the dry processing of asbestos, the emissions from the KCAC mining and milling operations (wet process) are probably overestimated. We understand that over the next month, your company will be quantifying the amount of asbestos that is collected in the baghouses at the King City Mill. This information will be useful in reviewing the emission factors for your mill operation. Without additional information, the emission factors in Part A could not be revised at this time.

We will continue to work with you to develop emission factors that are more appropriate for your operations. As stated earlier, the report can be revised if better information becomes available. I want to assure you that prior to proposing suggested control measures, the emissions from asbestos mining and milling operations will be extensively reviewed and investigated.

Page 2, Paragraph 5: We will clarify that KCAC, Inc. now owns and operates the asbestos mining and milling operations, instead of the Union Carbide Corporation.

Page 2, Paragraph 6: In 1982, the South Coast Air Quality Management District conducted a survey of manufacturers in Southern California that use asbestos in their products. One company, Armstrong World Industries, indicated that they produced vinyl asbestos floor tiles. The ARB staff contacted Armstrong World Industries and found out that they no longer produce vinyl asbestos floor tiles. We will note this on Table I-3 of the Part A report prior to submittal to the Board.

Page 2, Paragraph 7: Please refer to the attached ARB response letter to AIA's comments regarding the use of the averaging method (Page 2, Footnote #1).

Page 2, Paragraph 8: The rationale that the Department of Health Services used in converting from TEM measurements to PCM equivalents is discussed in Section 9.g. and Appendix A of the Part B report. If you have specific questions, please contact us and we can refer the questions to DHS.

Thank you again for your comments. If you have any questions, please call Todd Wong at (916) 322-0289.

Sincerely,

William V. Loscutoff

William V. Loscutoff, Chief
Toxic Pollutants Branch
Stationary Source Division

Attachment

cc: Peter Venturini

STATE OF CALIFORNIA
GEORGE DEUKMEJIAN, Governor

AIR RESOURCES BOARD
1102 Q STREET
P.O. BOX 2815
SACRAMENTO, CA 95812

November 6, 1985

B. J. Pigg, President
Asbestos Information Association
1745 Jefferson Davis Highway
Crystal Square 4, Suite 509
Arlington, Virginia 22202

Dear Mr. Pigg:

Comments on the Draft Asbestos Report

Thank you for your comments on the Draft Asbestos Report. We have referred your comments on Part B to the Department of Health Services (DHS) for response. Your comments and this letter will be included in Part C of the Report to the Scientific Review Panel. The DHS response to your comments will be transmitted to the Panel and incorporated into Part C when they are completed. We will send you a copy of the report when it becomes available along with DHS' comments. I will be responding to your comments in the order in which they appear in your letter, followed by the footnote comments at the end.

Page 1, Paragraph 2: Public involvement is an important aspect of the Air Resources Board's toxic air contaminant program. The staff will communicate with your Association throughout the process of evaluating asbestos. With respect to the U.S. Environmental Protection Agency's (EPA) program to revise the NESHAPS regulations for asbestos, we have been in contact with EPA staff working on the revisions and intend to continue to follow closely EPA's efforts to revise the existing NESHAPS regulations for asbestos.

Page 3, Paragraph 4 to end of Page 4: The SAI study was a limited monitoring program of ten locations in California. At each location, two to five samples were collected for short periods of time (1 to 4 hours). Based on the limited sampling results, we believe that it is difficult to conclude that asbestos emission sources contribute very little or no emissions to ambient asbestos levels.

The monitored levels of asbestos at individual sites do vary considerably and this was pointed out in the draft report. SAI stated that comparison of asbestos data with simultaneously

collected meteorological data indicated that ambient asbestos concentrations are influenced by changes in meteorological parameters such as wind and humidity. (This rationale also applies when comparing asbestos results from different locations in that conditions from one location to another are not the same.)

In summary, we realize the limitations of the SAI study; however, the intent was to document asbestos levels in the ambient air. The study accomplished this goal from our point of view. I assure you that prior to proposing suggested control measures or making other risk management decisions, that causal relationships, when they exist, between sources and exposure levels will be investigated and documented.

Footnote #1: In the report, the ARB staff discussed the purpose of the averaging method that was used to estimate asbestos fibers which were not detected during laboratory analysis (refer to page III-15). In using this averaging method, we did not intend to imply that amphiboles are present at the mill in King City. It was stated earlier in the report that only chrysotile fibers were detected at this location.

In the revised report, we have made a note in Table III-3 that we do not expect to find amphiboles at the mill in King City. However, for consistency of applying the averaging method to all sampling results, we did not change the averaged values in Table III-3.

Footnote #2: Air Resources Board staff contacted representatives of both mining companies and requested that they submit their emission estimates or other information to staff for review. The information the companies provided included process rates but not emission factors or emission estimates. The new process rates were used in the calculations in the revised report.

The emission estimates for mining and milling were based on the best emission factors available. All estimates assume California companies use the best controls available and therefore, the lowest emission factors were used. Because the emission factors were based on the dry processing of asbestos, the emissions from the King City milling operation (wet process) are probably overestimated. However, the King City mill operator could not provide better emission factors for their wet process and therefore, the estimates are not adjusted at this time.

In order to compare monitoring data to emissions, one needs to know the emissions at the time the monitoring is conducted. ARB emission estimates are based on average process and emission rates. At any particular time, these average values may be different than the actual emissions coming from the plant and therefore should not be used for comparisons.

If you have any questions or comments, please contact Todd Wong at (916) 322-0289.

Sincerely,

William V. Loscutoff, Chief
Toxic Pollutants Branch
Stationary Source Division

cc: Peter D. Venturini
Michael Lipsett, DHS

V. DEPARTMENT OF HEALTH SERVICES RESPONSES TO HEALTH-RELATED COMMENTS

State of California — Department of Health Services

Memorandum

To : Mr. William Loscutoff, Chief
Toxic Pollutants Branch
California Air Resources Board
P.O. Box 2815
Sacramento, CA 95812

Date : November 15, 1985

Subject: Responses to Public Comments on Part B of the AB 1807 Document on Asbestos

From : Epidemiological Studies and Surveillance Section

Your staff transmitted to the Department of Health Services (DHS) only one set of comments from the public on part B of the AB 1807 document on asbestos. The letter from the commenter, Mr. B.J. Pigg, President of the Asbestos Information Association (AIA), states in pertinent part:

> California's new assessment [and other government risk assessments on asbestos] must be understood to be "upper limit assessments" because they:
>
> (1) Assume a linear dose-response relationship;
>
> (2) Assume the same potency for all forms of asbestos despite significant data indicating lesser potency for chrysotile, particularly with respect to mesothelioma; and
>
> (3) Include within the calculated risk the substantial portion of the lung cancer risk attributable to cigarette smoking.
>
> As Dr. Crump details in his report [to the federal Occupational Safety and Health Administration, attached to Mr. Pigg's comments], risks of exposure to chrysotile fibers, even accepting the upper limit assumption of a linear dose-response relationship, are likely to better be estimated for non-smokers as at least an order of magnitude lower than the assessment employed by OSHA. 1/

1/ Dr. Crump also discusses selection of epidemiology studies to predict risks and notes that OSHA omitted from its consideration studies of Canadian asbestos miners and millers, an omission also made in the California assessment (Part B, p. 45). Such omissions are questionable in the OSHA context where the Agency was considering all possible workplace exposures and are particularly troublesome in the California context given that one of the focuses of emission concern will be fiber emissions from mines and mills within the State (Part A, p. 5). To the extent California is to be considering whether further mining and milling emissions controls are appropriate, it is inappropriate not to acknowledge that risks among miners and millers of chrysotile have been found to be much lower than for other asbestos occupational groups.

> In addition, because the California risk assessment is intended to predict risks at much lower exposure levels (0.001 fibers/cc and lower vs. 0.1 fibers/cc and higher) than the OSHA risk assessment, even greater uncertainty exists that such upper level limit assessments are appropriate. In extrapolating risks to even lower levels than OSHA extrapolated, considerable likelihood exists that the linear dose-response relationship overestimates human risk.
>
> In sum, we urge California to exercise great care in employing its risk assessment to predict risks at the very low, often near ambient, asbestos exposures, identified in its monitoring program. Despite the general agreement of its assessment with other recent assessments, all such assessments must be recognized as upper limit estimates of risk that may greatly over-estimate actual human health effects.

In the following pages, DHS staff respond to the comments submitted by Mr. Pigg. We have also referenced the testimony of Dr. Kenny Crump where relevant to Mr. Pigg's assertions. We have not responded to everything contained in Dr. Crump's lengthy (51 pp.) document, largely because it was written in response to a proposed revision of the federal occupational exposure standard. Futhermore, Mr. Pigg's letter indicated that Dr. Crump's comments were enclosed "for your information," not demanding a response. Finally, the overall import of Dr. Crump's comments - that the OSHA risk assessment represents an upper limit - does not differ from the position of Mr. Pigg, to whom we have responded in detail below.

Response:

DHS staff members do not disagree with AIA's assertion that the asbestos risk assessment should be considered to represent an "upper limit assessment." Indeed, to err on the side of protection of public health, such risk assessments are intended not to underestimate risks and may therefore in some instances provide overestimates. This issue has already been addressed:

> "In this document we present the best estimates and approximate upper confidence limit estimates and explain that such lifetime cancer risk values represent a range of conservative estimates and are unlikely to be exceeded by actual risks." (Part B, p.2)

Thus, AIA's main point does not appear to conflict with one of the principal stated purposes of the document. The specific justifications for AIA's position have already been discussed in the text of part B, but will be covered briefly below.

(1) Use of a linear dose-response relationship.

DHS staff summarized the rationale for using dose-response models that are linear with dose, as follows:

> The data upon which these models are based (i.e., the results of occupational epidemiological studies) are consistent with such a model, but do not rule out nonlinear dose-response relationships. For example, Nicholson has noted that the results of linear extrapolation cannot be distinguished from those derived using the logit, log-probit, or multistage models within the observable range for occupational asbestos exposures (Nicholson, 1981). Previous risk assessments have relied on a linear model because it is biologically plausible, conservative, and mathematically tractable (Royal Commission, 1984; NRC, 1984; Nicholson, 1985; CPSC, 1983). DHS staff members have found this rationale persuasive. (Part B, pp. 35-36)

Nothing in Mr. Pigg's comments or the supporting documentation of Dr. Crump (pp. 8-9, 25-26, 35-36) suggests that another model fits the observed data better or would be superior for purposes of risk assessment.

(2) Similar carcinogenic potencies for all forms of asbestos.

This issue is thoroughly discussed in section 9.c. of part B. To summarize briefly, there is no compelling epidemiologic evidence to differentiate among fiber types with respect to their ability to induce lung cancer. However, several epidemiologic studies suggest that chrysotile may be less potent than the amphiboles in mesothelioma induction. Nevertheless, DHS staff chose not to do a fiber-specific risk assessment because:

> First, there is limited evidence with respect to the airborne asbestos concentrations to which the study populations were exposed. The incidence of mesothelioma may therefore be more a function of fiber number (amphibole fibers tend to become airborne more easily and in greater numbers than do chrysotile fibers) than of fiber type (Royal Commission, 1984). Second, while some cases of mesothelioma occurring in persons exposed to chrysotile and one or more amphiboles have been attributed primarily to the latter, this conclusion is rather incautious from a public health standpoint. As Peto et al. (1982) have observed, "It may therefore be dangerously optimistic to attribute the substantial incidence of pleural mesothelioma among chrysotile factory workers to occasional crocidolite exposure, merely because mesothelioma is rare among chrysotile miners...The overall excess of lung cancer is also relatively low among chrysotile miners." Finally, animal studies involving experimental induction of mesotheliomas have repeatedly shown that chrysotile is at least as potent as crocidolite and amosite in producing peritoneal as well as pleural tumors (Bolton et al. 1982:IARC, 1977; Royal Commission, 1984). (Part B, pp. 64-65).

This approach was also adopted in risk assessments conducted by the National Academy of Sciences, the Consumer Product Safety Commission and Nicholson (for the Environmental Protection Agency), all referred to in the text of part B. Dr. Crump's comments on the OSHA risk assessment review some of the epidemiologic evidence suggesting that exposure to amphiboles may present a greater risk of mesothelioma than does exposure to chrysotile. While reasonable persons could differ with respect to whether differentiation by fiber type would be appropriate, the more conservative (i.e., health protective) approach has been consistently adopted by regulatory and scientific organizations in this country. DHS staff members have found nothing in AIA's submission that would compel the adoption of another, fiber-specific approach.

(3) Inclusion of lung cancer risk attributable to cigarette smoking within overall calculated risks.

Mr. Pigg asserts that DHS' calculated risks for lung cancer due to asbestos exposure include risks attributable to cigarette smoking. The implication is that DHS has overestimated the potency of asbestos by not takig into account the carcinogenic effects of cigarettes. The grounds for this assertion are unclear to DHS staff. On the basis of the observations by Hammond et al. (1979) that cigarette smoking and exposure to asbestos in an occupational setting appear to interact synergistically in pulmonary carcinogenesis, DHS predicted risks by smoking status. The model used to predict lung cancer risks includes a term for background lung cancer rates, which are significantly elevated in smokers. Thus, throughout part B the separation of risks due to asbestos exposure by smoking status is clearly delineated (cf. pp. 2, 12, 41, 42, 48, 50, 51, 70, 73). In referring to Dr. Crump's commentary, Mr. Pigg observes that estimated risks of lung cancer in non-smokers are about one order of magnitude less than in smokers. This observation is also made repeatedly in part B. Thus, unless Mr. Pigg is arguing that smoking and asbestos exposure display no interaction in carcinogenesis (a proposition for which no evidence has been submitted), DHS staff find his implication that we have failed to account for the effects of cigarette smoking unpersuasive, at best.

Finally, Mr. Pigg states in a footnote that DHS failed to consider the epidemiologic studies of Canadian asbestos miners and millers and that it is "inappropriate not to acknowledge that risks among miners and millers of chrysotile have been found to be much lower than for other asbestos occupational groups." In section 9.a.i.5 of part B, not only is it acknowledged that the lung cancer risks among miners and millers are lower than among most other occupational groups, but also the rationale for using a median proportionality constant ("C_ℓ") that excluded values from mining and milling studies is explained. To rephrase the rationale presented in part B: DHS staff assumed that fibers generated in mining operations would not be typical of general environmental exposures, particularly in urban environments. The low risks of lung cancer experienced by the mining and milling cohorts are thought to reflect the relatively unprocessed physical state of the fibers, many of which are large and nonrespirable. To the extent that this assumption is invalid - i.e., if a substantial fraction of ambient asbestos fibers sampled are found to be large and nonrespirable - the proportionality constant for lung cancer would have to be adjusted. Part A of the

asbestos document compiled by the Air Resources Board does not contain adequate information to resolve this issue entirely, although section III.C indicates that "nearly all (ambient sample) fibers were less than or equal to five micrometers in length." Thus it appears that, based on information provided by the Air Resources Board, DHS' decision to exclude the results of epidemiologic studies of Canadian miners and millers from the calculation of the median lung cancer proportionality constant is not without empirical support.

Michael Lipsett

Michael Lipsett, M.D., J.D.
Acting Chief
Air Toxics Unit

VI. ASBESTOS INFORMATION ASSOCIATION

ASBESTOS INFORMATION ASSOCIATION
NORTH AMERICA
1745 Jefferson Davis Highway, Crystal Square 4 Suite 509
Arlington, Virginia 22202 • (703) 979-1150

December 19, 1985

William V. Loscutoff, Chief
Toxic Pollutants Branch
Stationary Source Division
Attention: Asbestos
Air Resources Board
P.O. Box 2815
Sacramento, CA 95812

Dear Mr. Loscutoff:

The Asbestos Information Association/North America (AIA/NA) appreciates your willingness to consider comments we filed on October 18, 1985, concerning the Board's draft report on asbestos. I have forwarded your request for more up-to-date estimates of emissions from asbestos mines and mills to AIA/NA's two members in California who operate asbestos mines.

As we detailed in our previous letter to you, a number of criticisms have been made of the risk assessment methodology employed in government analyses including that in the draft document prepared by the Air Resources Board. In that connection, we sent to you a copy of a detailed critique of such risk analyses by Dr. Kenny S. Crump, a recognized assessment expert who has often worked for EPA and OSHA. Dr. Crump emphasized that such risk analyses must be understood to be "upper limit assessments" because they assume a linear dose-response relationship even to very low environmental levels, assume the same potency for all forms of asbestos despite significant data indicating lesser potency for chrysotile fibers, and include within the calculated risk a substantial portion of the lung cancer risk attributable to smoking. I am enclosing a recently published article by J. Corbett McDonald, a distinguished epidemiologist from McGill University, who has studied asbestos extensively. His article raises the same doubts as does Dr. Crump about estimating risks for low level environmental asbestos exposures.

Some of the same general criticisms were raised on November 20, 1985 by the Scientific Review Panel. Like Dr. Crump, the experts on that Panel questioned the accuracy of the risk assessment methodology, emphasizing that only a linear, and not a multi-stage model was used to extrapolate to low exposures. They further commented on the failure of the assessment to take into account the substantial portion of lung cancer health effects due to smoking. And, again as did Dr. Crump, they questioned whether the assessment took proper account of the lower carcinogenic risks of chrysotile as opposed to the amphiboles. The Scientific Review Panel in addition raised a few other issues that are relevant to review and revision of the risk assessment. They emphasized that any emissions from mines and mills in California would be solely of chrysotile fibers and not of amphiboles. They also questioned use of an 85-year lifespan rather than 70 years for predicting risks. Finally, they suggested the need for the California Air Resources Board to be aware that many of the risks predicted, given the very low emissions, are likely to be of de minimis public health significance, a factor that should be significant in assessing whether any need exists for regulatory control of such emissions.

AIA/NA appreciates the opportunities it has been given to comment on the Board's draft document. As indicated previously, we look forward to continued cooperation with the Air Resources Board.

Sincerely,

B. J. Pigg
President

Enclosure

Environmental Health Perspectives
Vol. 62, pp. 319-328, 1985

Health Implications of Environmental Exposure to Asbestos

by J. Corbett McDonald*

The health impact of environmental pollution resulting from the industrial use of asbestos can be assessed in three ways. First, there are the direct epidemiological surveys. These indicate that domestic exposure has been responsible for cases of mesothelioma and possibly lung cancer and radiological changes in family contacts of asbestos workers. Exposure in the neighborhood of crocidolite mines and factories has also resulted in cases of mesothelioma but no similar evidence exists for chrysotile or amosite. Neither air nor water pollution has been directly incriminated as a cause of either respiratory or digestive malignancies.

Second, a few attempts have been made to extrapolate from exposure response findings in industrial cohorts. For several reasons, even for lung cancer, this approach is dubious: the observed gradients have a 100-fold range in slope; the equivalences of dust, fiber and gravimetric measures are largely guesswork; and the carcinogenic potential of mineral fibers, particularly for the pleura, varies enormously with fiber type and/or dimensions. No adequate exposure-response observations have been made for mesothelioma.

A third approach makes use of the differing incidence of mesothelioma in men and women. Data from several countries indicate that, until the 1950s (i.e., 30–40 years after significant industrial use of asbestos began), the rates were similar in both sexes. Since then, the incidence in males has risen steeply—in the U.S. and U.K. at about 10% per annum. In females, on the other hand, there has been little or no convincing increase. These data suggest that the "background" level of mesothelioma in both sexes is and has been about 2 per million per annum and that—as at least some mesothelioma cases in females are directly or indirectly attributable to occupational exposure—there is little room left for any contribution from the general environment. It is recommended that mesothelioma surveillance, backed by appropriate epidemiological inquiries, offers an effective method of monitoring the health impact of asbestos air pollution.

Introduction

Fibrous mineral silicates are a common constituent of the earth's surface. Fibers of natural origin are present to a greater or lesser extent in air and water almost everywhere and probably always have been. The industrial value of certain of these minerals, collectively known as asbestos, was recognized at the end of the last century. Production and use increased enormously, with periods of acceleration related to both world wars (Fig. 1). Occupational exposure in asbestos production, manufacturing and user industries has reflected the conflicting trends of use and control. Since 1950, the number of workers exposed has greatly increased while their intensity of exposure has steadily decreased. Assuming a latent period of 30 to 40 years for malignant diseases to manifest themselves, we would expect to see the first effects, at least occupationally, in the 1950s, which is what actually happened. Industrial exploitation has lead to contamination of the general environment, the nature and extent of which is more difficult to document. Gross pollution in the immediate neighborhood of mines, factories and shipyards was commonplace 30 to 50 years ago but far less today. On the other hand, the general level of asbestos fibers in air, water, and food is probably higher than it was and may still be rising. Building construction and demolition have been responsible for much of this; for example, see Woitowitz and Rodels-

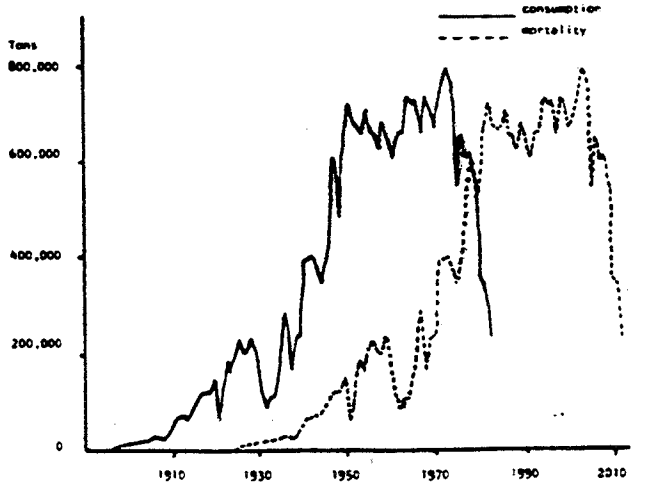

FIGURE 1. Asbestos consumption in the U.S. (*1*) showing probable pattern of related cancer mortality.

*School of Occupational Health, McGill University, Montreal, Canada.

berger (1). The control of occupational exposure in these industries has been slow and relatively ineffective with correspondingly great and continuing impact on the general environment, especially in cities. In addition, there is the widespread distribution and accumulation of a variety of asbestos-containing materials and products which gradually wear and deteriorate.

The health implications of this general picture are complicated by three additional factors. First, asbestos is not one but several materials, each of distinct chemical, physical, and biological qualities. In particular the amphiboles—crocidolite, amosite, anthophyllite, and tremolite—almost certainly differ from the serpentine mineral, chrysotile, in their health effects. Second, dimensions, durability, respirability, retention, and surface reactivity have considerable biological relevance, and, in different circumstances, the same mineral may vary enormously. Third, interaction between asbestos exposure and cigarette smoking is important in determining the risk of respiratory tract cancer, and unidentified factors may well play a role in the gastrointestinal tract.

This paper will attempt to assess the health impact of environmental pollution resulting from the industrial use of asbestos. Occupational exposure will be considered only to the extent that it can help to quantify the risk. So far as possible, the contribution of "natural" nonindustrial pollution will be excluded from the total. Although no precise geographical or temporal definitions are possible, the focus will be on North America (USA and Canada) in the 1980s. Nonoccupational exposures may be either respiratory or by ingestion and vary considerably both in duration and intensity. Air pollution has thus to be separated from contamination of water supplies; it can be further subdivided into three or four different grades. Domestic, indirect occupational, and bystander exposures have often been very high; neighborhood exposures in the vicinity of asbestos mines, plants, shipyards, etc., were also considerable. General urban pollution is much lower than any of these but a far larger proportion of the population is at risk. The order of magnitude of these exposures is shown in Table 1.

Three main methodologies will be considered and the results compared. First, there is the possibility of direct epidemiological investigation, by means of population-based studies—cohort or case-referent in type. The problem with the former is that adequate sensitivity for detection of low level risks is almost impossible to achieve; the problem with the latter is that reliable estimates of past exposure and source are even more difficult to determine. A second methodological approach depends on extrapolation from exposure–response data obtained from industrial cohorts to exposure levels observed or estimated in the general environment. The difficulties here include environmental measurement at very low fiber concentrations, the wide range of risks calculable from the few available sets of exposure–response data and the questionable validity of any extrapolation of this kind. A third approach entails the estimation of the overall impact of asbestos exposure on mortality followed by partition into occupational and nonoccupational components. Several methods of doing this have been used with results which are at best quite approximate. We shall suggest that an improved estimate can probably be obtained from examination of trends in male and female mesothelioma mortality. Even now, relatively few cases in women are attributable to occupation, and statistics for the past—before the development of a male excess—provide some indication of the natural background incidence.

Table 1. Current North American levels of exposure to airborne asbestos.

Type of exposure	Approximate level, ng/m³
Occupational	10,000–>50,000
Neighborhood/domestic	100–10,000
Urban	1–100
Rural/background	<1–2

Estimates of Health Impact

For the purpose of this paper, it seems reasonable to assume that only diseases for which there is evidence of causation in occupational studies deserve consideration in relation to nonoccupational exposure. This limits our concern to asbestosis, respiratory tract cancers, malignant mesothelioma tumors, and gastrointestinal tract cancers. As occupational studies suggest that even a lifetime at nonoccupational levels of fiber concentration would seldom, if ever, cause disability or death from pulmonary fibrosis, this response will be considered only to the extent that it provides evidence of significant past exposure. Laryngeal cancer will not be considered *per se*. It is an uncommon cause of death, and the etiological contribution of asbestos is still unclear. So far as air pollution is concerned, the major emphasis must be on lung cancer and mesothelioma, since the estimation procedures available are very crude and other diseases could only have a marginal effect. Cancers of the gastrointestinal tract will be discussed only in relation to drinking water.

Epidemiological Surveys

Neighborhood Exposure. There are several well-documented reports indicating the occurrence of mesothelioma cases in the vicinity of crocidolite mines and factories. The initial report by Wagner et al. (2) of the high prevalence of this disease around the crocidolite mines in the Cape Province, Republic of South Africa, included cases without occupational exposure. The case-control studies of Newhouse and Thompson (3) in Barking (London) and of Hain et al. (4) in Hamburg indicated

an excess in the immediate neighborhood of factories which processed asbestos, mainly from the same South African mines. On the other hand, no similar cases were seen near the amosite or chrysotile mines of South Africa nor, by extensive case-control studies, near the chrysotile mines of Canada or the U.S. (*5,6*). Also negative was an analysis of mortality in persons residing within half a mile of an amosite asbestos factory in Patterson, NJ (*7*). The employees of this plant had experienced high rates of both mesothelioma and lung cancer (*8*) and appreciable numbers of amosite fibers were still present in dust collected in the attics of neighboring houses. One doubtful case only was reported in the vicinity of the Balangero chrysotile mine in Italy (*9*) and no case has ever been reported from the Russian chrysotile mining area of Sverdlovsk (*10*).

In an early uncontrolled study of 42 cases in Pennsylvania (*11*), two lived close to asbestos plants and six others had worked next to an asbestos plant. A systematic investigation of all 201 cases of mesothelioma and 19 other pleural tumors reported to the Connecticut Tumor Registry, (1955–1977) and 604 randomly selected decedent controls found no evidence of risk from neighborhood exposure (*12*). In Northwest England, Whitwell et al. (*13*) examined lung tissue by phase-contrast optical microscopy from 100 cases of pleural mesothelioma, 100 cases of lung cancer and 100 controls who had died from conditions other than industrial lung disease or lung cancer. They found that the number of asbestos fibers was related to the occupational and not to the home environment. Subjects who had lived near probable sources of atmospheric asbestos pollution had no higher counts than those from further away. In this review of data on pleural mesothelioma in England and Wales, Gardner (*14*) commented on the highly localized geographical distribution "in which occupational and occupationally related exposure has been critical."

Several investigations have been made into the possible effects of environmental pollution on the resident populations of Thetford Mines and Asbestos, Québec, the two main centers of chrysotile production in the Western world. Geographical analyses by Graham et al. (*15*) of cancers reported to the Quebec tumor registry showed higher incidence rates for tumors of the pleura, lip, salivary gland, and small intestine in males and, additionally, of kidney and skin (melanoma) in females. However, no account was taken of occupational or domestic exposure. Pampalon et al. (*16*) did much the same thing using mortality statistics. Among women, there was no excess mortality; in men, mortality from respiratory cancer was raised in Thetford Mines (SMR 1.62) and from nonmalignant respiratory diseases in the town of Asbestos (SMR 1.53). In a later report (*17*), Siemiatycki showed that, as about 75% of the older male population of these towns had been employed in the mining industry (over 50% for 30 years or more) the raised SMRs could well be explained by occupational exposure—a possibility subsequently confirmed by Liddell (*18*).

Household Exposure. Despite the scarcity of environmental data, it is likely that household contacts of asbestos workers are much more heavily exposed than others who simply live in the area. Measurements made by Nicholson (*19*) in the homes of miners and nonminers in a chrysotile mining community in Newfoundland suggest that fiber concentrations were manyfold higher in the former than the latter. Three of the 42 cases of mesothelioma in Pennsylvania, mentioned above (*11*) were in the household contacts, and the studies of both Newhouse and Thomson in England (*3*) and of McDonald and McDonald (*5*) in North America all showed more frequent domestic exposure in cases than controls, after exclusion of occupation. Two further epidemiological surveys have specifically addressed the question. Vianna and Polan (*20*) studied the asbestos exposure history of all 52 histologically confirmed fatal cases of mesothelioma in females in New York State (excluding New York City), 1967–1977, with matched controls. Excluding six cases exposed at work, eight others had a husband and or father who worked with asbestos; none of their matched controls had a history of domestic exposure whereas the reverse was true in only one pair. Information on latency was not given, but two of the eight, whose husbands were asbestos workers, were only 30 and 31 years of age.

In a study by Anderson et al. (*21*), over 3100 household contacts of 1664 surviving employees of the Patterson amosite asbestos plant were identified in the period, 1973–1978. From over 2300 still living, 679 subjects who themselves had never been exposed to asbestos occupationally and 325 controls of similar age distribution were selected for radiographic and other tests. Small opacities and/or pleural abnormalities were observed in 35% of the household contacts and 5% of the controls. Pleural changes were rather more frequent than parenchymal. The readings were made by five experienced readers and although the interpretation was by consensus, it was made without knowledge of exposure category. The mortality experience of this population of household contacts is also under study; the methodology has not yet been adequately described but at least three cases of mesothelioma and excess mortality from lung cancer have been reported (*22*).

General Environmental Exposure. There is very little direct epidemiological evidence on the effects of urban asbestos air pollution. The question was addressed to some extent in analyses of the extensive surveys of malignant mesothelial tumors undertaken by our group (*5*) in Canada, 1960–1975, and in the U.S., 1972. Systematic ascertainment through 7400 pathologists yielded 668 cases which, with controls, were investigated primarily for occupational factors. After exclusion of those with occupational, domestic or mining neighborhood exposure, the places of residence of women were examined for the period 20 through 40 years before death. Of 146 case-control pairs, 24 cases and 31 controls had lived in rural areas only and 82 cases and 79 controls had lived in urban areas only. These very small differ-

ences could easily be due to chance, quite apart from the greater likelihood of case recognition in urban than rural areas and the contribution of exposure in the immediate neighborhood of plants, such as that in Patterson.

Exposure by Ingestion. It has been postulated that asbestos fibers in drinking water, and perhaps also in food, could conceivably increase the incidence of alimentary cancers in populations exposed over many years. For several reasons, this question will be only discussed briefly in this paper. In the first place, excepting mining areas, the occurrence of fibers in drinking water is usually the result of contamination from natural sources rather than from industrial processes and products. Second, even in industrial cohorts, the association of asbestos exposure with alimentary cancer is irregular (*23*) and not wholly convincing (*24*); also, the risks are small compared to lung cancer and largely confined to the most heavily exposed workers. Even so, water supplies are often carried in asbestos–cement pipes, mining and quarrying activities have led to heavy water pollution, and urban air pollution from asbestos plants and construction may well contaminate water and food.

There have been 13 analyses of cancer incidence and/or mortality by site in relation to estimated concentrations of asbestos fibers in drinking water in six areas of North America. In five of these—Connecticut, Quebec, San Francisco Bay area, Utah and Puget Sound area—the contaminating fibers were chrysotile in concentrations ranging from below detection to 10^6 fibers per liter. In the sixth population—Duluth—exposure was to an amphibole mineral in a similar range of concentrations, although to what extent the particles were truly fibrous is unclear. In all such studies, the main difficulty is to allow correctly for socioeconomic, occupational, nutritional, and other confounding variables. The results of all 13 studies were reviewed by Marsh (*25*) at a recent Summary Workshop sponsored by the U.S. Environmental Protection Agency (*26*). After exclusion of one study which did not give results by cancer site, eight providing independent data were included in a binomial probability analysis designed to test the degree of agreement between them. Despite the low level of agreement between male and female results, positive finds for esophagus, stomach, pancreas, and prostate (Table 2) were unlikely to be due to chance alone, although not necessarily to water supplies. As the first two of these sites are those for which there is also the strongest evidence of an association with asbestos in occupational cohorts, Marsh recommended that these specific etiologic hypotheses should be tested by case-control studies. He pointed out, however, that the detection of low level risks would require very large samples.

Extrapolation

The several inconclusive attempts to identify and interpret small differences in disease incidence in relation to fiber content of water supplies illustrates the virtual impossibility of direct epidemiological assessment of low environmental risks related to the more complicated constituents of urban air pollution. A common alternative approach is therefore to take the exposure–response relationships observed in occupational environments and extrapolate back to the much lower exposure levels recorded in the general environment. This procedure is fraught with difficulties, however, some of which are discussed below.

The Assumptions. Extrapolation is valid only to the extent that (a) some reasonable mathematical formula for the relationship exists; (b) the point of intercept on the exposure axis is known; (c) important interactions with other etiologic factors are multiplicative or additive. For lung cancer, the scanty data available are compatible with a nonthreshold linear relationship to accumulated exposure but do not exclude other models. The even more scanty data on the combined effects of cigarette smoking and asbestos exposure suggest that the interaction is more than additive but not necessarily multiplicative in all circumstances. No comparable evi-

Table 2. Drinking water and digestive cancers.[a,b]

	Duluth	Connecticut	Quebec	Bay Area, CA	Utah	Puget Sound
Fibertype	Amphibole	Chrysotile	Chrysotile	Chrysotile	Chrysotile	Chrysotile
Fiber density, million/L	1–30	0.7	1.1–1300	0.25–36	—	7.3–207
Population exposed	100,000	576,800	420,000	3,000,000	24,000	200,000
Site						
Esophagus	○			●		
Stomach	●		○	●		●
Small intestine						
Colon						
Rectum						
Biliary passage/liver						
Gallbladder						
Pancreas	●	○	○	●		
Peritoneum				●		

[a] Derived from analyses by Marsh (25)
[b] Key: (○) excess in males or females; (●) excess in males and females.

dence on either of these questions exists for asbestosis or mesothelioma.

Exposure–Response. Nine cohort studies in eight industrial groups (*27–35*) have been reported in which exposure to asbestos for each subject was estimated individually in duration and intensity and related to lung cancer risk. The studies are summarized in Table 3. The first eight studies shown (studies 1–8), produced linear exposure–response relationships, but of very varied gradients. With the exception of study 7, where the analysis was case-referent in type, the other studies used man-years methods primarily, with results presented as SMRs. Since, for various reasons, not all lines passed through the origin, the gradients in Table 2 are expressed in terms of relative slope, as calculated by Liddell and Hanley (*36*). The two textile plants (studies 4–6) have gradients manyfold more steep than the rest, the sharpest contrast being between the chrysotile-only textile workers and chrysotile miners and millers. Even less risk than in chrysotile production is seen in the two friction products plants, where it is quite doubtful whether there was any significant lung cancer excess. Although far below textiles, the two factories engaged mainly in the manufacture of cement and building products were severalfold above chrysotile production. The experience of American insulation workers (*37*) and of men engaged in the manufacture of amosite insulation products (*8*) are not shown in Table 2 because exposure was not assessed individually. However, with certain assumptions, especially as to linearity, it seems likely that the gradients for these two populations lay somewhere between the cement workers and the textile workers. Study 9, of asbestos cement workers in Ontario (*35*), is difficult to interpret: both chrysotile and amphiboles were used, there were relatively few lung cancer deaths, but substantial mortality from mesothelioma. Perhaps because of the small numbers and possible confusion between the two kinds of malignancy there was no systematic relationship between estimated exposure and lung cancer so no slope was calculated.

There were at least two possible explanations for the variation, first, that some of the exposure estimates were seriously incorrect. If so, the error was systematic or the response relationships would have been lost. Second, and I believe more likely, neither the original dust particle measurements nor the usual conversions to fibers, countable with the optical microscope, adequately reflected the biological hazard. Experimental work on fiber size and the dynamics of penetration and retention all suggest that this could be an important part of the explanation, perhaps all of it. Indeed, fibers wide enough to be seen with the light microscope have little carcinogenic effect (J.C. Wagner, personal communication).

Fiber Type and Mesothelioma. Differences between the various types of asbestos fiber can probably be ignored in predicting risks of lung cancer and asbestosis, but mesothelioma is another matter. The evidence that virtually all peritoneal and most pleural cases are attributable to amphibole exposure, rather than to chrysotile, has been reviewed elsewhere (*24,38*). Although not conclusive, the data are sufficiently persuasive for most countries—U.S. excepted—to have made a basic distinction as to fiber type in their control policies and legislation (*39*). In the present context, this major

Table 3. Exposure–response for lung cancer in male cohorts where exposure estimates were made for each subject individually.

Study no.	Type of industry	Study	Place	Fiber type	Number in cohort	Total deaths	Lung cancer expected cases	Relative slope per mpcf-yr
1	Mining and milling	McDonald (*24*)	Quebec	Chrysotile	10,939	3,291	184	0.164
2	General manufacture	Henderson and Enterline (*25*)	U.S.	Chrysotile Crocidolite Amosite	1,075	781	23.3	0.353
3	Cement products	Weill (*26*)	New Orleans	Chrysotile Crocidolite	5,645	601	49.2	0.658
4	Textiles	Dement (*27*)	S. Carolina	Chrysotile	768	191	7.5	6.896
5	Textiles	McDonald (*28*)	S. Carolina	Chrysotile	2,543	857	29.6	5.863
6	Mainly textiles	McDonald (*29*)	Pennsylvania	Chrysotile Amosite Crocidolite	4,137	1,392	50.5	5.101
7	Friction products	Berry and Newhouse (*30*)	England	Chrysotile Crocidolite	9,113	1,640	139.5	'effectively zero'
8	Friction products	McDonald (*31*)	Connecticut	Chrysotile	3,641	1,267	49.1	'effectively zero'
9	Cement products	Finkelstein (*32*)	Ontario	Chrysotile Crocidolite	536	138	5.4	not calculated

uncertainty is further compounded by the lack of adequate exposure–response information for mesothelioma. In none of the nine cohorts shown in Table 3, with individual measurements of exposure in terms of both intensity and duration, was the relationship of mesothelioma to "dose" examined. The relatively small number of cases and the confounding effects of fiber type discouraged such analyses. Despite this, some recent reports (*40,41*) suggest that an indication of risk can be obtained from a small number of other cohort studies, in which only average group exposure had been roughly estimated. All the cohorts used for these reports were exposed to pure amphibole or to amphibole–chrysotile mixtures and generally excluded from consideration were those in which the mesothelioma risk was low. Indeed, if the 18 cohorts so far reported with 200 or more deaths are listed in order of proportional mortality from this cause, those selected for these studies ranked as numbers 1,2,3,5, and 7.

Conversion. All the available exposure–response data from occupational cohorts are based on total respirable dust measurements made by impinger methods and expressed in millions of particles per cubic foot (mpcf). Determination of the equivalence of these measurements in terms of fibers (> 5 μm long) per milliliter (f/mL) is a difficult and dubious operation. Even in chrysotile mining and milling, the range of conversion ratios is at least 40-fold (*42,43*). A problem of similar magnitude concerns the equivalence in fiber terms of measurements made in the general environment, nearly all of which are gravimetric and usually expressed in nanograms per cubic meter (ng/m^3). These questions have been discussed by several authors with various conclusions; Nicholson (*40*) considered that the conversion factor relating mass to optical fiber concentration had a range of 5 to 150 and probably varied with fiber type.

On taking these many uncertainties into account, the range of possible error in any estimates made by extrapolation must be very wide indeed. Taken together, variations in exposure–response gradient and conversion factors for ng/m^3, mpcf, and f/mL could conceivably lead to estimates with a range of five orders of magnitude. Even this would not take account of such questions as sampling error in environmental measurement, fiber type, or fiber size distributions. Nevertheless, a few courageous estimates of environmental impact by extrapolation have been made. The results are not so widely disparate, at least for lung cancer, mainly because similar approaches on averaging have been used.

In a paper by Enterline in 1981 (*44*), estimates of lung cancer deaths, based on extrapolation from linear and curvilinear exposure–response models, were made. Using conversion factors of 3 for f/mL per mpcf and 40 × 10^3 for f/mL per ng/m^3 and linear extrapolation from his own exposure–response data (SMR = 100 + 0.658 mpcf-yr), he estimated that continuous lifetime exposure at 5 ng/m^3 (approximately the average outdoor level in urban areas of the U.S.) would result in 4.6 lung cancer deaths per million population. On the other hand, a curvilinear model, for which there is experimental but not epidemiological support, would result essentially in zero deaths. In a later paper (*45*), Enterline speculated on the apparent discrepancy between occupational exposures where excess lung cancer mortality generally exceeds that due to mesothelioma (*46*) and the nonoccupational situation. In the general population of the U.S., with average outdoor exposure at about 1.5 ng/m^3, the lifetime lung cancer risk was estimated by Enterline to be about 2 per million. Using data on mesothelioma incidence, however, he concluded that the lifetime risk of this disease was at least 100 per million. However, as discussed at the end of this paper, this latter estimate is probably not correct.

Table 4. Estimated lifetime risks per million population from nonoccupational exposure to asbestos.

	Lung cancer	Mesothelioma
Enterline (*42*)	2	100*
Schneiderman (*45*)	3–32	4–24
Nicholson (*40*)	12–18	6–24
NRC Committee (*46*)		
Smokers, male	64–320	
Smokers, female	23–120	
Nonsmokers, male	6–29	9–46
Nonsmokers, female	3–15	

*This figure should probably have been about 50 (see text).

Several other estimates of current and lifetime risk of lung cancer and mesothelioma for the U.S. population have been made purely by extrapolation. A simplified comparison of these estimates is set out in Table 4. To achieve a measure of comparability, some liberties were taken with the published data, and the figures shown are therefore approximate. Having regard for the enormous range of uncertainty, it is remarkable that the four estimates are as close as they are. The differences between the lung cancer estimates are mainly due to the idiosyncratic selection of exposure–response data from industrial cohorts. The NRC committee (*41*) used three of the nine cohorts included in Table 3 and added six others, in all of which only group estimates of exposure had been made. Schneiderman (*47*) used only two of the nine and included three of the six added by the NRC committee. Nicholson (*40*) used four of the nine cohorts and not the other five. The greater similarity of the mesothelioma figures is due to the fact that, apart from Enterline, whose figure was not obtained by extrapolation, the others used the same information (or lack of it) on exposure–response—all, however, from the cohorts at highest risk.

In the light of these critical comments, it is fair to ask whether anything better can be done. Until the explanation of the 100-fold difference in gradient of slopes for the eight or nine satisfactory sets of exposure–response data is explained, and better evidence on the equivalence and mass and fiber concentration measurements is obtained, any extrapolation is, in my view, pure guesswork. However, the possibility that mesoth-

elioma may be a more serious potential hazard than lung cancer, especially for nonsmokers is real. The theoretical basis for this view has been presented by Peto (*48,49*). His mathematical models are compatible with the evidence available, but his equations for lung cancer and mesothelioma both include constants which depend on fiber dimension and type and which may differ between the two diseases and in different circumstances.

Sex Differences in Mesothelioma Mortality

If the total number of deaths attributable to asbestos exposure were known or could be calculated, it might then be possible to partition them by causal type of exposure. We took this approach at the Banbury Conference in 1980 in trying to discover what proportion of cancer was attributable to occupational asbestos exposure (*46*). Three types of information were used: first the estimated incidence of fatal cases of mesothelioma; second, the ratio of mesothelioma to other types of cancer from all available cohorts (then numbering 24); and third, the proportion of mesothelioma related to occupation from case-referent surveys in Canada, 1960–1972, and in the United States, 1972 (*5*). At that time, our best estimates for North American males in 1975 were an annual mesothelioma incidence of 8.0 per million; 75% of cases attributable to occupational asbestos exposure; and a ratio of mesothelioma to excess mortality from other cancers of 3.3 (2.4 for respiratory plus 0.9 for digestive). The corresponding figures for females were 2.5 per million, less than 10% attributable, and a lower but undefined ratio to other cancers (especially respiratory). Our best indicator of mesothelioma incidence was the SEER Program of population-based cancer registries in five states and five city areas, for which data are now available for 1973–1980 (Biometry Branch, NCI, unpublished). The number of usable cohorts has also risen, from 24 to 32, with little change in median ratios of mesothelioma to excess respiratory cancer (males, 2.5; females, 1.25). We have not yet recalculated the ratio for digestive cancer.

Returning to the problem in hand, if a similar approach were adopted, we might have estimated that, in 1975, nonoccupational causes were responsible in males for about 2.0 per million cases of mesothelioma and 5.0 per million excess lung cancers. In females, the mesothelioma figure would be fairly similar and the lung cancer excess about 2.5 per million. These nonoccupational rates would then have to be apportioned between domestic, neighborhood and general environmental exposures on the one hand and background causes on the other. For mesothelioma, this approach seems reasonable, though difficult, but the extrapolation to lung cancer, empirically acceptable for the occupational estimate, is considerably more dubious for the nonoccupational component. However, the first task is to consider mesothelioma and, for this purpose, it may be useful to examine the theoretical model illustrated in Figure 2.

If there is a background incidence of mesothelioma, unrelated to the industrial exploitation of asbestos (although quite conceivably to mineral fibers), there is no reason to believe that the levels would be different in males and females. Consideration of Figure 1 and the usual latency for mesothelioma (30–40 years) suggests that, as stated earlier, we might begin to see the effects of asbestos in the 1950s, especially in men. The trend in male incidence might then parallel the increased industrial use of asbestos, reaching a peak in about year 2000 and, hopefully, falling some 40 years after that. In females, on the other hand, a much smaller effect would be expected from occupational exposure and any increased incidence would reflect more specifically the impact of domestic and environmental exposure.

There are several sets of data which suggest that this general pattern is being followed. In Canada, ascertainment through pathologists has shown a steady in-

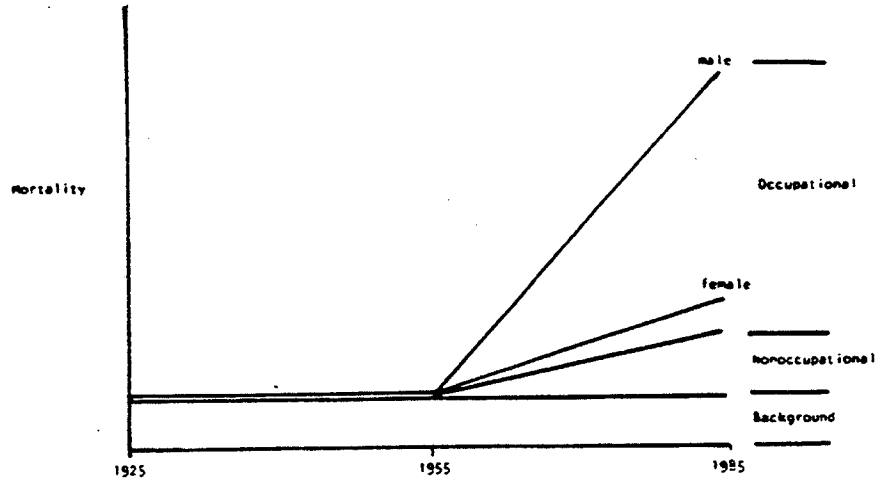

FIGURE 2. Conceptual model for mesothelioma mortality assuming complete ascertainment.

crease in male cases from about 10 in 1961 to 25 in 1974, whereas in females the annual number of cases averaged about 8 over the same period (*5*). In the U.K. (*14*), deaths from pleural mesothelioma in males have risen from 100 (4 per million) per annum in 1968 to 200 (8 per million) in 1978 (most sharply since about 1973)—a gradient of about 10% per annum. In females, the annual number of deaths has remained steady at just under 50 (2 per million). Data presented by Elmes and Simpson (*50*) tend to suggest that, in the U.K., the sex difference began to appear in about 1950. Finnish Cancer Registry statistics, 1953–1969, reported by Nurminen in 1975 (*51*) indicate that mesothelioma was equally frequent in men and women in Finland until about 1961 when they began to separate. In the U.S. data from the Connecticut Tumor Registry (*52,53*), show no sex difference until the mid 1950s, after which there was a rapid rise in the male rates. Of particular interest are the observations of Archer and Rom (*54*) on mortality by age and sex from diffuse malignant mesothelioma of the pleura in the U.S., 1950–1978. Until 1966, there was no difference between the rates for men and women in any age group. Thereafter there was a sharp divergence between the sexes, evident only after age 45 when the rate for males rose considerably and for females to a lesser extent. Below age 45, the rates for males and females continued equal and unchanged.

All these time trends are subject to the confounding effect of changes in level of diagnosis and ascertainment. Only the more recent data from the SEER program provide a reasonably complete and uniform level of ascertainment. However, the age-adjusted rates for mesothelioma, all sites, for the total period 1973–1980 are very informative. Figure 3, which also includes the essentially comparable estimate for 1970–1972, from the Third National Cancer Survey (TNCS), shows that the male rate is increasing by nearly 10% per annum whereas it is quite doubtful whether there has been any change in the female rate. These data are compatible with those of Archer and Rom and again suggest that the divergence began in the 1960s.

The conclusions seem clear enough. First, there is now good reason for believing that the background level of mesothelioma, whatever its cause, must be and has been about 2 per million in men and women for many years. Second, as there is evidence that both occupational and domestic exposure account for at least some mesothelioma cases in females, there is little or no room left for any effect attributable to environmental exposure or improved levels of ascertainment.

Finally, I return to Dr. Enterline's anomalously high estimate of 333 cases of mesothelioma in 1981 related to nonoccupational exposure—equivalent to a lifetime risk of about 100 per million (Table 4). The explanation is, first that he made no allowance for the "background" incidence and, second, that he took our estimate that 47% of male mesotheliomas in 1973 resulted from nonoccupational exposure (*44*) and applied this proportion to the much larger total number of cases in 1981. In

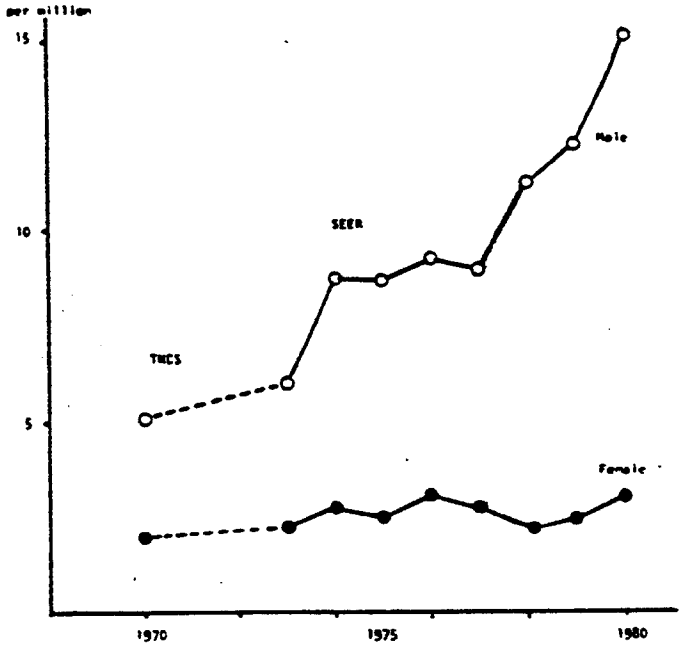

FIGURE 3. Mesothelioma incidence in the U.S., 1970–80, age-adjusted to the national population.

1970, the annual rate per million for males was 5.1 (TNCS), 47% of which is 2.4—a level similar to that shown for females in Figure 3. In 1980, we can see that nonoccupational exposure accounted for less than 20% of male cases; by the end of the century the proportion may fall to less than 10%.

Conclusion

This review does little to strengthen belief in the validity of extrapolation as a means of estimating the impact on health of urban levels of asbestos air pollution. However, the potential importance of the question and the need for prudence in matters of public health warrant the use of every available method, even this one. Linear extrapolation to very low fiber concentrations almost certainly overstates the true risk. The error may be compounded by use of inappropriate or unrepresentative exposure–response data; for example, the selection of occupational cohorts heavily exposed to amphibole fibers in estimating the risk of mesothelioma for the general population. Nevertheless, the fact remains that direct epidemiological studies may not be sensitive enough to detect very low risks.

Society thus faces something of a quandry: policies need be based on the best estimate, neither over or under, even though a decision may then be made regarding a margin of safety. One solution is to use carefully balanced extrapolation as the primary method of risk estimation, at the same time continuing to monitor the situation by direct survey methods. In this way, obvious over or under estimates of risk may be detected with least delay. The incidence of malignant mesothelial

tumors in women has great potential as an indicator of environmental asbestos exposure, especially if combined with field studies to estimate the contribution of direct and indirect occupational factors (*53*).

I am indebted to the Biometry Branch, National Cancer Institute, through the kind offices of Mr. Roger R. Connelly, for permission to quote unpublished data from the SEER Program.

REFERENCES

1. Woitowitz, H. J., and Rodelsperger, K. Asbestos emissions at the interface between workplace and environment. Institute and Policlinic of Industrial and Social Medicine, Giessen, 1982.
2. Wagner, J. C., Sleggs, C. A., and Marchand, P. Diffuse pleural mesothelioma and asbestos exposure in the North Western Cape Province. Brit. J. Ind. Med. 17: 260–271 (1960).
3. Newhouse, M. L., and Thomson, H. Epidemiology of mesothelial tumors in the London Area. Ann. N.Y. Acad. Sci. 132: 579–588 (1965).
4. Hain, E., Dalquen, P., Bohlig, H., Dahbert, A., and Hing, I. Retrospective study of 150 cases of mesothelioma in Hamburg area. Int. Arch. Arbeitsmed 33: 15–37 (1974).
5. McDonald, A. D., and McDonald, J. C. Malignant mesothelioma in North America. Cancer 46: 1650–1659 (1980).
6. Thériault, G., and Grand-Bois, L. Mesothelioma and asbestos in the Province of Quebec 1969–1972. Arch. Environ. Health 3: 15–19 (1978).
7. Hammond, E. C., Garfinkel, L., Selikoff, I. J., and Nicholson, W. J. Mortality experience of residents in the neighborhood of an asbestos factory. Ann. N.Y. Acad. Sci. 330: 417–422 (1979).
8. Seidman, H., Selikoff, I. J., and Hammond, E. C. Short term asbestos work exposure and long term observation. Ann. N.Y. Acad. Sci. 330: 61–89 (1979).
9. Rubino, G. F., Piolatto, G., Newhouse, M. L., Scansetti, G., Aresini, G. A., and Murray, R. Mortality of chrysotile asbestos miners at the Balangero Mine, Northern Italy. Brit. J. Ind. Med. 36: 187–194 (1979).
10. Kogan, F. M. Asbestos-Containing Dusts and Measures Preventing Their Noxious Effect on the Health of Workers (Russian). Mid-Ural Book Publishing Agency, Sverdlovsk, Russia, 1975.
11. Lieben, J., and Pistawka, H. Mesothelioma and asbestos exposure. Arch. Environ. Health 14: 559–562 (1967).
12. Teta, M. J., Lewinsohn, H. C., Meigs, J. W., Vidone, R. A., Mowad, L. Z., and Flannery, J. T. Occupational and geographic associations. J. Occup. Med. 25: 749–755 (1983).
13. Whitwell, F., Scott, J., and Grimshaw, M. Relationship between occupations and asbestos-fibre content of the lungs in patients with pleural mesothelioma, lung cancer, and other diseases. Thorax 32: 377–386 (1977).
14. Gardner, M. J. Tumour incidence after asbestos exposure in Great Britain with special reference to the cancer risk of the non-occupational population. VDI Ber. 475: 185–190 (1983).
15. Graham, S. Methodological problems in ecologic studies of the asbestos–cancer relationship. Environ. Res. 25: 35–49 (1981).
16. Pampalon, R., Siemiatycki, J., and Blanchet, M. Environmental asbestos pollution and public health in Quebec. Union Méd. Canada 111: 475–489 (1982).
17. Siemiatycki, J. Health effects on the general population: mortality in the general population in asbestos mining areas. Proceedings of the World Symposium on Asbestos, Montreal, 1983, pp. 337–348.
18. Liddell, F. D. K. Tumour incidence after asbestos exposure in the general population of Canada. VDI Ber. 475: 179–183 (1983).
19. Nicholson, W. J., Rohl, A. N., Weisman, I., and Selikoff, I. J. Environmental asbestos concentrations in the United States. In: Biological Effects of Mineral Fibres (J. C. Wagner, Ed.), IARC Scientific Publications, No. 30, Lyon, France, 1980, pp. 823–827.
20. Vianna, N. J., and Polan, A. K. Non-occupational exposure to asbestos and malignant mesothelioma in females. Lancet, i: 1061–1063 (1978).
21. Anderson, H. A., Lilis, R., Daum, S. M., and Selikoff, I. Asbestosis among household contacts of asbestos factory worker Ann. N.Y. Acad. Sci. 330: 387–399 (1979).
22. Anderson, H. A. Family contact exposure. Proceedings of t World Symposium on Asbestos, Montreal, 1983, pp. 349–362.
23. McDonald, J. C. Mineral Fibres and Cancer. Ann. Acad. Me Singapore 13 (Suppl.): 345–352 (1984).
24. Acheson, E., and Gardner, M. J. Asbestos: The Control Lin for Asbestos. Health and Safety Commission, HMSO, Londo 1983.
25. Marsh, G. M. Critical review of epidemiologic studies related ingested asbestos. Environ. Health Perspect. 53: 49–56 (1983)
26. U.S. Environmental Protection Agency. Summary workshop ingested asbestos. Environ. Health Perspect. 53: 1–204 (1983)
27. McDonald, J. C., Liddell, F. D. K., Gibbs, G. W., Eyssen, G. E and McDonald, A. D. Dust exposure and mortality in chrysoti mining, 1910–1975. Brit. J. Ind. Med. 37: 11–24 (1980).
28. Enterline, P. E., and Henderson, V. Type of asbestos and re piratory cancer in the asbestos industry. Arch. Environ. Healt 27: 312–317 (1973).
29. Hughes, J., and Weill, H. Lung cancer risk associated with ma ufacture of asbestos-cement products. In: Biological Effects Mineral Fibres (J. C. Wagner, Ed.), IARC Scientific Publication No. 30, Lyon, France, 1980, pp. 627–635.
30. McDonald, A. D., Fry, J. S., Woolley, A. J., and McDonald, J. Dust exposure and mortality in an American chrysotile textil plant. Brit. J. Ind. Med. 40: 361–367 (1983).
31. Dement, J. M., Hams, R. L., Symons, M. J., and Shy, C. M Estimates of dose-response for respiratory cancer among chry sotile asbestos textile workers. Ann. Occup. Hyg. 26: 869–88 (1982).
32. McDonald, A. D., Fry, J. S., Woolley, A. J., and McDonald, J. Dust exposure and mortality in an American factory using chry sotile, amosite and crocidolite in mainly textile manufacture. Brit J. Ind. Med. 40: 368–374 (1983).
33. Berry, G., and Newhouse, M. L. Mortality of workers manufac turing friction materials using asbestos. Brit. J. Ind. Med. 40: 1–7 (1983).
34. McDonald, A. D., Fry, J. S., Woolley, A. J., and McDonald, J. C Dust exposure and mortality in an American chrysotile asbestos friction products plant. Brit. J. Ind. Med. 41: 151–157 (1984).
35. Finkelstein, M. M. Mortality among long-term employees of a Ontario asbestos-cement factory. Brit. J. Ind. Med. 40: 138–14 (1983).
36. Liddell, F. D. K., and Hanley, J. Relations between asbestos exposure and lung cancer SMRs in occupational cohort studies. Brit. J. Ind. Med. 42: 389–396 (1985).
37. Selikoff, I. J., Hammond, E. C., and Seidman, H. Mortality experience of insulation workers in the United States and Canada, 1943–1976. Ann. N.Y. Acad. Sci. 330: 91–116 (1979).
38. McDonald, J. C. Asbestos-related disease: an epidemiological review. In: Biological Effects of Mineral Fibres (J. C. Wagner, Ed.) IARC Scientific Publications, No. 30, Lyon, France, 1980, pp. 587–601.
39. McDonald, J. C. Aspects of the asbestos standard. In: Occupational Lung Disease (J. B. Gee, W. K. L. Morgan and S. M. Brooks, Eds.), Raven Press, New York, 1984, pp. 139–149.
40. Nicholson, W. J. Tumour incidence after asbestos exposure in the USA: cancer risk of the non-occupational population. VDI Ber. 475: 161–176 (1983).
41. Non-Occupational Health Risks of Asbestiform Fibres. NRC Report. National Academy Press, Washington, DC, 1984.
42. Dagbert, M. Etude de corrélation des mesures d'empoussiérage dans l'industrie de l'amiante. Document 5. Québec: Comité d'études sur la salubrité dans l'industrie de l'amiante (R. Beaudry, président).
43. McDonald, J. C., Gibbs, G. W., and Liddell, F. D. K. Chrysotile fibre concentration and lung cancer mortality: a preliminary report. In: Biological Effects of Mineral Fibres (J. C. Wagner, Ed.).

IARC Scientific Publication No. 30, Lyon, France, 1980, pp. 811–814.
44. Enterline, P. E. Extrapolation from occupational studies: a substitute for environmental epidemiology. Environ. Health Perspect. 42: 39–44 (1981).
45. Enterline, P. E. Cancer produced by nonoccupational asbestos exposure in the United States. J. Air Pollut. Control Assoc. 33: 318–322 (1983).
46. McDonald, J. C., and McDonald, A. D. Mesothelioma as an index of asbestos impact. In: Quantification of Occupational Cancer. (Banbury Report No. 9), (R. Peto, and M. Schneiderman, Eds.), Cold Spring Harbor, N.Y. 1981, pp. 73–85.
47. Schneiderman, M. S., Nisbet, I. C. T., and Brett, S. M. Assessment of risks posed by exposure to low levels of asbestos in the general environment. bga-Ber. 4: 1–27 (1981).
48. Peto, J. Dose and time relationships for asbestos-related cancers, and risk assessment in the general population. VDI Ber. 475: 309–312 (1983).
49. Peto, J., Schneiderman, H., and Selikoff, I. J. Mesothelioma mortality in asbestos workers: implications for models of carcinogenesis and risk assessment. Brit. J. Cancer 45: 124–135 (1982).
50. Elmes, P. C., and Simpson, M. J. C. The clinical aspects of mesothelioma. Quart. J. Med. [45] 179: 427–449 (1976).
51. Nirminen, M. The epidemiologic relationship between pleural mesothelioma and asbestos exposure. Scand. J. Work Environ. Health 1: 126–137 (1975).
52. Lewinsohn, H. C., Meigs, J. W., Teta, M. J., and Flannery, J. T. The influence of occupational and environmental asbestos exposure on the incidence of malignant mesothelioma in Connecticut. In: Biological Effects of Mineral Fibres (J. C. Wagner, Ed.), IARC Scientific Publications No. 30, Lyons, France, 1980, pp. 655–660.
53. Bruckman, L., Rubino, R. A., and Christine, B. Asbestos and mesothelioma incidence in Connecticut. J. Air Pollut. Control Assoc. 27: 121–126 (1977).
54. Archer, J. E., and Rom, W. N. Trends in mortality of diffuse malignant mesothelioma of pleura. Lancet, ii: 112–113 (July 9, 1983).
55. McDonald, A. D. Mesothelioma registries in identifying asbestos hazards. Ann. N.Y. Acad. Sci. 330: 441–454 (1979).

STATE OF CALIFORNIA
GEORGE DEUKMEJIAN, Governor

AIR RESOURCES BOARD
1102 Q STREET
P.O. BOX 2815
SACRAMENTO, CA 95812

February 3, 1986

L. J. Pigg, President
Asbestos Information Association
1745 Jefferson Davis Highway
Crystal Square 4, Suite 509
Arlington, Virginia 22202

Dear Mr. Pigg:

Asbestos Report

Thank you for your December 19, 1985 letter and for the article by J. Corbett McDonald. Since The Department of Health Services (DHS) had not reviewed this article previously, I have forwarded a copy to them for their review. I expect to have their comments back in time to include with the upcoming report to the Air Resources Board on asbestos.

I appreciate you forwarding our request for better emission estimates to Asbestos Information Association of North America's two members in California. I understand that KCAC, Inc. has already contacted my staff and is working on providing better estimates for our use.

In your letter you also restated comments on the asbestos report that you had provided in a previous letter to us. Since our response to your previous comments is already included in Part C of our asbestos report, I have not included a response in this letter.

If you have any questions or additional comments on this matter, please feel free to contact Gary Murchison of my staff at (916) 322-6521.

Sincerely,

William V. Loscutoff

William V. Loscutoff, Chief
Toxic Pollutants Branch
Stationary Source Division

cc: Peter Venturini
Michael Lipsett, DHS
John Holmes

State of California

Department of Health Services

Memorandum

To : Mr. William V. Loscutoff, Chief
Toxic Pollutants Branch
Air Resources Board
P.O. Box 2815
Sacramento, CA 95812

Date : February 7, 1986

Subject: Responses to Additional Comments on Part B of the AB 1807 Asbestos Document

From : Michael Lipsett, M.D., Chief
Air Toxics Unit
Epidemiological Studies and Surveillance Section

Our staff has reviewed the supplementary comments submitted by the Asbestos Information Association (AIA) regarding Part B of the AB 1807 document on asbestos. The AIA's submission, dated December 19, 1985, reiterates statements made in a previous letter (dated October 18, 1985) and summarizes a few points raised by Scientific Review Panel (SRP) members at the meeting November 20, 1985. The Department of Health Services has responded to both the AIA's earlier comments and to the SRP's concerns in memoranda to your staff dated November 15 and December 19, 1985 and January 14, 1986. The only new information offered by the AIA in the current submission is an article by J.C. McDonald, "Health Implications of Environmental Exposure to Asbestos," (Environ. Health Perspect. 62:319-28, 1985). As noted in the AIA letter, McDonald's paper "raises the same doubts as does Dr. Crump [cited in the AIA's previous submission] about estimating risks for low level environmental asbestos exposures." These doubts have already been addressed in the original Part B, in our previous responses to comments, and on the record at the SRP meetings November 20, 1985, and January 14, 1986.

One additional issue raised by the McDonald article that has not been previously addressed is the validity of low-dose risk assessments for asbestos-induced mesotheliomas in view of gender-specific differences in mortality ascribed to this neoplasm. McDonald asserts that the rate of mesothelioma in men has increased recently due to occupational exposure, while the rate in women has remained relatively stable at about two cases per million in several large populations. Thus, "as there is evidence that both occupational and domestic exposure account for at least some mesothelioma cases in females, there is little or no room left for any effect attributable to environmental exposure or improved levels of ascertainment" (p. 326).

This is a rational argument about which, however, reasonable people can disagree. DHS staff have already implicitly acknowledged the validity of this perspective to some extent in Part B by indicating that the low end of the range of risks predicted is zero (Tables 9-6 through 9-9). This is a reflection of the fact that the effects at such low levels of exposure are unknown. McDonald does not attempt to explain the existence of the background

incidence of mesothelioma, some (if not most) of which may be attributable to asbestos exposure. The ubiquity of large body burdens of asbestos fibers precludes ruling out asbestos exposure as an etiologic explanation of the background incidence of mesothelioma (see Part B, Section 7.a.). In addition, a comparison of DHS staff's risk estimates with recent mesothelioma incidence in the San Francisco-Oakland Bay Area indicated that ambient exposures may account for a small to a substantial percentage of mesothelioma cases in females (see Part B, Section 9.h.). Finally, McDonald's observation that the background incidence in females has remained stable at two per million may not be applicable to California, or at least not to the San Francisco Bay Area, where the rate has been approximately twice as high (see Part B, Section 9.h.).

ML:dc