Projection of asbestos related diseases in the United States, 1985-2009 I. Cancer

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ABSTRACT Projections of asbestos associated cancer mortality in the United States during the 25 year period 1985-2009 were made based on previously published estimates. These estimates were reviewed for malignant mesothelioma, lung cancer, and gastrointestinal cancers. Particular attention was given to the assumptions used in the original derivation of the estimates. For malignant mesothelioma mortality, previous estimates ranged from 15 500 to 300 000. Using recently published data from the Surveillance, Epidemiology, and End Results project, coupled with the previously published estimates, projected asbestos related malignant mesothelioma mortality in the United States for the period 1985-2009 was estimated to be 21 500. For lung cancer, previous estimates were reviewed, particularly with regard to the ratio of deaths from lung cancer to deaths from malignant mesothelioma. Using these ratios, a range of projected deaths was established and a median of those estimates used as a project, which was 76 700 such deaths in the United States between 1985 and 2009. Gastrointestinal cancer mortality has been projected by only three investigators. A median of those estimates (33 000) was used. In conclusion it is estimated that 131 200 deaths from asbestos associated cancer will occur in the United States between 1985 and 2009.

There is little doubt that exposure to asbestos results in diseases such as malignant mesothelioma, lung cancer, and asbestosis. The precise relative risks for different durations, intensities, and type of exposure may be argued but the fact remains that extensive exposure to asbestos in the past has resulted and will continue to result in considerable disability and a substantial number of deaths.

Measuring the current disease risks from asbestos has several problems, some of which are insurmountable. Consider the problem of determining specific exposure levels in the past; accurate data are rarely available, leaving the investigator to use such crude classifications as "heavy" and "light." Estimating future events is therefore exceedingly difficult and the imprecision of such estimates is apparent when one reviews the projections developed by several workers¹⁻¹⁰ (and K Bridbord *et al*, unpublished data). The estimates vary over two orders of magnitude, illustrating the lack of agreement within the scientific community on the methods for and the results of such extrapolations. In general, efforts to project future cases and deaths from asbestos have been unreliable because they have depended on information that may be characterised as poor—namely, the extent of exposure in various occupational groups in the past and the inadequate data on exposure response.⁸

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The data needed for fairly precise calculations of the number of asbestos related cases of cancer and asbestosis are not now, and never will be, available. The necessity, however, for providing some reasonable estimate of the future number of cases is driven by both pending litigation and by a need to determine projected health care resource demands.

In the present paper we report our projections of the future number of cases of asbestos related malignant mesothelioma, lung cancer, and gastrointestinal cancers in the United States during the next quarter of a century (1985-2009). We reviewed critically a considerable amount of published and unpublished reports, some of which are cited and discussed in this paper. Each disease is presented separately with the rationale for the conclusion reached. A future paper will consider how many cases of asbestosis there were in the United States in 1985.

The first major attempt to project the number of cases of cancer (all sites) attributable to exposure to asbestos appeared in a 1978 document generally attributed to the National Institutes of Health. This projection of asbestos related malignancies was the byproduct of an effort to determine the proportion of cancers that were occupationally induced. The report, which was never published and therefore never peer reviewed, has met with much criticism.¹¹⁻¹⁶ For instance, an editorial in *The Lancet*¹⁵ summarised the

paper and highlighted its weaknesses. Referring to the previous efforts, the editorial stated:

"... On the basis of data stemming predominantly from one follow-up study, the NIH workers suggest that, over the next three decades, roughly 13–18% of the total cancer mortality will be due to work-exposure from asbestos. Yet its frame-work is insubstantial—remarkably so, in view of the fierce criticism of other people's work. The asbestos extrapolation is based predominantly on follow-up of American shipyard workers¹⁷; there is no review of the full range of epidemiological studies that have been published on this subject (in which, as usual in cancer epidemiology, there is no complete agreement). Though cancer mortality is estimated for the very large workforce potentially exposed to asbestos since the 1940s, no data are presented on the degree of exposure in these workers, and hence on their risk of lung and other cancers; it seems very rash to suppose that these risks may be estimated from one specific study, by the use of a crude division of workers into heavily and less heavily exposed. ... Though the problems of assessing the proportion of cancers related to occupation are acknowledged in the report, these difficulties seem to have been forgotten when the conclusions were drafted. Quantification of the hazards of occupations is a complex matter. Bridport [sic] and his colleagues¹ were well placed to set matters in proper perspective. It is sad to see such a fragile report under such distinguished names."

The 1978 report, although using no information on observed exposure to asbestos, suggested that about 1.6m asbestos associated deaths would occur between 1980 and 2010. Of this number, about 90% would be due to lung cancer, which corresponds to about 1.44m such deaths during a 30 year period. (There are at present about 175 000 deaths from lung cancer a year in the United States.)

The 1978 estimates were based on conjectural estimates of the number of workers exposed to asbestos (divided into heavy and light exposures) and mortality estimates from one heavily exposed cohort of American insulation workers.¹⁷ Though the paper did take into account the presumed mortality of those exposed, it did not provide any indication of how the estimated mortality rates were derived nor how the projections were made. As a result of the techniques used in calculating the number of asbestos related cancers, the number of deaths from malignant mesothelioma, generally seen as being the sentinel neoplasm for exposure to asbestos fibres, was predicted to increase to about 10 000 a year, which is at least five times greater than that presently observed in the United States.^{11 18} (and K. Bridbord, unpublished

data). Also, as Doll and Peto noted, the 1978 estimates result in the conclusion that over 10% of all cancers are occupationally related to exposure to asbestos.¹ Most other estimates, they observed, result in the conclusion that, at most, only about 2% of such deaths are related to asbestos. The implication of this observation for projected asbestos related mortality is clear: the 1978 projections grossly overestimate the number of future asbestos related deaths.

Malignant mesothelioma

Studies of trends in, or of the magnitude of the incidence of, and mortality from malignant mesothelioma are particularly difficult because of the paucity of data. Mortality data are inadequate because of the absence of a specific ICD (International Classification of Diseases) code for malignant mesothelioma. At present many deaths from intrathoracic malignant mesothelioma are coded as lung cancers.^{19 20} The only national incidence data available are from the Surveillance, Epidemiology and End Results (SEER) Programme of the National Cancer Institute, although data for malignant mesothelioma are not regularly published in its annual reports. A further complication in assessing the magnitude or trends, or both, is the apparent misclassification of the disease.¹⁸ Studies that have included a review of cases of mesothelioma have concluded that up to 74% are erroneously classified as malignant mesothelioma and that the overdiagnosis is influenced by knowledge of exposure to asbestos.²¹ It has also been suggested that up to 50% of cases of malignant mesothelioma may not even be related to asbestos; however, such estimates are controversial.²² Despite these apparent deficiencies in the availability of both mortality and incidence data on malignant mesothelioma, many investigators have developed projections for the number of asbestos related cases that will occur in the future.

At a 1979 American Health Foundation conference on the primary prevention of cancer, Higginson presented an estimate of 4000 deaths from asbestos associated cancer annually in the United States; 1000 of those deaths, he forecast, would be due to malignant mesothelioma.^{3 4} At the Banbury Conference at the Cold Spring Laboratory in 1981, the question of how much cancer could be attributed to occupational exposures was considered and several estimates of future asbestos related cancer mortality were presented.^{2 3} One such projection was presented by Enterline who referred to a variety of sources for data on the number of individuals exposed to asbestos.⁴ Then, assuming a linear dose response relation between exposure to asbestos and risk of cancer (he noted that previous research both by himself and by others suggested that the relation was indeed linear), he

calculated that when all the cases of cancer in all groups were totalled, about 660 deaths from asbestos associated malignant mesothelioma would occur annually or 16 500 deaths from malignant mesothelioma for the period 1985–2009. (Enterline assumed that two thirds of all deaths from malignant mesothelioma would be related to exposure to asbestos.)

In 1981 Selikoff prepared a report in response to a United States Department of Labor request to examine the number of future claimants for compensation for deaths related to asbestos.¹⁵ Revised portions of the report, prepared in conjunction with Nicholson and Perkel, appeared in 1981 and 1982.^{5,6} The first paper, discussed at the 1981 Banbury Conference by Nicholson, estimated that 13.2m workers were occupationally exposed to asbestos fibres (the types were not specified), of whom 4.2m were still alive in 1981.⁵ The approach used by Nicholson *et al* was a direct one—that is, using industry specific estimated populations and the corresponding risks of developing lung cancer and malignant mesothelioma, they calculated “expected” numbers of deaths. (Because of the poor survivorship associated with malignant mesothelioma, incidence is equivalent to death.) The number of cases of malignant mesothelioma was forecast to be about 54 105 for the period 1980–2000.

In a paper in 1982 Nicholson *et al* presented another estimate of the number of future cases that will occur.⁶ The imprecision of their estimate is apparent from their own statements that:

(1) “The precise number of persons occupationally exposed to asbestos at any given time is not known.”

(2) “The level of exposure to asbestos necessary to increase the risk of incurring asbestos-related disease is only imperfectly known, estimates being complicated by the varying interactions of the two elements into that ‘dose’ (time and intensity).”

(3) “The extent to which workers have changed occupations and/or industries from time to time so as to place them at risk to asbestos-related disease (or to end such exposure) at any time in the past four decades is not known.”

Although important information was lacking, Nicholson *et al* provided estimates by using “the best available data concerning worker exposure to asbestos and the turnover of workers in the occupations and industries involved.”

They reviewed the various industries and occupations in which exposure to asbestos could have occurred. These included primary industries (those that produced manufactured goods from asbestos, such as floor tiles, roofing felts, and insulating material), secondary industries (those that processed asbestos manufactured products to make other products, such as furnaces and electric fans), and

consumer industries (those that used a finished product containing asbestos, such as asbestos cement pipe sections and sealants). Occupational groups that they deemed to have been at high risk included shipbuilders, construction workers, insulation workers, car body repairers and mechanics, marine engine room personnel, maintenance employees in the chemical and petroleum manufacturing industries, steam locomotive repairmen, stationary engineers, stationary firemen, and power station operators. Their inclusion of all of these groups seemed reasonable since members of the groups would have been exposed to asbestos. The difficulty, however, was in determining the actual number of individuals exposed and the time, duration, type, and intensity of their exposure. Unfortunately, this information was not available and many assumptions had to be made by Nicholson *et al* regarding those factors.

They relied heavily on data from the Bureau of Labor Statistics (BLS) regarding information on the numbers of employees in the various industries and occupations considered to be at risk and they also used data from industry and union sources such as the International Association of Heat and Frost Insulators and Asbestos Workers (IAHIAW). Unfortunately, some of the data presented in their paper do not agree with the official statistics published by the BLS. Particularly noteworthy is the estimated number of IAHIAW active workers provided to Nicholson by the union. These numbers, particularly for the years 1946–65, differed from BLS data by as much as 100% with the union’s data consistently showing a higher number. Presumably this group could have had the highest continuous exposure to asbestos, so that this type of error would have a pronounced effect on the projected number of asbestos related cases. Unfortunately, this particular error was not a singular one. For instance, Nicholson *et al* had to provide a further refinement to the BLS data in order to estimate the workforce in various occupations back to 1940. They extrapolated available data using regression methods with the implicit assumption of a straight line trend. This assumption may have been somewhat tenuous; however, without the actual data, it is virtually impossible to validate.

A further problem was related to the acquisition of data for new entrants to the workforce. In the absence of precise information, Nicholson *et al* were once again forced to make estimates. Here, the potential for error was apparent and could have resulted in an overestimate of the workforce because of the number of individuals who may have worked in more than one asbestos related occupation or industry.

The final estimate by Nicholson *et al* of workers exposed to asbestos between 1940 and 1979 was 27 500 000, with 14 100 000 of those alive on 1 Jan-

uary 1980 having had significant exposure to asbestos. Nicholson *et al*, recognising the potential for considerable error in this figure, noted that:

"The uncertainties in estimating this number have been described previously, but they cannot be overstressed. The number is an approximation. Further, it includes a large number of individuals whose potential exposure to asbestos would have been of low intensity or of short duration because of high labor turnover."

In support of this observation, they stated in a later section of the paper:

"One notable feature is that the asbestos products manufacturer has an extremely high turnover during the first month after hire."

The estimate of Nicholson *et al* of the exposed population was considerably higher than many other estimates. Even the rather high estimate of cases of asbestos related cancer produced by Bridbord and his colleagues, was derived from a figure of only 4m workers alive today who had had heavy exposure to asbestos¹ (unpublished data). Hogan and Hoel in 1981 provided an estimate of the potential size of the asbestos workforce occupationally exposed during and/or after the second world war.² A life table approach was used to project the expected mortality experience of exposure level subgroups over time. They estimated that about 4m workers alive in 1980 had been exposed to asbestos and were at risk of dying from some form of asbestos related cancer. Enterline, on the other hand, estimated that as of 1981, there were 70 000 to 90 000 persons alive in the United States who had had substantial exposure to asbestos.⁴ Including all types of occupational exposure to asbestos, Enterline estimates that there were 7 605 000 such workers exposed who were alive in 1981, a figure that was actually about half that used by Nicholson and his colleagues.

If, indeed, the estimates of exposed workers by Nicholson *et al* are too high then the projections of future cases of malignant mesothelioma must also be high. This argument may be substantiated by examining the data from 1977 to 1982 when Nicholson *et al* predicted 1425 cases of malignant mesothelioma a year in 1977 increasing to 1755 a year in 1982. Data from the SEER programme indicate that about 1200 cases occurred in 1977.¹⁸ This includes non-asbestos

related cases of malignant mesothelioma which, as noted above, could account for at least 25% of the total and perhaps as much as 50%.^{21,22} Thus it appears that the Nicholson *et al* figure may be overestimated by up to 100%. The estimates provided by Enterline, Peto, and McDonald, discussed below, are similar and more consistent with the observed United States incidence rates from SEER data.^{4,7,8,18}

Peto *et al* used an approach similar to that of Nicholson and his co-workers, the main difference being the technique of "aging" the exposed cohorts.⁷ For the period 1985–2009, the approximate number of deaths from mesothelioma projected by these workers is shown in table 1 (from table 7 in ref 7).

McDonald and McDonald, using data on the incidence of fatal malignant mesotheliomas in the population and on the ratios of deaths attributable to asbestos exposure caused by malignant mesotheliomas on the one hand and other malignant diseases (respiratory and digestive cancers) on the other, estimated that about 920 deaths from asbestos associated mesothelioma would occur in 1975.⁸ Over a 25 year period, about 23 000 such deaths would occur.

In 1982 Walker and his colleagues at Epidemiology Resources, Inc, prepared an estimate of the number of expected cases of lung cancer and malignant mesothelioma for 1980–2009.^{9,10} Using a technique similar to that of Enterline, where an exposed population estimate is conditional on current mortality rates to determine future mortality projections, they estimated that 15 500 cases of asbestos induced malignant mesothelioma would occur during the period 1985–2009. The estimate provided by Walker *et al* for the number of cases of malignant mesothelioma may be criticised for several reasons. Three important assumptions were made by these authors in deriving the annual number of cases of mesothelioma (974) in the United States. The first dealt with the annual rate of increase, estimated to be 10%. Data from the Third National Cancer Survey (TNCS) (1969–71) and Surveillance, Epidemiology and End Results (SEER) (1973–8) were combined to derive this estimate. This may be inappropriate since these two surveys covered different geographical areas and used different methods of case ascertainment. The TNCS was conducted in nine areas of the United States and it used an active case ascertainment method to obtain all

Table 1 Projected number of deaths from asbestos associated malignant mesothelioma by four and five year time intervals, 1985–2009

	Year						
	1985–88	1989–93	1994–98	1999–2003	2004–08	2009	Total
No of cases	3640	4690	4601	4115	3198	441	20 505

Source: Peto *et al*.⁷

Projected asbestos related cancer

incident cases of cancer. The SEER system, conducted in some areas not included in the TNCS, used a combination of both active and passive surveillance. Recent data from SEER, the New York State Cancer Registry, and the Los Angeles County Cancer Registry suggest that the rate of increase is greater than 10%.¹⁸ It should also be noted that diagnostic acumen for malignant mesothelioma has improved considerably since 1969. Thus any projected increase in incidence should have separated the real change in incidence from the artifactual change due to improved diagnostic methods. Admittedly, this is not an easy task but some adjustment would have been appropriate.

The second assumption relates to the non-representative sampling of the United States in the SEER programme. It is true, as stated by the authors, that the SEER areas do not represent the United States as a whole. Nevertheless, it is at best speculative to presume that they *overrepresent* areas with higher rates of malignant mesothelioma incidence because of the presence of shipbuilding industries (Seattle and San Francisco, two areas included in the SEER programme, were singled out in the Walker report). Many other shipbuilding areas are not included in SEER—for example, Massachusetts, Maine, New Hampshire, Virginia, or Maryland. Furthermore, all malignant mesothelioma incidence cannot be attributed to shipbuilding activities alone.

The third assumption, of underreporting in SEER because of its "regional" nature, is questionable. Many large referral cancer centres are located within the SEER areas. Of the ten SEER areas, five are major urban areas (San Francisco-Oakland, New Orleans, Seattle, Atlanta, Detroit) with such cancer referral centres. The other five areas that are covered by state

wide registries (Connecticut, Utah, New Mexico, Hawaii, and Iowa) are also well served by major cancer diagnostic and treatment facilities. In fact, one could argue that the SEER incidence rates of malignant mesothelioma may be greater than those in the other areas of the United States because of the presence of major cancer centres, which may stimulate greater sensitivity and attention to diagnostic accuracy.

The assertion that "in heavily exposed industrial cohorts, the peritoneum probably accounts for half of all the cases" (p 6 of ref 10) is questionable. In fact, the data presented in the report (table 4, p 8) show that, in the seven studies which Walker *et al* reviewed, cases of peritoneal malignant mesothelioma accounted for between 0% and 64% of the total and exceeded 50% in only two of the studies. Indeed, Spirtas *et al* concluded that pleural cases were more frequent than peritoneal ones.¹⁸ In the TNCS, most cases were intrathoracic—that is, pleural—suggesting that peritoneal cases account for much less than 50% of such cases.¹⁹

An important assumption was made in the Walker *et al* report regarding the constancy of the heavy and light exposures until the 1960s and 1970s, when dust control measures were introduced.¹⁰ This assertion requires further substantiation and should have included consideration of the type of fibre used over the period, which is very important in formulating estimates of future cancer mortality.

The estimate of the number of exposed workers used by Walker *et al* did not take into account the concentration of the fibres to which individuals were exposed. The mathematical formula used to derive the numbers of exposed workers could be validated against Bureau of Labor Statistics data and company employment records. Specifically, the data presented

Table 2 Summary of projected numbers of deaths from asbestos related lung cancer and mesothelioma

Year	Author (reference)	Years	Estimated No of deaths from lung cancer	Estimated No of deaths from mesothelioma
1978	Bridbord <i>et al</i> (unpublished)	1980–2010	1.44m	300 000
1980	Higginson ¹	1985–2009	37 500*	25 000
1981	Hogan and Hoel ²	1980–2010	400 000	63 000
1981	Enterline ³	1985–2009	62 525	16 650
1981	Nicholson <i>et al</i> ⁴	1981–2000	131 625†	54 105
1981	Peto <i>et al</i> ⁵	1985–2009	79 919‡	20 925
		1985–2009	153 993§	—
		1985–2009	30 758*	—
		1985–2009	36 476	—
1981	McDonald <i>et al</i> ⁸	1985–2009	123 750	22 870
		1985–2009	142 500‡	—
		1985–2009	281 625§	—
		1985–2009	56 250*	—
1982	Nicholson <i>et al</i> ⁴	1985–2009	124 210	81 740
1982	Walker <i>et al</i> ⁹	1985–2009	37 300	15 500

*Extrapolation using Higginson's ratio of 1.5 deaths from lung cancer per death from mesothelioma.

†Lung cancer and other non-mesothelial malignancies.

‡Extrapolation using Enterline's ratio of 3.80 deaths from lung cancer per death from mesothelioma.

§Extrapolation using Enterline's ratio of 7.51 deaths from lung cancer per death from mesothelioma.

|Extrapolation using the time specific ratio of death from lung cancer to deaths from mesothelioma (shown in table 4).

in table 9 of the Walker *et al* report do not agree with either the data provided to Nicholson *et al* by the International Association of Heat and Frost Insulators and Asbestos Workers (as reported by Nicholson *et al* in ref 6) or with the data in the Bureau of Labor reports.¹⁰

In summary, the estimated number of future deaths from asbestos associated malignant mesothelioma varies widely (table 2). This would suggest that no single estimate of future mortality from asbestos associated mesothelioma resulting from past exposures to asbestos may be made. Indeed, it would seem that for such projections an additional estimate would serve only to confuse the issue rather than to clarify it. For the period 1985–2009, the estimates for malignant mesothelioma alone range from 15 500 (Walker) to 300 000 (Bridbord). For the reasons given above, neither of these figures appears reasonable. The two estimates of Nicholson *et al* are also excessive (as noted above) as are those provided by Hogan and Hoel. The projections provided by Enterline, Higginson, Peto and his coworkers, and the McDonalds ranged from 16 650 to 25 000. These figures are reasonable—that is, they are in accordance with current SEER incidence data—and probably represent a fair assessment of the future number of deaths from asbestos associated malignant mesothelioma. In view of the tenuous nature of any precise number, it would appear that between 20 000 and 23 000 deaths would be a fair assessment of the number of cases of asbestos related malignant mesothelioma likely to occur over the next 25 years (1985–2009).

A recent paper by Spirtas *et al* provides some support for this figure.¹⁸ Analysing the most recent incidence data from cancer registries in Los Angeles

County (1972–80), New York State (exclusive of New York City) (1973–80), and the SEER programme (1973–80), they presented the number of cases and age, sex, and race specific annual incidence rates. For both races and both sexes combined (SEER programme only), there were 117 cases annually. Projected for the entire United States population, this would amount to about 1200 cases. The average annual increase was 12.1% for white men and 0.9% for white women. Assuming the increase continues into the early 1990s and then diminishes, there would be about 35 000 cases of malignant mesothelioma among whites in the United States between 1985 and 2009. Using conservative estimates of overdiagnosis (10%) and the proportion of cases not due to asbestos (25%), this would reduce the number of future asbestos related malignant mesotheliomas to 23 625, a number close to the estimate provided above.

Lung cancer

Projection of asbestos related lung cancer mortality is a complex task for several reasons. Firstly, it is currently estimated that the attributable risk of lung cancer to cigarette smoking is about 80%.²⁴ It is known, however that many patients with lung cancer who were occupationally exposed to asbestos were also cigarette smokers.^{11,25} Also, the positive interaction between exposure to asbestos and cigarette smoking that results in the development of lung cancer suggests that some proportion of the 80% attributable risk for lung cancer accorded to cigarette smoking probably results from exposure to asbestos.²⁵ What proportion of that attributable risk for cigarette smoking is in fact attributable to occupational exposure to asbestos is not well established. Secondly, the proportion of the population that either are or

Table 3 Estimated percentages of current and former smokers, adults according to age and sex, in the United States, 1955–75

	1955		1964		1966		1970		1975	
	Current smoker	Former smoker	Current smoker	Former smoker	Current smoker	Former smoker	Current smoker	Former smoker	Current smoker	Former smoker
Men										
21–24	51.4	3.6	67.0	9.5	61.9	7.2	49.8	20.0	41.3	16.0
25–34	63.4	9.0	59.9	18.0	59.9	19.7	46.7	27.9	43.9	22.5
35–44	62.1	11.1	59.9	22.9	59.0	21.9	48.6	31.4	47.1	25.8
45–54	56.9	12.6	53.1	25.3	53.8	26.0	43.1	34.4	41.1	36.0
55–64	43.6	15.7	50.9	24.5	47.7	31.0	37.4	41.4	33.7	38.8
≥65	22.3	13.6	29.9	27.0	27.8	29.5	22.8	43.8	24.2	36.2
All ages	52.6	10.9	52.9	22.2	51.9	23.6	42.3	32.6	39.3	29.2
Women										
21–24	29.7	3.5	41.9	7.6	49.2	7.9	32.3	13.2	34.0	19.9
25–34	35.8	5.8	40.6	9.3	45.1	12.0	40.3	18.9	35.4	16.5
35–44	32.4	4.9	39.2	9.4	40.6	10.5	38.8	15.8	36.4	17.7
45–54	22.8	3.9	36.4	6.8	42.0	9.6	36.1	15.5	32.8	15.5
55–64	10.8	2.6	20.5	7.0	20.6	10.5	24.2	16.0	25.9	15.0
≥65	3.5	1.6	7.8	3.3	7.6	5.2	10.2	8.2	10.2	10.7
All ages	24.5	3.9	31.5	7.4	33.7	9.4	30.5	14.8	28.9	14.5

Source: Office of the Surgeon General.²⁶

were cigarette smokers, while still large, has fallen a great deal during the past two decades (table 3).²⁶ It is well established that cessation of cigarette smoking reduces the risk of developing lung cancer; for ex-smokers 15 years or more after ceasing to smoke, the risk of lung cancer is essentially equal to that of a non-smoker.²⁴⁻²⁶ The extent, however, to which cessation of smoking reduces the risk for a smoker with a history of exposure to asbestos is not known. Hence, any estimate of future lung cancer mortality attributable to exposure to asbestos that takes into account the smoking habits of those exposed will necessarily be at the upper end of the range of estimates. Thirdly, the relative influence of fibre type used on the relative risk estimates is not clear.²⁷⁻²⁹ For example, does the relatively higher use of chrysotile asbestos in the United States result in an appreciably different relative risk estimate compared with the crocidolite asbestos used in the United Kingdom?²⁷⁻²⁹ Finally, for occupations in which a relation to exposure to asbestos has been identified based on the incidence of malignant mesothelioma (automobile repair for example) it is not clear what the corresponding risk of lung cancer might be for that exposure. Indeed, the extent to which such an exposure interacts with cigarette smoking in producing lung cancer is not known and will probably not be definitely determined because of the lack of adequate information on exposure. As with malignant mesothelioma, the survivorship for cases of lung cancer is short; hence, in the present discussion, a case of lung cancer will be considered synonymous with a death.

Higginson, in 1980, developed an estimate of about 1500 cases of lung cancer attributable to exposure to asbestos annually.³ He based this estimate on an annual incidence of about 1000 cases of malignant mesothelioma in the United States and a ratio of 1.5 cases of lung cancer per case of malignant mesothelioma. Since cases of lung cancer have poor survivorship, the total number of deaths from asbestos associated lung cancer for 1985–2000 would be about 37 500. Higginson's approach assumes that all cases of malignant mesothelioma are related to exposure to asbestos. As mentioned earlier, recent work suggesting that as much as 50% of such cases may not be associated with asbestos would indicate that projections based on Higginson's assumptions would result in an overestimate.²¹ On the other hand, Higginson's ratio of 1.5 cases of lung cancer per case of malignant mesothelioma is one of the lowest. This point will be considered further below.

In 1981 one of the authors of the 1978 NIH report, Hoel, developed a different estimate with a colleague (Hogan) at the National Institute of Environmental Health Sciences.² Hogan and Hoel first noted that half the workforce that had been exposed to asbestos was

probably dead by 1980. Also, they assumed that the number of significantly exposed individuals was probably one fourth of that used in calculating the 1978 estimate. They then determined the number of future deaths from asbestos related cancer, expressed as a percentage of future cancers, including malignant mesotheliomas, lung cancers, and gastrointestinal cancer. Deaths resulting from shipyard exposures in the second world war received special emphasis. When the percentage figures were translated into numbers, Hogan and Hoel concluded that about 497 000 deaths from asbestos associated cancer would occur between 1980 and 2010. Of these, some 400 000 would be from lung cancer.

Nicholson *et al* estimated the total deaths from asbestos related cancer for the period 1985–2009 as 185 730.⁵ Hence, there will be about 131 625 deaths due to non-mesothelial malignancies secondary to asbestos exposure. Clearly, not all such malignancies will necessarily be lung cancers; hence, the estimate of 131 625 deaths from cancer is an upper limit for the number of deaths from asbestos related lung cancer. Of interest is their ratio of such asbestos related deaths to deaths from malignant mesothelioma, which is about 2.4, somewhat greater than Higginson's ratio of 1.5.

In the 1982 revision of these estimates Nicholson *et al* followed the same procedure as described above. The details of the calculations, however, were provided in much greater detail in the 1982 publication than in the previous report. Also, whereas the 1981 report concerned projected numbers of malignancies resulting in death before the year 2000, the 1982 revision provided an extension of the estimates up to 2027. For the 25 year period 1985 to 2009, the estimated number of deaths from asbestos related lung cancer is about 124 210 (shown in table XXII of ref 6). For the same period 81 740 deaths from asbestos associated malignant mesothelioma were projected (from table XXIII). The ratio of deaths from lung cancer to deaths from malignant mesothelioma was forecast in the revised estimates to vary with time (table 2).

These ratios will be used in extrapolating from other investigators' projected malignant mesothelioma mortality to obtain estimates of future asbestos related cancer mortality. As a comparison, based on Enterline's estimates, the ratio of deaths from asbestos related lung cancer to deaths from occupationally related malignant mesothelioma is 7.51 (2501/333) whereas the same ratio, irrespective of place of exposure, is 3.80 (2529/666).

The projections from Peto *et al* presented at the 1981 Banbury Conference, may be scaled to provide estimates of the number of expected deaths from asbestos associated lung cancer.⁷ If one used the

Table 4 Ratio of deaths from asbestos associated lung cancer to deaths from malignant mesothelioma in the United States, by time, 1987–2007

No of	Year				
	1987	1992	1997	2002	2007
Lung cancer deaths	5472	5497	5259	4693	3921
Malignant mesothelioma deaths	2398	2748	2969	3060	2999
Ratio of lung cancer to mesothelioma deaths	2.28	2.00	1.77	1.53	1.31

Source: Nicholson *et al.*⁶

Enterline ratio of 7.51 deaths from lung cancer per death from occupational malignant mesothelioma the number of future deaths from lung cancer would be 153 993; using the “overall” Enterline ratio of 3.80, it is 79 919. Both estimates are greater than Enterline’s own estimate of about 63 225 deaths from asbestos associated lung cancer. The projection changes, however, if one uses the ratios of Nicholson *et al* provided in table 4, in which case the estimated number of future deaths from asbestos related lung cancer would be about 36 476. Alternatively, using Higginson’s ratio of 1.5, the projected number would be 30 768. Also presented at the 1981 Banbury Conference was a paper by McDonald and McDonald which suggested that the actual ratio of cases of lung cancer to cases of malignant mesothelioma is of the order of 3.3 or so, never greater than 4.0.⁸ The number of future deaths from malignant mesothelioma attributable to asbestos for 1985–2009 that would be expected by the McDonalds is 37 500.^{8,11} This corresponds to 123 750 deaths from lung cancer attributable to asbestos. For different lung cancer/mesothelioma ratios, the estimate changes accordingly. For instance, the two Enterline ratios of 7.51 and 3.80 correspond to 281 625 and 142 500 future deaths from lung cancer respectively. For the Higginson ratio of 1.5, the estimate would be 56 250 deaths from lung cancer related to exposure to asbestos.

Generally, the projections for deaths from lung cancer may not adequately take into account the effects of cigarette smoking. These estimates need careful review and recalculation to verify that this

effect has been properly adjusted for. The American Cancer Society has estimated that there will be 98 000 new cases of lung cancer among United States men in 1985. If smoking accounts for 85% of all cases of lung cancer as has been estimated in many studies then only 14 700 cases will be due to other factors.²⁴ There is some confounding of cigarette smoking and exposure to asbestos but the importance of cigarette smoking in such calculations cannot be dismissed.

For asbestos related lung cancer mortality, projected for 1985–2009, a review of the estimates in table 2 shows four groups of estimates: one group between 30 000 and 37 500; the second between 56 250 and 79 919; the third between 123 750 and 153 999, and the fourth between 281 625 and 1 440 000. The last group includes two estimates (Bridbord *et al* (unpublished data) and Hogan and Hoel²) that are so great in magnitude that they are clearly overestimates. The third member of this group, 281 625 deaths from lung cancer, is the result of an extrapolation using the Enterline ratio of 7.51 deaths from lung cancer per death from malignant mesothelioma.

Few data support the use of that particular ratio. Indeed, the McDonalds’ review suggests that a 3.3–3.8 ratio is more in line with observed data sets. The lowest group is comprised of estimates that are similarly flawed. The difficulties with the estimate of Walker *et al* were discussed previously. Two other estimates in this group (37 500 and 30 476) were based on the Higginson ratio of 1.5 deaths from lung cancer for each death from malignant mesothelioma. The remaining member of this group, 36 476, is based on the time specific ratio of lung cancer mortality per death from malignant mesothelioma given by Nicholson *et al*. Whereas the magnitude of the Nicholson estimates may be questioned (for reasons stated above), the relative magnitude of the deaths from lung cancer and malignant mesothelioma do not appear to be questionable in their validity. The second group of estimates below 100 000 includes a projection from Peto *et al* using Enterline’s ratio of 3.8 deaths from lung cancer per death from malignant mesothelioma (79 919), Enterline’s estimate of 62 525, and the projection from the McDonalds’ data using Higgin-

Table 5 Summary of listing of projected numbers of asbestos associated digestive system cancers in the United States, by investigator, 1985–2009

Investigator (reference)	Years	Estimated No of digestive system cancers*
Enterline ⁴	1985–2009	31 250
McDonald & McDonald ⁶	1985–2009	33 750
Nicholson ⁶	1985–2009	33 715

*Does not include peritoneal mesothelioma.

Projected asbestos related cancer

son's ratio of 1.5. The latter may be dismissed for the same reason as for the other estimates made using the Higginson ratio—that is, there are few data to support its use. From the third group of estimates, the 1982 projection by Nicholson *et al* was discussed previously. (The 1981 estimate by the same group included cancer sites other than the lung.) The projection of 153 993 was made using the Enterline ratio of 7.51 which, like the Higginson ratio of 1.5, is unsupported by others. Hence, the estimates that appear to be based on published assumptions are 62 525, 79 919, 123 750, and 142 500. Given the best estimate of approximately 20 000 to 23 000 deaths from malignant mesothelioma that would occur between 1985 and 2009 and a ratio of 3.3 to 3.8 deaths from lung cancer for each death from mesothelioma, this would suggest that the projection of deaths from lung cancer should be between 66 000 and 87 400. The Enterline estimate (62 525) is not quite within the range, although it is close. The estimate of Peto *et al* (79 919) is, however, within this range. An average of the upper and lower limits of the range provides an estimate of about 76 700 deaths from asbestos associated lung cancer between 1985 and 2009, inclusive.

Non-respiratory non-mesothelial cancers

The relation of asbestos to cancers of the digestive system is controversial.¹⁸⁻³⁰ Nevertheless, three of the groups that formulated estimates of future lung cancer mortality attributable to asbestos have also formulated estimates of future asbestos related digestive system cancers (table 5). All of these estimates "cluster" between 30 000 and 35 000. Hence, an estimate may be made of about 33 000 non-respiratory non-mesothelial malignancies developing between 1985 and 2009 resulting from prior exposure to asbestos.

Summary

In conclusion, about 131 200 deaths from cancer will occur in the United States from 1985 to the end of 2009 as a result of past occupational exposures to asbestos. This will include about 21 500 deaths from malignant mesotheliomas, 76 700 deaths from lung cancer, and 33 000 deaths from gastrointestinal cancers.

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