PART II: RECENT APPROACHES TO THE CONTROL OF CARCINOGENIC EXPOSURES

CASE STUDY 1: ASBESTOS—THE TLV APPROACH

William J. Nicholson

Environmental Sciences Laboratory
Department of Community Medicine
Mount Sinai School of Medicine of the
City University of New York
New York, New York 10029

PLAINTIFF'S EXHIBIT

SA-586

Threshold Limit Values (TLV) have had extensive use in limiting exposure of workers to toxic substances. They have evolved from crude standards designed primarily to prevent fatalities, to sophisticated levels based upon detailed toxicological and metabolic considerations. In general, however, their use has been in limiting exposures that would produce short-term acute effects such as irritation, narcosis, or alteration of body functions. In such circumstances, it is not difficult to determine a level below which the effect in question is rarely seen in exposed individuals, and application of a TLV is usually sufficient to assure safety. The extension of this concept, however, to the control of carcinogenic substances raises serious questions, some of which can be considered by reviewing the use of a TLV for the control of exposures to asbestos.

HISTORICAL PERSPECTIVES

Asbestos is an especially appropriate choice for the example illustrating the control of carcinogenic substances by the TLV approach. It was one of the first materials for which a TLV was suggested. It was on the first list of Maximum Allowable Concentrations (MAC Values) published by the American Conference of Governmental Industrial Hygienists (ACGIH). Finally, it was the substance for which the first emergency standard and the first permanent standard were adopted by the Department of Labor under provisions of the 1970 Occupational Safety and Health Act. It is also possibly the least suitable substance for control using a TLV and can therefore well illustrate the limitations of this approach to the control of carcinogenic substances.

The earliest recommendation of a TLV for asbestos was made in 1938 by Dreessen et al. of the U.S. Public Health Service.[1] Following a survey of 541 employees of four North Carolina textile mills, they proposed a tentative standard of 5 million particles/cubic foot (mppcf) for the prevention of asbestosis. This was the only disease of concern, since no substantial data then existed linking asbestos exposure with any cancer. Unfortunately, in this study, only 13% of the work force surveyed had had more than ten years of asbestos exposure, and a scant three employees were known to have worked with asbestos for more than 20 years. Moreover, 150 of the workers in these mills were discharged prior to the Public Health Service survey because of the possibility that they might be suffering from asbestos disease. Because of the dearth of individuals with long-term exposure, this standard was clearly specified by Dreessen et al. as tentative. Nevertheless, they expressed the opinion, "It appears from these data that if asbestos dust concentrations in the air are kept below this limit, new cases of asbestosis would not appear."

Just as Dreessen et al. appreciated the need for observation of long-term employees in the evaluation of disease, they also recognized limitations of the sampling instruments in the assessment of exposure. The instrument of choice in defining asbestos air concentrations was the impinger, in which all particles having dimensions greater than 1 micron were counted, including many nonasbestos particles. Estimates were made of the number of asbestos and cotton fibers in the samples. The percentage of fibers ranged from 26% in weaving, to 7% in carding, 5% in twisting, and to as low as 1% in crushing operations. The variability in the ratio of the number of asbestos fibers to total particle count limited the utility of the proposed standard in controlling exposures in textile operations. Its extension to other operations, some of which could have significantly different ratios of fibers to particles, had even greater limitations.

Despite these serious constraints, particularly the fact that it was based on the experience of individuals with only short-term exposure, the 5-mppcf standard survived as the only guide in the United States for more than 30 years, being adopted into the ACGIH list of MAC Values in 1946 and, in 1948 and thereafter, into the ACGIH listing of TLVs. These TLVs, in turn, became legally enforceable standards in 1968 for those industries to which the Walsh-Healy Act applied. This included all manufacturers who sold more than $10,000 worth of material to the government. Additionally, it was published as a hygiene standard for Great Britain by the Ministry of Labour in 1960.

Earlier attempts to limit disease from asbestos exposure emphasized application of existing ventilation technology without reference to numerical dust concentrations. This was necessitated by the absence of accepted procedures for evaluating asbestos air concentrations. The earliest such attempt was mentioned by Dr. H. Montague Murray at a compensation regulations hearing in 1906.[2] He described the severe pulmonary fibrosis found at autopsy, in 1900, in the last survivor of a group of ten workmen employed fourteen years previously in an asbestos textile carding room. At the hearing, Dr. Murray offered the optimistic prognosis, "One hears, generally speaking, that considerable trouble is now taken to prevent the inhalation of dust, and so the disease is not so likely to occur as heretofore." Subsequently, however, various cases of pulmonary fibrosis following inhalation of asbestos were published in the medical literature, including one by Cooke,[3] who gave the disease its current name, *asbestosis*. A 1928–1929 study by the British Factory Inspectorate of asbestos textile operations revealed the extent of the continuing problem.[4] In a clinical survey of mill employees, 80% of those employed for 20 or more years had x-ray evidence of asbestos disease. This finding stimulated the Factory Inspectorate to require the introduction of extensive environmental control technology in the industry and to establish an ongoing medical surveillance program. Again an optimistic prognosis was issued, in 1930: "The outlook . . . is good. . . . In the space of a decade, or thereabouts, the effect of energetic application of preventive measures should be apparent in a great reduction in the incidence of fibrosis."

In time, however, the spectrum of disease from asbestos exposure expanded. In 1947, lung cancer was found in 13% of individuals who died with asbestosis in Great Britain,[5] and fully documented as causally related to asbestos exposure in 1955.[6] Mesothelioma, a rare tumor of the lining of the abdomen or chest, was described in an asbestos worker in 1954[7] and unequivocally associated with asbestos exposure in 1960.[8] Gastrointestinal cancer was also found to be in excess among asbestos-insulation workers in the United States.[9] Despite these

revelations, no consideration was taken by standard-setting organizations of the carcinogenic properties of asbestos.

The first modern approach to the setting of an asbestos TLV, in terms of fiber concentrations, was proposed by the British Occupational Hygiene Society (BOHS) in 1968.[10] A subcommittee of the Society reviewed clinical and x-ray data on 290 men at work in an asbestos factory in 1966 supplied by its medical director. All of the men had been first employed after January, 1933, following implementation of dust-control measures mandated by the Factory Inspectorate in 1931. Estimates were also provided by the company of the fiber exposure of these workmen. Of the 290 individuals, eight were stated to have x-ray evidence of asbestos disease and 16 had rales (dry crackling sounds within the lungs). Subsequent data [11] from the same factory suggest that a greater prevalence of x-ray abnormalities may now exist in workers exposed since 1933. This would be expected, considering the progressive nature of asbestos disease. Noteworthy in the 1966 data was the preponderance of individuals who were less than 20 years from their first exposure. Only 118 of 290 had worked for longer than 20 years and a scant 13 were employed for 30 or more years.

After a review of these data, the BOHS proposed a standard that was adopted with minor modifications by the British government in 1969, and implemented in May 1970. Counting all fibers between 5 and 100 μ in length, the standard required no action to be taken below 2 f/cm^3. Between 2 f/cm^3 and 12 f/cm^3, control measures commensurate with the exposure circumstances (time and frequency of worker exposure) were prescribed. Above 12 f/cm^3, full application of control measures, including respiratory protection, was mandatory. In their report, the BOHS offered the prediction that the risk of being affected to the extent of having the earliest clinical signs of asbestos exposure (rales) would be less than one percent for an accumulated exposure of 100 fiber-years/cm^3 (2 f/cm^3 for 50 years, 4 f/cm^3 for 25, etc.). It remains to be seen whether this optimistic view is correct or whether it will be as much in error as those of past decades.

The BOHS recommended standard was based on data related to *asbestosis*, and the Society clearly cautioned that since a quantitative relationship between asbestos exposure and cancer risk was not known, it was not possible at that time to specify an air concentration known to be free of that risk in this respect.

In the United States, a Federal standard of 12 fibers/milliliter (f/ml) greater than 5 μ in length, or 2 mppcf, was promulgated on May 20, 1969, under the provisions of the Walsh-Healy Public Contracts Act. After the Occupational Safety and Health Act became effective, this Federal value was proposed by the Secretary of Labor as an interim standard on May 29, 1971. This TLV was short-lived for on Dec. 7, 1971 a temporary emergency standard of 5 f/ml was promulgated. The final standard adopted by the Occupational Safety and Health Administration (OSHA) on June 7, 1972, largely derived from the BOHS recommendation,[12] was an eight-hour time-weighted average exposure of 5 f/ml greater than 5 μ in length, with a ceiling value of 10 f/ml, which is mandated to go to 2 f/ml for the time-weighted average exposure with a ceiling of 10 f/ml on July 1, 1976. If the limits were exceeded, the employer was required to undertake a compliance program immediately. This included provisions for controlling exposures: that asbestos mortars, cements, grouts, and plaster be mixed in closed bags or other containers; that asbestos scrap and waste be collected and disposed of in sealed bags or other containers; and that all cleanup of settled asbestos dust be done by vacuum cleaners. Other provisions required local exhaust ventilation of power tools, portable exhausts for confined spaces, protective clothing, and acceptable respirators. *None of these provisions was mandatory unless the asbestos air concentration standards either were or might be exceeded.**

Thresholds for Carcinogens

In spite of considerable research on the effects of carcinogenic substances, no data exist that would define a threshold for any carcinogen. The conceptual and experimental difficulties encountered in determining whether such thresholds can exist for carcinogens have been discussed by several authors. Shabad [13] takes a strong position against the concept of a threshold for carcinogens, but Stokinger,[14] citing the possibility of adaptive mechanisms, suggests that such a level may exist in some circumstances. Various nonthreshold mathematical models of risk and the difficulties of their utilization have been reviewed by Schneiderman et al.[15]

The task confronting one who would define a level below which no carcinogenic risk exists for human populations is virtually an impossible one. This is especially true for asbestos. Serious human disease can readily be seen in studies of occupational groups exposed at high concentrations,[16] although the levels of exposure may be only crudely defined. At lower exposures, however, three unfulfilled requirements confront the investigator attempting to establish a "no effect level" for asbestos:

1) a sufficiently large population for observation;
2) knowledge of the asbestos concentrations to which the population was exposed; and
3) an observation time sufficient for the effects of asbestos to be manifest.

An example of the effects of asbestos exposure at high levels is the mortality experience of workers in an asbestos products manufacturing facility.[17] Here, a study of all 20-year production employees reveals the presence of the full spectrum of asbestos-related diseases. In this study, the mortality experience of all 689 individuals who were working on January 1, 1959 and who were first employed prior to 1939 was documented. From 1959 through 1971 it was expected that about 134 deaths would have occurred in this population. Instead, 199 died, 50% more than should have. About 28 cancers were expected; 72 were observed. The usual asbestos-related tumors were found in excess: bronchogenic carcinoma, mesothelioma, and gastrointestinal cancer. Table 1 lists a detailed breakdown of expected and observed deaths, by cause, during this period.

In considering the first requirement mentioned above, a population at least two or more orders of magnitude greater than that which provided the data of Table 1 is required. Additionally, the individuals should be exposed to asbestos concentrations at least one hundredfold less than the previous population (which included all eligible production employees in the largest U.S. asbestos products manufacturing facility). Even with enormous populations under study, positive effects can be lost in the statistical fluctuations of experimental data. A "negative" result serves only to define the upper limit of a level of risk.

* See NOTE ADDED IN PROOF.

TABLE 1

EXPECTED * AND OBSERVED DEATHS AMONG 689 ASBESTOS PRODUCTION AND TEXTILE WORKERS, JAN. 1, 1959–DEC. 31, 1971

	Observed Deaths	Expected Deaths
Total cancer (all sites)	72	27.8
Cancer of lung, pleura, trachea, bronchus	35	8.4
Lung cancer	27	†
Pleural mesothelioma	8	‡
Peritoneal mesothelioma	7	‡
Cancer of stomach, colon, and rectum	13	5.0
Cancer all other sites	17	14.4
Asbestosis	24	‡
All other causes	103	106.5
Total deaths	199	134.3

* Expected deaths based upon United States mortality data from the U.S. National Office of Vital Statistics.

† United States data not available, but figure should be only slightly less than 8.4.

‡ United States data not available, but these are rare causes of death in the general population.

In the case of asbestos, the second criterion, the need for accurate exposure data, cannot be fulfilled. Few dust counts were taken prior to the late 1960s and, when taken in earlier years, they usually enumerated all dust particles present in the environment, including nonasbestiform minerals. Estimates can be made from such data, but they are extremely insecure. Even today, the techniques of determining air concentrations of asbestos are quite rudimentary. The method prescribed by the National Institute for Occupational Safety and Health (NIOSH) for the assessment of airborne concentrations of asbestos involves counting, in a phase-contrast light microscope, all fibers longer than 5 μ collected on appropriate membrane filter material. It is generally recognized that this procedure enumerates only a fraction of the asbestos fibers present. What is not generally recognized is that the fraction counted varies with the type of asbestos operation under evaluation.

FIGURE 1 shows a typical size distribution, measured by electron microscopy, of fibers collected during the cutting of calcium silicate block insulation that contained chrysotile asbestos. Only 3.5% of the fibers exceeded 5 μ in length. Similar measurements during other types of asbestos operations are listed in TABLE 2. It can be seen that the fraction of asbestos fibers in a work-environment evaluation can vary by tenfold when a single variety of asbestos is used, and by one hundredfold when different varieties are considered. In reality, our technology for the determination of occupational asbestos air concentrations uses a rubber yardstick. These considerations are made to emphasize the limitations of our current techniques, not to suggest alternative ones. Other procedures suffer even greater difficulties.

Finally, the time criterion is of utmost importance, since the latency period for the development of asbestos effects must be recognized. Few cancers are seen prior to twenty years from onset of exposure; often, they are not seen before forty years. TABLE 3 shows the expected and observed deaths among 17,800 asbestos-insulation workers in the United States and Canada.[18] Although

some excess mortality can be seen in the population with less than 20 years from onset of exposure, the total number of deaths in this group is small, because its members were relatively young. However, after twenty years from onset of exposure, the percentage of excess deaths, particularly from cancer, and the total number of deaths increase significantly. TABLE 4 lists the expected and observed deaths from lung cancer, in five-year intervals, from first exposure. A more dramatic illustration of this effect of time is shown in FIGURE 2, where the excess lung cancer risk, normalized to an equal population within each time interval, is plotted. The significant increase in risk after thirty years is clearly evident.

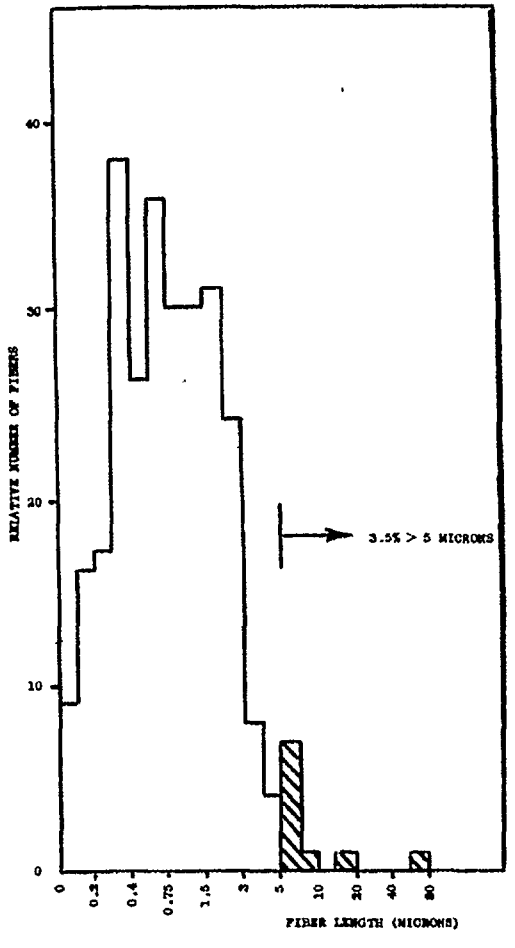

FIGURE 1. The size distribution of airborne asbestos fibers during the cutting of asbestos-containing calcium silicate insulation material. The observations were made with transmission electron microscopic techniques.

TABLE 2

PERCENTAGE OF FIBERS LONGER THAN 5 MICRONS IN VARIOUS INSULATION-WORK ACTIVITIES

Activity	Percentage of Fibers >5 μ
Cutting calcium silicate block	3.5
Mixing cement	1.2
Fabrication of amosite blankets	29
Removal of pipe covering	5.9
Indirect exposure in engine room during application of insulation	0.4

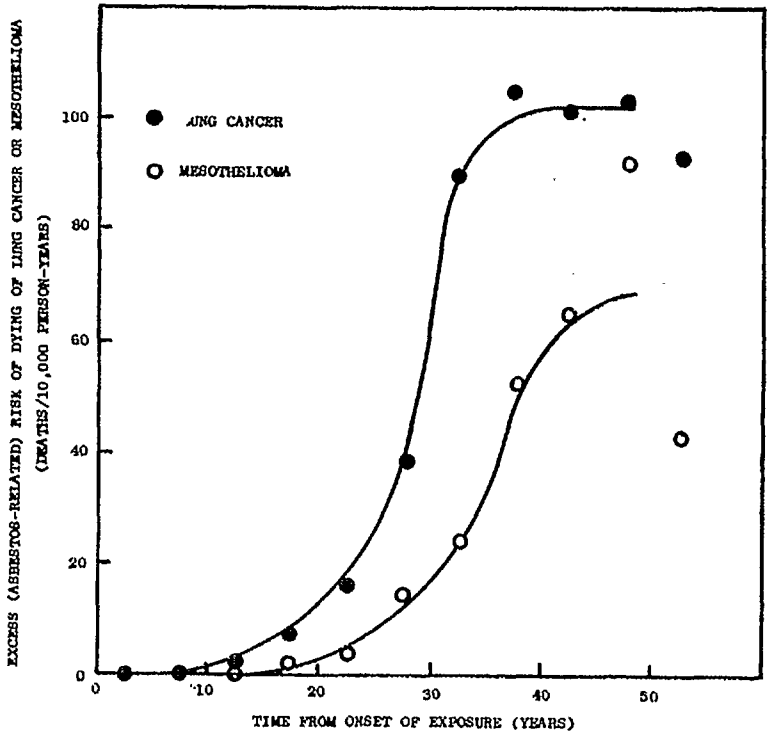

FIGURE 2. The excess, asbestos-related risk of dying of lung cancer or of pleural or peritoneal mesothelioma.

TABLE 3

EXPECTED AND OBSERVED DEATHS AMONG 17,800 ASBESTOS-INSULATION WORKERS IN THE UNITED STATES AND CANADA, JANUARY 1, 1967–DECEMBER 31, 1972

	Duration from Onset of Exposure			
	Less than 20 years		More than 20 years	
	Expected *	Observed	Expected *	Observed
Total deaths—all causes	203.90	249	756.12	1109
Cancer—all sites	30.42	64	145.13	511
Lung cancer	8.40	28	47.47	247
Asbestosis	†	7	†	94
All other causes	173.48	178	610.99	504
Number of persons	12,681		5,119	

* Expected rates are based upon age-specific white male death rate data of the U.S. National Office of Vital Statistics. Rates for 1972 were extrapolated from rates from 1967 to 1971.

† U.S. rates are not available, but these are rare causes of death in the general population.

TABLE 4

DEATHS FROM LUNG CANCER AND MESOTHELIOMA AMONG 17,800 ASBESTOS-INSULATION WORKERS IN THE UNITED STATES AND CANADA, JANUARY 1, 1967–DECEMBER 31, 1973: RELATION TO ELAPSED PERIOD FROM ONSET OF EXPOSURE

Years from Onset	Person-Years at Risk	Lung Cancer			Pleural and Peritoneal Mesothelioma
		Expected Deaths *	Observed Deaths	Ratio	Observed Deaths †
<10	24024	0.61	0	—	0
10–14	21284	2.20	6	2.73	0
15–19	25218	6.67	26	3.90	5
20–24	20344	11.38	42	3.69	7
25–29	12433	12.93	61	4.72	19
30–34	6969	10.36	73	7.05	17
35–39	3028	6.02	38	6.31	16
40–44	2306	5.58	29	5.20	15
45–49	1721	5.23	23	4.40	16
50+	1845	6.01	23	3.83	8
Totals	119170	66.99	321	4.79	103

* Expected deaths are based upon age-specific white male death rate data of the U.S. National Office of Vital Statistics.

† Expected deaths from pleural and peritoneal mesothelioma are virtually zero.

If human studies are inadequate to document a threshold effect, would animal experiments suffice? Here, also, the question of numbers exists. However, assuming that so-called "megamouse" experiments are performed, the extrapolation from animal to man may present insurmountable difficulties. I have only to call attention to the fact that lung cancer was first reported in an asbestos worker in 1935 [19, 20] and documented with substantial data in 1947.[5] The first lung cancer in animals was not produced until 1967.[21] Even in this last year, a report was issued in which no respiratory cancers were found in a study of asbestos-exposed animals,[22] but in another study, bronchogenic cancer was produced in animals exposed to asbestos for as short a time as one day.[23] The selection of an appropriate animal model is, of course, of paramount importance.

Risk Assessment

We must recognize that in dealing with carcinogens, we cannot set a true Threshold Limit Value. At any specified level above zero, we may assume that there will be some risk associated with the exposure to asbestos and to other carcinogens. We are thus setting what might better be called "Risk Limitation Values." Assuming that the risk can be defined at different exposure levels, this raises the political and social question regarding what is an acceptable risk to society and to the workers directly exposed. We have not, as yet, determined how this question should be answered.

Passing now to an assessment of that risk, we find that there are scant data that would allow a dose-response relationship to be determined for any industrial carcinogen in use. In the case of asbestos, the information we have is that an extraordinary rate of cancer occurs at asbestos concentrations considerably above the current TLV. We have attempted to develop some information on a dose-response relationship for asbestos. In the factory mortality study described previously, workers and union officials were able to categorize jobs according to relative dustiness. The rankings included jobs with little asbestos exposure, such as those in departments that did not use the mineral, as well as the dusty operations, those in the textile mill, the pipe department, or thermal insulation manufacturing. The estimates are probably quite accurate, as can be seen by considering the percentages of deaths from asbestosis in different dust categories, shown in Table 5. The highest category was the textile mill, where it was found that more than 40% of the deaths occurred from asbestosis. This percentage decreased as dustiness was reduced, until, in the lowest category, less than 5% of the deaths were due to asbestosis. Considering this table, the disconcerting feature is that even though deaths from asbestosis were reduced as dustiness decreased, those from cancer were not. There was a reduction in the highest category, that of the textile mill; workers there died of asbestosis before reaching the age of highest risk from cancer. Thus, airborne asbestos concentrations that may not greatly increase the risk of death from lung scarring can still produce a significantly increased risk of death from the various asbestos-related cancers. This point gains importance when one recalls that the current British standard and the United States standard, which was derived from it, were primarily based upon data concerning asbestosis. As noted, information was not available that allowed a level to be set that would demonstrably protect against cancer.

It is useful to review the experience of another cohort, the membership of

the New York and New Jersey locals of the Asbestos Workers Union,[16] because information also exists on the environmental exposure of these workers. Thus, we can relate observed asbestos disease with estimates of asbestos-fiber concentrations. Table 6 shows the mortality experience through 1971 of individuals who had 20 or more years since first exposure to asbestos. Over this period, 421 men died, whereas only 280 deaths were expected. Looking at the causes of death, it is not difficult to identify the sources of excess mortality. Lung cancer, asbestosis, gastrointestinal cancer, and mesothelioma are all found in excess. Among those who died, 1 in 5 died of lung cancer; 1 in 12 from asbestosis; 1 in 10 from gastrointestinal cancer; and 1 in 13 from mesothelioma. The distribution of deaths is very similar to that of the lowest dust category in the asbestos-products manufacturing facility. Considering the expected frequency of these various cancers in this population, nearly 40% of the deaths of these workers can be attributed to their occupational exposure to asbestos.

One noteworthy feature of the data in Table 6 is that in the first nine years of observation, there were actually fewer deaths than expected. This is a common occurrence in mortality studies of working populations; individuals employed at the start of a study are healthier than many in the general population, and this is usually reflected in a lessened mortality risk. It is worth noting, however, that even in these first few years, the excess of asbestos-related cancers can be seen.

Table 5

Percentage of Deaths Due to Given Cause by Estimated Dust Category

Cause of Death	Dust Level Min.	Mod.	High	Textile
Asbestosis	5	13	20	39
Lung cancer	16	10	16	9
Mesothelioma	6	13	8	5
G.I. cancer	9	3	4	5
All other cancer	9	7	16	5
All other causes	55	54	36	39
All cancer	41	33	44	29
No. of workers in each category	86	61	25	24

Using the standard membrane-filter technique proposed by the U.S. Public Health Service for counting asbestos fibers, three different laboratories in the United States [24-27] have found that the average concentrations of asbestos dust in insulation work between 1968 and 1971 ranged from 3 to about 6 f/ml. A similar study in the Devonport Naval Dockyard,[28, 29] in Great Britain, with the same techniques, obtained 8.9 f/ml for the average of long-term samples of asbestos concentrations measured during the application of insulation materials aboard ship. These data represent average levels when men were working with asbestos-containing materials; however, more than half the time of United States insulation workers during these years was spent using other materials: fibrous glass, mineral wool, polyurethane, and so on. Considering this distribution of their work activities, the overall time-weighted average exposure of United States asbestos workers in the late 1960s was less than 3 f/ml.

TABLE 6

EXPECTED AND OBSERVED NUMBER OF DEATHS AMONG 623 NEW YORK–NEW JERSEY ASBESTOS-INSULATION WORKERS, JAN. 1, 1943–DEC. 31, 1961, AND FORTY OR MORE YEARS AFTER ONSET OF FIRST EXPOSURE TO ASBESTOS *

	1943–1951		1952–1961		1962–1971		Total 1943–1971	
	Exp.	Observ.	Exp.	Observ.	Exp.	Observ.	Exp.	Observ.
Total cancer: all sites	11.3	28	18.3	57	17.6	104	47.2	189
Lung cancer	1.5	13	3.5	23	5.1	48	10.1	84
Pleural mesothelioma	— †	1	—	2	—	5	—	8
Peritoneal mesothelioma	—	1	—	3	—	20	—	24
Cancer of stomach, colon, rectum, esophagus	4.1	7	5.0	18	3.9	16	13.0	41
Cancer all other sites	5.7	6	9.8	11	8.6	15	24.1	32
Asbestosis	—	1	—	10	—	22	—	33
All other causes	65.1	44	89.4	94	78.3	94	232.8	199
Total all causes	76.4	73	107.7	161	95.9	187	280.0	421
Person-years of observation:	3,726		4,406		2,898		11,030	

* 632 members were on the Union's rolls on January 1, 1943. Nine died before reaching 20 years from first employment. All others entered these calculations upon reaching the 20-year-from-onset of first exposure point. Expected rates are based upon age-specific death-rate data of U.S. National Office of Vital Statistics 1949–1967. Rates were extrapolated 1943–1948 from rates for 1949–1955 and for 1968–1971 from rates for 1961–1967.

† —: U.S. death rates not available but these are rare causes of death in the general population.

In the research that led to these data, it was reported that peak exposures could be extremely high. It was not uncommon, for example, for two-to-five-minute concentrations of asbestos to range between 50 f/ml and 100 f/ml during the mixing of cement. This mixing, however, would consume only a few minutes' time and be done perhaps once an hour. Thus, exposures measured during that hour, including the mixing, would seldom average more than 5 f/ml. Similar experiences were subsequently reported by Cooper,[30] at Lyon, who stated, "Peak concentrations may be high for brief periods, while time-weighted averages are often deceptively low."

We have direct information on asbestos-fiber concentrations, measured by the currently prescribed analysis procedures during recent years only. Insulation materials have changed from earlier years. Fibrous glass has found extensive use, but work with cork is seldom seen today. Moreover, changes in the asbestos composition of insulation products have taken place. Pipe covering and insulation block may have had twice the asbestos content in past years as they have today. During this period, however, work practices were virtually identical to those of past years, and during the period of these measurements, few controls of significance were in use. Thus, dust concentrations measured under these conditions have relevance for the estimate of levels of past years. Considering the possible doubling of asbestos content of insulation materials, and considering that workers may have used asbestos materials more often in the past than now, the data from these three studies would suggest that the insulators' average exposures in the United States during past years could have ranged from 10 to 15 f/ml.

The only early research of note on asbestos-dust concentrations in past insulation work is the 1945 study of Fleischer and his colleagues,[31] who reported asbestos dust levels during insulation application in four United States shipyards. In this study, dust concentrations were assessed with use of a konimeter (an instrument widely used at that time, but no longer employed), and both total dust and fiber levels were recorded. The study is difficult to evaluate, since the average dust levels reported in different shipyards varied by nearly 100 times. In two yards, average dust concentrations of about 1 f/ml were found; in a third yard, 90 f/ml; and in the fourth, 35 f/ml. During 1965 and 1966, the fourth yard was resurveyed by personnel of the Department of Industrial Hygiene, Harvard School of Public Health.[32] In the resurvey, a time-weighted average exposure of about 8 f/ml was determined.

These fiber counts represent all fibers visible in the field of view of a konimeter. Fibers perhaps as short as 1.5 μ would be enumerated. Supplementary data[33] on the size distribution of amosite aerosols in shipyards suggest that this overestimates the number of fibers longer than 5 μ by a factor of two. If we take this factor into account, and simply average the data from the four shipyards studied by Fleischer in 1945, an estimate of from 15 to 20 f/ml is obtained for average asbestos concentrations in insulation work during this period. Similar considerations would yield a value of 4 f/ml for the shipyard survey by Murphy in 1965. It must be emphasized, however, that averages are highly subjective and depend strongly on the vagaries of the particular work practices selected for sampling and the conditions present at that time.

These summaries of asbestos concentrations from 1945 through 1971 by five different research groups in two countries are summarized in TABLE 7. The estimate of from 10 to 15 f/ml for past insulators' average asbestos exposures

TABLE 7

SUMMARY OF AVERAGE ASBESTOS AIR CONCENTRATIONS DURING INSULATION WORK

Research Group	Average Fiber Concentration: Light and Heavy Construction	Marine Work
Average concentrations of fibers longer than 5 evaluated by membrane filter techniques and phase-contrast microscopy		
Reitze-Nicholson, Mount Sinai	6.3	
Balzer-Cooper, U. of Calif.	2.7	6.6
Burgess-Lynch, Harvard		2.9
Harries, Great Britain		8.9
Average concentrations of all visible fibers counted with a konimeter and bright-field microscopy		
Murphy, Harvard		8.0
Fleischer, U.S. Navy		30–40
Estimates of past exposure based on current membrane-filter data		
Nicholson, Mount Sinai	10–15	

in nonmarine work and 15–20 f/ml for marine work does not offer much confidence that 5 f/ml or even 2 f/ml is sufficient to protect asbestos workers.

SYNERGISTIC EFFECTS

Increasing evidence is accumulating that many cancers have a multiple-factor etiology. For example, lung cancer in asbestos workers is strongly associated with cigarette smoking. In the large cohort of 17,800 insulators observed by Selikoff and Hammond,[16] smoking habits of the majority of workers were obtained at the beginning of their study. TABLE 8 illustrates the effect of cigarette smoking on lung cancer mortality. In 2066 noncigarette smokers, only two lung cancers were seen in a six-year period; 179 were observed in 9,590 men with a history of cigarette smoking. Although the data are still insufficient to accurately determine the risk of dying of lung cancer in nonsmoking asbestos insulators, they do suggest to establish that the risk is less than that for cigarette-smoking males in the general population who do not work with asbestos. However, the combination of cigarette smoking and asbestos has a multiplying effect. From data on the New York and New Jersey insulators cohort, it has been calculated that the combined risk for dying of lung cancer of an asbestos worker who smokes is 92 times that of an individual who neither smokes nor works with asbestos.[34]

It is clear that it would be necessary to include evaluation of multiple-factor effects in calculating threshold values for asbestos cancer risk. It is equally clear that this requirement would introduce insurmountable sample-size, statistical, and sampling requirements.

INDIRECT EXPOSURES

Data have accumulated since 1960 showing that individuals exposed by virtue of living in the neighborhood of an asbestos facility may be at risk of developing mesothelioma.[8, 35] Household contacts similarly may be at risk from asbestos disease.[35] It has been reported that x-ray evidence of asbestos exposure is manifest in approximately 35% of family members of former asbestos workers examined 20–30 years after onset of household exposure.[36] Workers could be employed in dust concentrations that would meet defined standards, yet dust brought home on their clothes could expose family members to concentrations sufficient to produce disease. Without concomitant specified work practices, dependence on TLVs is inadequate to protect the total population at risk, including family contacts and indirectly exposed workers in other trades.

ENFORCING SPECIFIED STANDARDS

Assuming one had accurate data on human dose-response relationships and a socially acceptable risk-benefit criterion on which one could establish a numerical standard, a Risk Limitation Value, the enforcement of prescribed concentrations would still be uncertain. At the present time, OSHA has about 200 industrial hygienists. When one considers that 5 million workplaces fall within the jurisdiction of OSHA, the enormity of the task is apparent.

In order to obtain a quantitative assessment of the effectiveness of OSHA, state, and industry monitoring in the construction industry, a survey was conducted of all members of the International Association of Heat and Frost Insulators and Asbestos Workers (AFL-CIO, CLC) during 1972. Each worker was asked about dust counts he had seen at any time during his employment from June 7 through December 6, 1972, a period when the permanent asbestos standard required that at least one dust count be taken in each workplace using asbestos. Only 171 of 4956 workers reported seeing a dust count at any time during this period, and 54 of these dust counts were seen in shipyards or chemical plants having permanent industrial hygiene staffs. TABLE 9 lists the complete

TABLE 8

EXPECTED AND OBSERVED DEATHS OF LUNG CANCER AMONG 17,800 U.S. AND CANADIAN ASBESTOS-INSULATION WORKERS, JANUARY 1, 1967–DECEMBER 31, 1972: RELATION OF CIGARETTE SMOKING

	No. of Persons	Deaths from Lung Cancer: Expected *	Observed	Ratio
Smoking habits not known	6144	16.76	94	5.4
History of cigarette smoking	9590	31.60	179	5.7
No history of cigarette smoking	2066	7.51	2	0.3

* Expected deaths based upon age-specific U.S. mortality rates for white males, disregarding smoking. Lung cancer estimates based upon U.S. rates for cancer of lung, pleura, bronchus, and trachea, categories 162 and 163 of the International Classification of Diseases and Causes of Deaths, 7th Revision.

TABLE 9

QUESTIONNAIRE: OBSERVATION OF ASBESTOS STANDARD
JUNE 7, 1972–DECEMBER 6, 1972

1. Number of Dust Counts Seen

Region	Dust Counts Seen? Yes	No	Percentage of Men Seeing a Dust Count
New York–New England	12	743	1.6
Middle Atlantic	25	755	3.2
Southeast	6	326	1.8
Southwest	18	474	3.7
Midwest	5	935	0.5
Central	18	740	2.4
West	24	509	4.5
Canadian	9	363	2.5
Maintenance Locals	23	38	37.7
Shipyard Locals	31	73	29.8
All Regions	171	4956	3.4

2. Work clothes and facilities

Facilities and supplies for clothes change were available:

All the time	(100%)	1291
Usually	(50–75% of time)	940
Occasionally	(1–49% of time)	872
Never	(0%)	1964

3. Respirators

Were provided by the employer

All the time	(100%)	2038
Usually	(50–75% of time)	1014
Occasionally	(1–49% of time)	1242
Never	(0%)	787

4. The following materials and equipment were available

	Always	Usually	Occasionally	Never
Cement in plastic bags	570	549	616	3252
Exhausted power table saws *	594	402	603	3004
Exhausted power hand saws *	112	74	176	4125
Vacuum cleaner for cleanup	203	136	425	4127
Bagging of waste for disposal	407	388	681	3439
Drop cloths and collector for hand-sawing	190	227	513	3943
Portable exhausts for confined spaces	125	154	443	4150

* It should be noted that an ambiguity exists in the replies to the availability of exhausted power saws. On some jobs, where there was no use of power equipment, the response as to the availability of exhausted saws was "never."

responses to queries on dust counts and availability of other environmental control procedures described by the standard.[37] Thus, even if we could define acceptable levels for work exposure, at this time we do not have the capability of enforcing those levels throughout an industry, at least not in one as extensive as the asbestos industry.

CURRENT PERSPECTIVES

With this discouraging picture of inadequate knowledge of risk, ill-defined exposure information, and limited enforcement of existing levels before us, one may well ask of what value a TLV is for asbestos, or for any carcinogen. Should such materials be banned from use in all forms? Asbestos is extensively used in industry for insulation, for inclusion in plastics and other products, for reinforcing high-stress materials. At present, nearly 1 million tons are used annually in the United States. For some uses, as in brake linings, it is difficult to find a replacement. A societal decision to ban the use of asbestos would create serious, if not insurmountable, difficulties. Moreover, we would still face control problems posed by the large quantities of asbestos in current use. Our only recourse at this time is to limit human exposures to asbestos and other similarly recognized carcinogens to the lowest possible levels, with existing technology.

In the case of asbestos, a TLV can serve a purpose: Recognizing that it is, in fact, a Risk Limitation Value, however ill-defined that risk might be, it can serve to mandate implementation of available technology and rule out the small fraction of work processes in which available technology fails to keep up with the major portion of the industry. More, however, is required than the specification of a number. The specification of work practices and engineering controls offers an essential supplement to a numerical TLV if the latter is used at all. Application of many economically and technically feasible procedures can reduce exposure to levels much below existing numerical values. These should be mandated. Moreover, such procedures can be specified with joint government-union-management cooperation and can be monitored much more readily than can dust concentrations. TLVs and work-practice standards should be reviewed frequently with a view to achieving continued reduction in worker exposures. The specification of a proposed TLV can serve as a stimulus for the development of new engineering-control methods or to rule out marginal processes that cannot be controlled. As new engineering developments evolve, the lowering of a minimal standard can be undertaken along with the specification of additional protective work procedures.

To a limited extent, this has taken place in the asbestos industry. The promulgation of the 5 f/ml time-weighted average standard stimulated some of industry to install extensive dust-control equipment. The scheduled reduction in the time-weighted average to 2 f/ml in July of 1976 has stimulated the development of new methods of engineering control and of new asbestos-free materials. Some parts of the industry have responded commendably. In the United States factory previously used for illustrative purposes, we have been told by workers in the plant that virtually all work stations are below 2 f/ml at this time and that dust conditions are immeasurably better. In the insulation industry, asbestos has been eliminated from a majority of insulation products, significantly reducing the exposure of insulation workmen and of other construction workers. However, the problem still exists, especially in small opera-

tions. Exemplary situations can be described, but in many parts of the industry, concentrations far exceeding the current standard still may be found.

Summary

A review of the control of carcinogenic exposures using the TLV approach presents a prospect of limited effectiveness. With asbestos, as with any carcinogen, no threshold is known below which no health effect may be manifest. At best, we have only limited dose-response information at levels much above those of practical concern. In the case of asbestos, current exposures can only be described crudely at any level of exposure, and health effects are only known for past high, but ill-defined, exposures. Limited information exists on the effects of synergistic interactions with other materials. The current U.S. TLV, based on data concerned with occurrence of asbestosis, has not been evaluated with regard to possible effectiveness in the prevention of asbestos cancer. Yet cancer is the heart of the asbestos-hazard problem.

Finally, enforcement of the existing TLV, especially for asbestos has been limited, frequently absent, and often ineffective. Workers are exposed in many situations to levels much above the current standard.

As discouraging as this picture may seem, a TLV can be useful for stimulating the development and application of engineering-control procedures. The application of these procedures, however, must be specified and mandated in future standards to lower worker exposures to the minimum commensurate with existing technology. As technology is developed that makes lower exposure levels possible in a large part of the industry, TLVs should be reduced to take advantage of that technology.

[**NOTE ADDED IN PROOF:** On October 9, 1975, the United States Department of Labor proposed a reduced time-weighted average exposure limit of 500,000 f/m³ (0.5 f/ml). In the preamble of the proposal, special concern was expressed over the carcinogenic property of asbestos.]

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