THE ASBESTOS DILEMMA:
1. ASSESSMENT OF RISK

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This paper gives a critical review of current problems related to quantitative health risk assessment of exposure to asbestos, and particularly to chrysotile, the only type of asbestos still available on the market. The paper reviews types, sources, uses and the main recognized health effects of asbestos, paying particular attention to the health-related properties of fibres and the role of their biopersistence. The main focus is on yet unresolved issues which introduce a large margin of uncertainty into the published quantitative risk assessments: 1) Are all asbestos types equally dangerous or is chrysotile asbestos less dangerous than amphiboles? 2) Are health effects of asbestos fibres threshold or non-threshold effects? 3) Are errors in mathematical modeling of risks so great as to make the risk evaluations worthless? Attention is also given to errors in estimates of past exposures, uncertainties and unspecificities of models and to the unfeasibility of practical application of some well-recognized risk assessment models.

KEY WORKDS: *amphiboles, biopersistence, chrysotile, risk assessment, thresholds*

In 1989, the U.S. Environmental Protection Agency (EPA) issued the "Asbestos Ban and Phase-out Rule", which would have banned practically all uses of asbestos in the USA by 1996 (1). In 1991, however, a U.S. Court of Appeals revoked the ruling. In 1991, the Commission of the European Communities enacted a Directive prohibiting the marketing and use of all amphibole fibres and the products containing them (2). It also prohibited the use of 14 categories of chrysotile products, permitting the continuation of use of the important chrysotile products – asbestos cement and friction materials. However, in 1999, the Commission enacted a Directive prohibiting the use of all asbestos types in the EU member-states by the year 2005 (3). Thus in the two parts of the Western world developed an unusual situation of conflicting regulatory approach to the use of asbestos, as issue loaded with scientific controversies for years. The problem induces a dilemma for the responsible authorities in Croatia: Should the country follow the "ban approach" of the EU or the "controlled use" approach of the International Labour Organization (ILO) (4), the latter practically supported by the current regulatory situation in the US (official exposure limits)? If the former approach is selected, which is likely in view of the political interest of the country to join the EU, should the rule be applied by year 2005, although Croatia will not yet have become the member of EU at the time?

TYPES OF ASBESTOS, THEIR SOURCES AND USE

My recent article "Asbestos and Health" describes the types, sources and the use of asbestos in detail (5). There are two basic mineralogical groups of asbestos: serpentine and

amphibole. Chrysotile (white asbestos) is now the only commercially important member of the first group which accounts for more than 98% of the current world consumption of asbestos. The main members of the amphibole group of minerals are amosite (brown asbestos), crocidolite (blue asbestos), and tremolite which mainly occurs as an impurity of chrysotile. Only the first three asbestos types have found commercial use. In general, asbestos minerals are characterized by high tensile strength, flexibility and durability, as well as heat insulation and flame retardant properties. In addition, they do not evaporate, burn or undergo significant reactions with chemicals. Asbestos has been used in thousands of products (see Table 1 for a brief list). Currently, asbestos is used principally in high-density products in which the asbestos fibes are embedded in a cementitious or resinous matrix. Asbestos-cement products, mostly pipes (for drinking water supply, sewage disposal and irrigation), shingles and sheets, account for about 85% of the total use of asbestos.

Natural erosion and many human activities are the sources of asbestos fibres. The latter range from ore recovery and processing, manufacturing, application and usage, to disposal activities. Fibres are also released during the construction and demolition of buildings and possibly during maintenance. Asbestos was produced in 24 countries in the world. In addition, the manufacture of asbestos-containing products took place in more than 100 countries. The world production peaked at over 5 million tonnes, but has been declining since the mid-1970's. The current production is about 2 million tones (6).

TABLE 1 *Main asbestos-containing products*

Products	Uses
Asbestos-cement products	Water supply and sewage piping
	Drain pipes and guttering
	Interior wall panels
	Casings for electrical wires
	Fire protection material
	Chemical tanks
Asbestos friction products	Clutch facings
	Brake lining for road and railway vehicles
	Industrial friction materials
Asbestos paper products	Table pads and heat-protective mats
	Heat and electrical wire insulation
	Industrial filters for beverages
	Underlining material for sheet flooring
Asbestos textile	Packing components
	Heat and fire-resistant clothing
	Fire-proof curtains
Asbestos felt products	Noise insulation
Other asbestos products	Ceiling tiles
	Gaskets and packing
	Paints, coatings and sealants
	Patching tape
	Plastics

HEALTH EFFECTS

There is no consistent evidence that drinking or eating asbestos is associated with adverse health effects (7-11); only exposure to airborne asbestos fibres is a proven cause of disease. All types of asbestos, if inhaled at sufficient doses, can cause three main serious health disorders: asbestosis, lung cancer, and mesothelioma. Significant overt clinical symptoms of asbestosis are unlikely to appear until approximately 20 years after the onset of exposure. No asbestosis has been found in the general population, except in populations living in the immediate vicinity of intense and uncontrolled sources of emission. It usually takes 20-40 years between the first exposure to asbestos fibres and the onset of lung cancer. Smokers are at a considerably greater risk of developing lung cancer than nonsmokers. Mesothelioma takes between 30 and 50 years to develop. This form of cancer is unavoidably fatal. Increased mortality rates have been observed in non-occupationally exposed subjects sharing the household with asbestos workers, or living in the vicinity of uncontrolled asbestos emission sources. It remains to be seen whether the observed and projected increases of mesothelioma mortality in the general population in the U.S.A., New Zealand, and some European countries (12-19) are the effects of exposure to asbestos, and particularly to chrysotile, or not. Unlike in cancer, smoking does not contribute to the development of mesothelioma.

HEALTH-RELATED PROPERTIES OF FIBRES

Negative health effects are induced only by fibres which are inhaled, deposited and retained in the respiratory tract. Only fibres thinner than 3μm, having an aerodynamic diameter of about 10 μm, can enter the conducting airways of the respiratory tract. Longer fibres are more dangerous. Therefore, in the regulations of many countries, as well as in some international recommendations (20), asbestos fibres to be measured in occupational environmental assessment are defined as those having a diameter $\leq$ 3 μm, length $\geq$ 5 μm, and length to diameter ratio at least 3:1 ("regulated fibres"). There is evidence that the most hazardous asbestos fibres are those longer than 5-8 μm and thinner than 1.5 μm. Early experimental results of *Stanton and Layard* (21) and *Pott* (22) indicated that implanted asbestos fibres of length to diameter ratio <5:1 are not carcinogenic, that the carcinogenicity of fibres of length to diameter ratio <10:1 is mall, and that only fibres of length to diameter ratio >10:1 have significant carcinogenic properties. The conclusion is that it would be justifiable to measure fibres of length to diameter ratio >10:1 in the environmental health assessment (23,24).

Biopersistence is also considered an important health-related property of asbestos fibres. It depends on the relative insolubility of the fibre, that is, on its retention in the respiratory tract. It is generally believed that the greater the biopersistence, the higher the probability of fibrogenic or carcinogenic effect (5,25), although there are opinions that long retention of fibres in the respiratory tract is not the prerequisite for the formation of neoplasms (26).

UNRESOLVED ISSUES

In spite of years of studies of the effects of asbestos fibres and hundred of scientific and other papers published, there remains a number of unresolved issues and unanswered questions.

Are all asbestos types equally dangerous?

Scientists and regulators are divided on this issue in two apparently irreconcilable groups. Some believe that the risk of exposure to amphiboles, particularly to crocidolite, is considerably higher than the risk of exposure to chrysotile. A minority disagree. In 1977, a group of experts of the Commission of the European Communities (CEC) concluded that there was general agreement that the risk of mesothelioma was fibre-related and decreased from crocidolite to amosite to chrysotile (27). The summary of a consultation of the World Health Organization (WHO) on occupational exposure limits for asbestos (28) says the following:

> *The human evidence suggests a lower risk of lung cancer from exposure to chrysotile than to crocidolite or amosite […] Pleural mesothelioma has been produced by all types of asbestos fibre, but in general, the human evidence suggests a much lower risk from exposure to chrysotile than to crocidolite or amosite. Peritoneal mesothelioma can be produced by crocidolite and amosite, but has probably not been produced by chrysotile.*

A Working Group of the International Programme on Chemical Safety (IPCS) on the Reduction of Asbestos in the Environment (29) recommended as follows: " In any given situation, priority should be given to the control of air pollution by amphibole asbestos fibres (crocidolite, amosite, tremolite)". The 1996 CEC's evaluation says:

> *Recent studies have shown that amphibole-type fibres are more harmful than chrysotile …. In general, epidemiologically, the risk levels seem to be, in descending order, crocidolite and amosite (two amphibole types of asbestos), followed by chrysotile and anthophyllite (another amphibole)* (30).

The latest evaluation of IPCS/WHO in 1998 (31) agreed with the previous evaluation of 1986 (7) that "the risk of mesothelioma in persons exposed to chrysotile is lower than the risk in persons exposed to crocidolite or amosite".

There are scientists and regulators who do not agree with the significant difference in the potency between fibres of different asbestos types. This is reflected in different approaches of the two groups in setting exposure limits. It is obvious that exposure limits for amphiboles must be lower than for chrysotile if the risks of exposure to the former are higher. Table 2 reflects the differences in the approach of authorities in a number of member states of EU (30); while the exposure limits are higher for chrysotile than for other types of asbestos in Belgium, France, Greece, Italy, Netherlands, Spain, United Kingdom and EU, there is no difference in Austria, Denmark, Finland or Germany. The prestigious American Conference of Governmental Industrial Hygienists (ACGIH) also differently evaluated chrysotile and amphibole asbestos (32). However, the US Occupational Safety and Health Administration (OSHA) (33) does not accept this approach – just like EPA which attempted to prohibit all the asbestos types (1). Under the influence of these US governmental agencies, the ACGIH, in its latest list of threshold limit values (34), adopted the OSHA limit of 0.1 f/ml for all asbestos fibres. It is surprising, however,

that they included chrysotile among substances for which information is being solicited, which suggests doubts about the TLV of this substance. Table 2 shows that Croatia has enacted different exposure limits for different asbestos types (35), but the fibres are not physically specified.

TABLE 2 *Occupational exposure limits (f/ml) for chrysotile and amphiboles*

Source	Chrysotile	Amosite	Crocidolite
WHO (1989)	1	<1	<1
ACGIH (1995/1996)	2	0.5	0.2
EPA (1989)	ban	ban	ban
OSHA 1994	0.1	0.1	0.1
Croatia (1992/1993)*	2	1	0.5

	Chrysotile	Other asbestos types
	(Commission of the European Communities, 1996)	
Austria	0.15	0.15
Denmark	0.3	0.3
Finland	0.3	0.3
Germany	0.15	0.15
Belgium	0.5	0.15
France	0.3	0.1
Greece	1.0	0.5
Italy	0.6	0.2
Netherlands	0.3	0.1
Spain	0.6	0.3
United Kingdom	0.5	0.2
EU	0.6	0.3

(*) Exposure limits expressed as counts of fibres of undefined dimensions

Table 3 shows the EPA's inconsistency in the approach to carcinogenic potency of different asbestos fibres. It shows modified values of the coefficient K_L, taken from an EPA publication (36), indicating considerable differences in the potency of different asbestos fibres. The coefficient K_L reflects the carcinogenic potential of the exposure to carcinogens; it is the estimated increase in lung cancer risk due to one-year exposure to the unit concentration of 1f/ml. The values presented in Table 3 clearly show that the carcinogenic risk is by far the lowest in the exposure to chrysotile only, with the exception of chrysotile in textile production. Exposure to amosite fibres alone involves a much greater risk, as is the case with the combined exposure to amphiboles and chrysotile. The high K_L value in pure chrysotile textile production is attributed to a significantly higher content of more carcinogenic long chrysotile fibres in textile production (37-40).

Rich evidence of the significant difference in the potencies between fibres of chrysotile and amphiboles gave grounds for introducing "the chrysotile hypothesis" and "the amphibole

hypothesis". The first says that the human risk becomes acceptable at a sufficiently low exposure level to chrysotile, and the second that the carcinogenic risk at low concentrations of chrysotile is present only if amphiboles are also present. These hypotheses are not generally accepted; they have particularly been rejected by the US regulatory agencies (1,33) and by the Ramazzini Society (12,41). The controversy about whether there is a difference in the carcinogenic potency between chrysotile and amphibole fibres is continued in more recent papers by most reputable authors in the field. While *Berry* (42), *Landrigan and co-workers* (43), and *Dement* (44) believe that chrysotile is less potent than amphiboles in its ability to cause mesothelioma, and *Hodgson* and *Darnton* (45) conclude that specific risks of mesothelioma from chrysotile, amosite and crocidolite are in the ratio 1:100:500, respectively, *Landrigan and co-workers* and *Dement* consider that the lung cancer risk from chrysotile is at least as high as that from amphiboles, and *Smith and Wright* (46) regard chrysotile as the main cause of pleural mesothelioma in humans. While *McDonald and McDonald* (50) and *McDonald* (53) state that the carcinogenic risk at present day levels of exposure to commercial chrysotile is vanishingly small and that the remaining risk is due to contamination of chrysotile by the amphibole tremolite, *Dement* (44) maintains that chrysotile should not be controlled differently than other asbestos types.

TABLE 3 *Weighted values of unit exposure risk K_L (36)*

Asbestos process or use	Types of fibre	$K_L \times 10^4$
Textile production	Predominantly Chrysotile	200
Friction products manufacturing	Chrysotile	2.3
Mining and milling	Chrysotile	9.8
Amosite insulation production	Amosite	430
All processes	Amosite Chrysotile Crocidolite	65
All processes except mining and milling	Amosite Chrysotile Crocidolite	100

In the cohort of some 11,000 Quebec miners and millers (47,53), 25 cases of mesothelioma were identified from miners in the Thetford Mines region and 8 from the large mine at Asbestos. The proportion of tremolite in the chrysotile was 3 times higher in the former than in the latter region. The analysis of deaths from mesothelioma in men employed in the Thetford Mines, with matched references, showed that odds ratios for work in the central mines,

where the tremolite content was 3 times higher, were significantly elevated for mesothelioma and lung cancer. By contrast, in the peripheral mines, where the tremolite content was 3 times lower, there was little or no evidence of increased risk. The authors conclude that these long-term studies – including data from as early as 1970's – show that chrysotile rarely caused mesothelioma and was not a major cause of lung cancer, except at very high levels of exposure. They attribute the remaining risk to tremolite, because its biopersitence is much higher than that of chrysotile. However, the Mount Sinai group (54) in their analysis of the lung and mesothelial tissues taken from 151 human malignant mesothelioma cases, found asbestos fibres in almost all the lung tissues as well as in the mesothelial tissue, the most common asbestos types being an admixture of chrysotile and amphiboles, followed by amphiboles alone and chrysotile alone. The most common of asbestos types in the mesothelial tissues were chrysotile alone, followed by chrysotile plus amphibole, and amphibole alone. They conclude that chrysotile can induce human malignant mesothelioma without the presence of amphiboles, since, in some of the mesothelioma cases, the fibres detected in the lung or mesothelial tissues were exclusively chrysotile fibres.

The controversy continues.

Are health effects of asbestos fibres threshold or non-threshold effects?

All asbestos-related diseases are dose-related: the higher the concentration and duration of exposure, the higher the prevalence of the disease and mortality. However, the form of the dose-response curve at low doses, typical for the exposure of general population, is not known. There are contradictory opinions as to whether the dose-response relationship in the region of low doses is linear or not. It is practically impossible to measure the effects at such low doses either epidemiologically or experimentally. It is for this reason that mathematical extrapolations ("low-dose extrapolations"), which carry errors of several orders of magnitude, are used in the quantitative risk assessments. I criticized these extrapolations in 1988 (55) and again in 1991 (56) and in 1993 (57). Recently, in 2001, *Berman* (58), reported that "the published dose-response coefficients for asbestos vary by more than a factor of 500 for lung cancer and more than a factor of 1,000 for mesothelioma". Extrapolation of the most frequently used linear relationship into the origin of coordinates means that there is no exposure threshold, i.e. that even the lowest exposure to asbestos may carry some risk of disease and death. Others, however, believe that there is an asbestos fibre exposure threshold for chrysotile below which there will be no pathologic effects (particularly asbestosis or lung carcinoma) or that the effects are so rare that they cannot be epidemiologically detected. As negative effects cannot be proven in practical risk assessment, the issue remains unresolved. An expert group of the CEC concluded the following in 1977 (27):

> *It is impossible to come to reliable quantitative assessment of the risk of malignancies for the general public. It is possible that there is a level of exposure (perhaps already achieved in the general public) where the risk is negligibly small.*

The evaluation of IPCS/WHO in 1986 (7) was:

*In the general population the risks of mesothelioma and lung cancer
attributable to asbestos cannot be quantified reliably and are probably
undetectably low. Cigarette smoking is the major etiological factor in the
production of lung cancer in the general population. The risk of asbestosis is
virtually zero.*

However, the latest IPCS /WHO evaluation in 1998 (31) stated that no threshold had been
identified for carcinogenic risks from chrysotile asbestos. There is an almost general consensus
that no threshold exists for amphiboles. There is still a controversy as to whether there is a
threshold, or at least a practical threshold, for chrysotile. Studies are limited to only two
industrial cohorts with relatively pure exposure to chrysotile fibres containing sufficient high
quality data for exposure-response analysis. These studies include the Quebec miners and
millers (47-53, 59) and South Carolina textile workers (37-40). Table 4 shows standard
mortality from lung cancer in Quebec miners and millers (48), 1976-1988, in relation to exposure
accumulated up to the age of 55 years, and the lung cancer mortality by cumulative exposure in
South Carolina workers (39) employed between 1940 and 1990. There is no indication of a trend
in standard mortality over 7 lowest categories of exposure of miners and millers (<10 -<990 f/ml
yrs). The standard mortality was elevated at the three highest levels, i.e. at the cumulative
exposure of more than 990 f/ml yrs. A completely different result was obtained in South
Carolina textile workers. There was a consistent increase in the risk of lung cancer with
increasing cumulative exposure in all the exposure categories of cumulative exposure more than
2.7 f/ml yrs. The proportional mortality from mesothelioma in the Quebec cohort was only
0.45% (33 deaths among 7,312 workers) by end of 1988. Comparing the very high slope of
0.021 per f/ml yr in textile workers with the very low slope of 0.0005 per f/ml yr in Quebec
miners and millers, the authors of the last exposure response analysis (40) attribute this large
difference to the considerably higher proportion of carcinogenic long fibres in the textile
production. It was on the basis of the results obtained in Quebec workers that the authors (48,
50, 53) concluded that chrysotile was not the cause of lung cancer, except at very high levels of
exposure above 25-30 f/ml, well above current exposure even under poor conditions. Can the
finding that there was no trend in standard mortality over 7 lowest exposure categories of miners
and millers be taken as the basis for the conclusion that there is a practical threshold for
chrysotile (49)?

The situation with mesothelioma is somewhat different. The standard mortality rates in
several countries show an increasing trend. The results of some evaluations caused panic.
British (14, 19), French (17), New Zealand (15), and the US (12,18) data projected thousands of
deaths per year of mesothelioma in the decades to come. As a considerable proportion of
diagnosed mesothelioma was believed to be the consequence of exposure to asbestos fibres, there
is a tendency to attribute all these deaths to the effects of these fibres without an objective proof
and without differentiating the type of fibres. It is worth noting that the description of
mesothelioma in literature preceded the exploitation of asbestos (59) and that other causes of
mesothelioma have also been described (60). The role of Simian virus SV40 in the development

of human mesothelioma has recently received more attention. Some authors (60) assume that SV40 may contribute to the development of human mesotheliomas that occur in people not exposed to asbestos.

However, they state that the available epidemiological data are insufficient to explain the role that SV40 may have played in contributing to the increased incidence of mesothelioma currently recorded. Other authors (18,61,62) propose that asbestos and SV40 may be cocarcinogens.

The latency period for the development of mesothelioma is between 30 and 50 years, so that the current mesothelioma deaths are predominantly the consequence of exposure to mixtures of chrysotile and amphiboles in the far past when the exposure levels were incomparably higher than those of today. It is impossible to evaluate whether the current (considerably lower) exposures to pure chrysotile would bring about similar consequences.

TABLE 4 *Lung cancer mortality in relation to cumulative exposure (39,48)*

MINERS			TEXTILE WORKERS		
Exposure (f/ml x yrs)	Deaths O/E	Standard mortality	Exposure (f/ml x yrs)	Deaths O/E	Standard mortality
<10	36/31.4	1.14	<1.4	7/7.6	0.92
10 < 33	28/25.3	1.11	1.4 – 2.7	4/5.5	0.73
33 < 99	33/31.3	1.05			
99 < 198	39/24.4	1.60	2.7 – 6.9	15/6.2	2.4
198 < 330	26/22.8	1.14	6.9 – 27.0	10/5.1	1.96
330 < 660	32/28.3	1.13	27 – 110	16/5.2	3.08
660 < 990	20/7.3	1.15	110 – 274	18/2.2	8.18
			>274	2/0.2	10.00
990 < 1320	16/10.7	1.50			
1320 < 3300	42/25.4	1.65			
>3300	22/7.2	3.04			

O – Observed; E – Expected

UNCERTAINTIES IN RISK ASSESSMENT

Errors in estimates of past asbestos exposure

The current mortality from asbestos-related cancer is the consequence of exposures of 20-50 years ago, or even longer. There is no doubt that the exposure levels in the distant past were considerably higher than those of today. As an example, Table 5 shows the concentrations measured in mines and towns of Canada in the period 1973 to 1995 (63).

TABLE 5 *Concentrations in mines and towns of Canada: 1973 – 1995 (63)*

Year	Mean value	Mines Highest value	Lowest value	Towns Mean value
1973	15.9	52.2	4.3	0.08
1974	11.4	24.7	3.3	0.08
1975	8.7	16.7	2.7	-
1977	2.6	5.4	1.5	0.04
1979	1.1	2.0	0.7	0.05
1981	1.0	1.5	0.6	0.02
1983	0.8	1.0	0.5	<0.01
1985	0.7	1.4	0.3	<0.01
1987	0.5	0.9	0.1	<0.01
1989	0.7	0.9	0.5	<0.01
1991	0.6	0.7	0.3	<0.01
1993	0.4	0.5	0.3	<0.01
1995	(0.4)	(0.5)	(0.2)	<0.01

Results in Parentheses – personal communication

In the distant past, the techniques of exposure measurement did not specify asbestos fibres, but referred to either gravimetric concentration to particles in the air, expressed in grams or mg per m³ or, later, to count concentrations of particles (not fibres) expressed in million particles per cubic foot of air (mppcf). Thus, the early method measured all particles, of which fibres constituted only a minor fraction. As exposure levels in the past must be taken into account in the quantitative risk assessment, various authors estimates assumed specific concentrations of airborne asbestos fibres converting the measured gravimetric or count concentrations of total particles to the currently defined fibres using a number of mathematical conversions. These conversions relied on many dubious assumptions and approximations, and included errors of several orders of magnitude into the mathematical estimates of historical airborne fibre concentrations. This is one of the main reasons why I cautioned – quite early – that the quantitative risk assessment equations and particularly low dose extrapolations used for predicting mortality or morbidity in populations exposed to considerably lower exposure levels were very uncertain (56,57). Table 6 shows some errors in the conversion of such concentrations. The first part of the table shows the relationships between asbestos fibre diameter and length and the concentration expressed in fibres per ml for the gravimetric concentration of 10 ng/ml air [based on calculations by *Pott* (22)]. The table shows that the same air with weight concentration of 10 ng/ml may contain 32 f/ml if the fibre diameter is 2.0 µm and the length 40 µm, while it may contain 8,200,000 f/ml of fibres with the diameter of 0.03 µm and the length 0.63 µm. The errors involved in the conversion of weight concentrations of total particles of unknown size distribution into the count concentrations of fibres of a defined size fraction are so great that the obtained results may be complete nonsense.

Table 6 also shows an example of EPA's conversion in 1986 (36). EPA took 30 (the geometric mean of conversion factors ranging 0.5-150 obtained in six studies) as the conversion factor to be used, introducing a possible error of more than 200 in the conversion. *Robock* reported in 1984

(64) that the conversion factor for converting mppcf into f/ml obtained in a large number of samples was between 0.5 and 47.8, which introduces a hundredfold error into conversions.

TABLE 6 *Variations in concentration conversions*
No. of asbestos fibres in ml of air corresponding to weight concentration of 10 ng/ml (22)

Diameter (µm)	Length (µm)	f/ml
2.0	40	32
1.0	10	500
0.25	5	16,000
0.03	0.63	8,200,000

Conversion of weight concentration to no. of fibres per unit volume (36)
ug/m^3 – f/ml   0.5 – 150 (from 6 studies)
                                      30 (geometric mean)

Conversion of particles per unit volume into no. of fibres per unit volume (64)
mppcf - f/ml   0.5 – 47.4

Uncertainties and unspecifities of models

Table 7 shows the estimation of lifetime risk due to lethality from mesothelioma (L: excess deaths per million population) induced by the asbestos concentration of 0.0004 f/ml for an age of 73 years, calculated by the well known equation of the National Research Council of the US National Academy of Sciences (NRC/NAS) L=C (conc.) (age) ^{K} (65). Using the values of the coefficients C (0.85 – 7.22 x 10 ^{8}) and K (2.6-5.0), obtained in epidemiological investigations, the number of calculated excess deaths ranges from 0.2-60,000 per million population, yielding a ratio of up to 300,000 in estimated mortality per million population and rendering the risk assessment meaningless (56).

TABLE 7 *Lifetime risk estimates of mesothelioma death in seven studies (65) based on equation: L = c (0.0004) (73)^k*

c	k	2.6	3.0	3.2	3.5	3.8	4.0	5.0
0.85 x 10 $^{-8}$		0.2	1.3	3.0	11	41	97	7000
2.53 x 10 $^{-8}$		0.7	4	9	34	120	290	21000
7.22 x 10 $^{-8}$		2	11	26	96	350	820	60000

In 1991, I criticized (56) those EPA's uncertainties in risk assessments which led to their proposal of the asbestos ban. Table 8 shows the number of cancer cases expected by EPA to be avoided in 13 years following the proposed asbestos ban, as set forth by three consecutive EPA proposals. The very fact that the number of cancers varied from 1,000 in 1986 (36) to 315.8 in 1988 (66), ending with 148-202 in the Final Rule of 1989 (1), sheds strong doubt on EPA's risk estimates.

TABLE 8 *Cancer cases predicted by EPA to be avoided by the ban of asbestos in the future period of 13 – 15 years (56)*

Product	1986 (36)	1988 (66)	1989 (1)
Vinyl asbestos floor tiles	468	0.0	-
Friction products	386	282.0	99.39 – 143.7
Asbestos-cement pipes	82	6.0	2.10 – 4.38
Asbestos-cement plates	31	0.9	0.70 – 1.51
Gaskets	-	14.0	6.68 – 42.54
Others	33	12.9	39.13 – 9.87
TOTAL	1,000	315.8	148 - 202

I wish to single out the problem of asbestos-induced cancers due to exposure to friction materials. In the Final Rule of 1989 (1), EPA attributes up to 144 projected cases of cancer to exposure to friction materials. These risks account for the majority of all risks in the Final Rule. These risk assessments were obtained using exposure-response relationships for cancer in different industries and in populations exposed to different asbestos materials of which the friction materials in only one. In their study of more than 13,500 workers manufacturing friction materials in the period 1942-1980, *Berry and Newhouse* (67) found little excess cancer and the only excess mortality comprised 10 deaths from pleural mesothelioma, out of which 8 at least partly due to exposure to crocidolite. The slope for increased lung cancer risk was only 0.00058 fibres /ml years. *McDonald and co-workers* (68) found practically no lung cancer risk and no mesothelioma in the group of long-term workers and in higher exposure categories in their study of more than 3,500 men employed in the manufacturing of friction products in the period 1938 – 1958. The slope for increased lung cancer risk was practically zero. The authors interpreted the results as "doubtful whether there was any significant lung cancer excess". I strongly disagreed (57) with the approach to the estimation of the projected number of cancers using the mean of slopes derived in all studies, of which only two (by far the lowest) were obtained in the friction products exposures. The population with expected exposure of asbestos fibres are garage mechanics, because of their work on the maintenance and repair of automobile asbestos-containing brakes and clutches. In a large case-control survey of all cases of mesothelioma diagnosed by pathologists in the USA and Canada during a defined period, *McDonald* (69) observed a substantial excess risk of mesothelioma in many occupations with exposure to asbestos, and particularly to amphiboles, but no excess was observed in the category of garage mechanics.

In 1988 (70), I analyzed all the available literature regarding asbestos risk in vehicle manufacture, maintenance and repair, and concluded that, provided good work practices are followed and no amphiboles are used, detectable risks in vehicle maintenance and repair are not to be expected. As in 1991 (56) and 1993 (57), I still disagree with the EPA's approach to the estimation of the projected number of cancers due to exposure to friction materials by using a mean slope of 11 studies (1,36), of which only two (having by far the lowest slopes) were obtained in the friction products exposure. It is hardly justifiable to estimate risks due to exposure to one type of fibre population by using the slopes obtained in exposure to completely different fibre populations, while being fully aware of the large variations among the slopes. This approach has resulted in an ungrounded overestimation of the projected number of cancers in exposure to friction materials.

Unfeasibility of practical application of risk assessments

As early as in 1988 and later in 1993, I pointed to the implications and practical unacceptability of the results of some well-known published asbestos risk estimates (55,57). Table 9 shows my calculations of exposure limits for asbestos in the atmosphere derived from some of these risk assessments.

A 1986 WHO Expert Meeting proposed the lifetime risk estimate for smokers (mesothelioma: 12×10^{5}, lung cancer: 16×10^{5} as upper limits of the number of expected deaths per 100,000 population) at an assumed airborne asbestos fibre concentration of 500 f/m^3 (71). Assuming that the acceptable risk, used for carcinogens in the WHO Water Quality Guidelines (72), is 1×10^{5}, the calculated exposure limit is 18 fibres per cubic meter of air. Taking the risk estimate of 13.5×10^{5} for nonsmokers and using the same acceptable risk (1×10^{5}), the obtained exposure limit is 37 fibres per cubic meter. Confronted with prevalent concentrations found in the air of rural areas with no specific asbestos sources (up to 100 f/m^3) (7), these exposure limits seem to suggest that in areas without any specific source of asbestos emission, a nearly 6-fold reduction of current asbestos levels would be required, which is practically impossible to achieve.

Table 9 also illustrates that an exposure limit of 45 asbestos fibres per cubic meter can be derived from the asbestos risk estimate published in the WHO Air Quality Guidelines of 1987 (11×10^{5} for a population with the hypothetical proportion of 30% smokers) (73). This value is lower or as low as the concentrations found in rural areas without specific asbestos emission. The table also shows prevalent asbestos fibre concentrations in urban areas (from fewer than 100 to 10,000 per cubic meter) (7).

TABLE 9 *Estimated lifetime risks from exposure to asbestos at 500 f/m^3 and calculated threshold limit values at the assumed acceptable risk of 1×10^{-5} (57)*

Expert meeting (71) (upper limit)	Risk (smokers): 12×10^{5} (mesothelioma) $+ 16 \times 10^{-5}$ (lung cancer) $= 28 \times 10^{-5}$ TLV on the basis of acceptable risk 1×10^{-5} : $500/28 - 18$ f/m^3 Risk (non-smokers) 12×10^{-5} (mesothelioma) $+ 1.5 \times 10^{-5}$ (lung cancer) $= 13.5 \times 10^{-5}$ TLV on the basis of acceptable risk 1×10^{-5} : $500/13.5 \sim 37$ f/m^3
Air Quality Guidelines (73)	Risk (30% smokers): 1×10^{-4} (mesothelioma) $+ 1 \times 10^{-5}$ (lung cancer) $= 11 \times 10^{-5}$ TLV on the basis of acceptable risk 1×10^{-5} : $500/11 \sim 37$ f/m^3

Prevalent asbestos concentrations: rural areas < 100f/m^3, urban areas <100-10000 f/m^3, indoor 400-500 f/m^3

Table 10 shows the same calculations on the basis of the risk assessment by the NRC/NAS (65). Applying the same level of acceptable risk (1×10^{-5}) and using the number of estimated deaths from mesothelioma and lung cancer for male smokers and nonsmokers at the

assumed asbestos concentration of 400 fibres per cubic meter, the respective calculated exposure limits are 9 and 22 fibres per cubic meter. In other words, these limits require a nearly 10-fold reduction of asbestos fibre levels in rural areas without specific asbestos emission!

It is obvious that mathematical extrapolations of asbestos risk lead to unfeasible threshold limit values.

TABLE 10 *Estimated lifetime risks(*) from exposure to asbestos at 400 f/m^3 and calculated threshold limit values at the assumed acceptable risk of 1 x 10^{-5} (57)*

Mesothelioma	15.6 x 10^{-5}
Lung cancer – male smoker	29.2 x 10^{-5}
Lung cancer – male non-smoker	2.7 x 10^{-5}
lung cancer – female smoker	10.5 x 10^{-5}
lung cancer – female nonsmoker	1.4 x 10^{-5}

Risk – male smokers: 15.6 x 10^{-5} + 29.2 x 10^{-5} = 44.8 x 10^{-5}
TLV on the basis of acceptable risk 1 x 10^{-5}: 400/44.8 ~ 9 f/m$_3$

Risk – male non-smokers: 15.6 x 10^{-5} + 2.7 x 10^{-5} = 18.3 x 10^{-5}
TLV on the basis of acceptable risk 1 x 10^{-5}: 400/18.3 ~ 22 f/m^3

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(*) National Research Council of the U.S. Academy of Science, 1984 (65)

CONCLUSIONS

There is no doubt that fibres of all the prevalent forms of asbestos can cause lung cancer and mesothelioma. The weight of evidence convincingly suggests that amphiboles are more potent carcinogens than chrysotile. No threshold has been identified for any of the types of asbestos except possibly for chrysotile; a practical threshold was found in chrysotile mining operations, in the manufacturing of chrysotile friction products and in some cohorts of workers in asbestos-cement production. The unit risks, estimated in studies acceptable as regards the number of examinees, the duration of follow-up and the quality of data vary by several orders of magnitude. To a large extent, this is the consequence of considerable uncertainty in the estimates of past exposure levels due to errors in conversion from weight (μg/m^3) or count (mppcf) concentrations of total particles to the currently used count concentrations of defined fibres. The practical application of unit risks of such uncertainty leads to unachievable exposure limits. In spite of hundreds of papers published on asbestos health effects, there are still important unresolved issues. The effects seen today are the consequence of uncertain exposure of 20-50 years ago. It cannot be predicted with any degree of certainty what will the consequences of the current, incomparably lower exposure levels be in the future. Yet, there is no doubt that it is advisable to replace any potential carcinogen with noncarcinogenic or less carcinogenic material whenever possible. At this point in time, however, there are few materials of known toxicity / carcinogenic and at least equal technological performance. There is a potential for the development of such materials, but their toxicological properties have not been

evaluated sufficiently. This is the main problem the world is facing on the eve of the possible worldwide asbestos ban, which will be considered in the second part of this paper: "The Asbestos Dilemma: II. The Ban".

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