Projections of Asbestos-Related Disease 1980-2009

Alexander M. Walker, M.D., D.P.H.; Jeanne E. Loughlin, M.S.; Emmy R. Friedlander, M.S.; Kenneth J. Rothman, D.P.H.; and Nancy A. Dreyer, M.P.H., Ph.D.

Approximately 19,000 cases of mesothelioma and 55,000 cases of lung cancer will arise in U.S. men with histories of nontrivial occupational exposure to asbestos. There are approximately 65,000 U.S. men now alive with clinically diagnosable asbestosis. These estimates are based, in the case of the cancer, on estimates of the effective number of asbestos-exposed workers required to produce the current national incidence of mesothelioma. The asbestosis estimates are based on a number of rough measures relating the prevalence of asbestosis to the incidence of mesothelioma, the incidence of compensable asbestosis in other countries, the prevalence of and mortality from pneumoconioses generally, and the number of workers heavily exposed to asbestos.

Overview

The purpose of this report is to arrive at estimates of the number of cases of mesothelioma, lung cancer, and asbestosis which will arise in the United States between the years 1980 and 2009. This is a slightly different goal from that of others who have made similar attempts, generally restricted to cancers (e.g., Hogan and Hoel 1981 and a number of contributors to the ninth Banbury Report, 1981, edited by Peto and Schneiderman.) Whereas others have tried to estimate the extent of disease attributable to asbestos exposure, we provide here estimates of the total amount of disease in persons with nontrivial exposure to asbestos. We chose this latter approach because the projections were undertaken out of a need to estimate the numbers of lawsuits which might arise from asbestos-exposed, ill persons. Since attribution of the cause of an illness is difficult at best on an individual case basis, all ill persons in an exposed population represent potential litigants, and it is their number that we seek to estimate.

Projection of future cases of mesothelioma and lung cancer depend on a number of steps, all of them starting with the number of cases of mesothelioma occurring in the United States. We begin with the cases of asbestos-related mesothelioma occurring in the late 1970s and infer the size of the asbestos-exposed populations which would be required to produce that number of cases. Using actuarial techniques and Johns-Manville (J-M) case data to provide some details of exposure timing, we then back-calculate to estimate the size of the original exposed work force from the 1930s on whose remnants are now alive. Again using actuarial methods and drawing on known exposure-disease incidence curves, we then project the number of cases of mesothelioma and lung cancer which are likely to occur in the future in the exposed worker population.

Since the clinical manifestations of mesothelioma vary according to the intensity of asbestos exposure, we can make a limited refinement of the procedure above by classifying the projected cases as deriving from relatively heavy or relatively light exposures. This is achieved by comparing the distribution of sites of mesothelioma in known relatively heavily exposed cohorts, such as insulation workers, in whom disease is peritoneal at least half the time, with that observed in the United States as a whole, in which peritoneal disease occurs only 10% of the time.

Projection of the burden of asbestosis in the United States depends both on the rate of occurrence of new disease and on the prevalence of old disease, which may or may not yet have been medically diagnosed in any given individual. Accounting for prevalent but as yet undiagnosed cases of old disease is necessary for asbestosis but not for mesothelioma or lung cancer because the latter cancers are either detected or lead to death (usually both) within a period less than two years after clinical onset of disease. Asbestosis sufferers, on the other hand, may live for many years with diagnosable (but undiagnosed) disease and represent a large pool of potential litigants who can "behave like" new cases at any time, simply by being made aware of the nature and probable origin of their disease.

We have inferred the number of prevalent asbestosis cases in the late 1970s by two principal methods. In the first, we estimate what proportion of mesothelioma cases have diagnosable asbestosis, and we compare this figure to

From the Department of Epidemiology, Harvard School of Public Health, Boston, Mass. (Drs. Walker and Rothman), and Epidemiology Resources, Inc., Brookline, Mass. (Mss. Loughlin and Friedlander, and Drs. Walker, Rothman, and Dreyer).

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the rate at which people with asbestosis develop mesothelioma. Knowing the approximate number of mesothelioma cases with asbestosis and the rate at which mesothelioma occurs in asbestotics, we can calculate about how many asbestosis sufferers there must be in order to account for the observed number of mesothelioma cases occurring among them. In the second method we have drawn on another, independent aspect of the asbestosis-mesothelioma relationship. In studies of groups occupationally exposed to asbestos, the death rates from mesothelioma and asbestosis have been found to be nearly identical. Thus, projections of mesothelioma deaths in persons exposed to asbestos can be expected to give an approximation of the number of asbestosis deaths. Several studies have provided data on the mortality rate in asbestotics and on what proportion of the mortality is due to asbestos. The number of asbestotics can be inferred from the number of asbestosis deaths and the mortality rates in persons with asbestosis.

At this point the asbestosis projections depend on a scientific judgment which has to be made on the basis of very little directly relevant data. The question is: "Do new cases of asbestosis continue to appear many years after the cessation of exposure or, after a certain lag period, does the occurrence of new cases stop?" Put another way: "Does cleaning up the workplace diminish the risk of those workers who have already been heavily exposed to asbestos but, as yet, have no disease?" Preliminary J-M data suggest that cleaning up the work environment does reduce the risk of those already exposed, although not immediately to zero. Asbestosis prevalence projections have been made on the assumption that new cases actually occur through 1984 and that from 1985 on any apparent new cases represent new diagnoses of existent disease.

Several other "quick and dirty" asbestosis projection methods are available. These depend on drawing analogies between the United Kingdom and the United States on use of relative mortality figures, and on the extrapolation of data from x-ray surveys of exposed workers.

J-M data on women are too scanty to allow any direct estimation of the number of cases in women of asbestos-related disease. (Less than 5% of suits derive from women.) Estimating female disease has to be based on deriving approximate proportionality constants: based on the probable historical timing of female workers exposed to asbestos, the current 5% figure can be expected to decline to nearly zero over the next two decades.

The tasks and subtasks which are involved in disease projection are as follows:

1. Determine the effective number of past asbestos workers.
   a. Determine the number of cases of mesothelioma in the United States, 1975-1979.
   b. Calculate the fraction of mesothelioma cases with a documentable history of asbestos exposure and what fraction of the exposed are likely to have been heavily exposed.
   c. Estimate the timing of the exposure history for U.S. cases.
   d. Calculate the number of workers now alive and exposed at different times in the past which would be required to account for the current observed mesothelioma incidence.
   e. Using actuarial techniques, calculate the size of the originally exposed worker population which would yield the estimated numbers of currently living, previously exposed workers.
   f. For exposure in the more recent past (which would give rise to no current disease), estimate exposure which could give rise to future disease.
      i. Use survey data to estimate exposure histories.
      ii. Use information on changing workplace environments to adjust crude exposure estimates.
      iii. Adjust all original estimates of the number of exposed workers so that the total number of cases of mesothelioma being observed is consistent with total estimates of the exposed workforce (distant past plus recent past)
2. Project mesothelioma incidence.
   a. Actuarially adjust the size of the exposed population to account for future mortality and calculate the incidence of new cases in the reduced exposed populations.
   b. Examine sensitivity of projections to component assumptions.
3. Project lung cancer incidence.
   a. As above, adjust the size of the at-risk populations to account for future mortality. Calculate the future incidence of lung cancer as a function of future age, future elapsed time from first exposure, and the future size of the population at risk.
   b Compare projected and observed lung cancer figures.
4. Estimate current and future asbestosis prevalence.
   a. Asbestosis prevalence using mesothelioma mortality in asbestotics.
      i Mesothelioma incidence as in (1a).
      ii Proportion of mesothelioma with asbestosis.
      iii. Estimate frequency of occurrence of mesothelioma in asbestotics.
      iv. Infer prevalence of asbestotics.
      v. Age the 1980-1984 prevalence group using actuarial techniques.
   b. Estimate current and future asbestosis prevalence based on the equivalence of mesothelioma and asbestosis mortality.
      i. Derive expected number of asbestosis deaths from projected mesothelioma deaths.
      ii. Compare asbestosis deaths to death rates in asbestotics to derive an estimate of the number of asbestotics.
      iii. Age the current prevalence pool as in (4a).
   c. "Quick and dirty" projections
      i. U.K./U.S. equivalence.
      ii. Relative mortality data.
      iii. Extrapolation from x-ray surveys
   d. Derive a general methodology for predicting lawsuits given propensity to sue and disease prevalence
5. Estimate the amount of asbestos-related disease likely to occur in women.

Task 1a: Determine the number of cases of mesothelioma in the United States, 1975-1979.

The National Cancer Institute (NCI) has sponsored two major cancer incidence surveillance programs since 1969. The first, covering the period 1969-1971, coordinated existing regional tumor registries and supported the establishment of new registries, permitting a direct assessment of cancer incidence for about 7% of the U.S. population; this was the third National Cancer Survey (TNCS). In 1973, the NCI reconstituted the administrative structure of the TNCS to provide for an ongoing system of monitoring cancer incidence. This new program, named the Surveillance, Epidemiology and End Results program (SEER) has been in operation continuously since then. SEER reporting regions are Hawaii, Seattle, San Francisco-Oakland, New Mexico, New Orleans, Utah, Connecticut, Atlanta, Detroit, and Iowa. Collectively these represent about 10% of the population of the United States. In 1980, the NCI (Connelly 1980) released a detailed report of trends in mesothelioma incidence based on TNCS (1969-1971) and the first six years of SEER (1973-1978). The annual age-specific mesothelioma incidence for males in SEER is given in Table 1, which also provides an estimate of the total number of men developing mesothelioma in the United States in 1977. The age-specific estimated counts were obtained by multiplying the SEER incidence rates times the Census Bureau's 1977 estimates of the U.S. male population in the various age categories.

The implied total of about 854 new cases of mesothelioma in U.S. men in 1977 is probably inaccurate for a number of reasons and should be adjusted accordingly:

1. Comparison of the TNCS (1969-1971) and SEER (1973-1978) age-standardized male incidence figures shows an overall rise from 0.51 to 0.88 cases per 100,000 men per year, approximately a 10% annual increase from the midpoint of the TNCS to the midpoint of the reported SEER years (1975.1.2). To obtain a 1977 incidence figure, a further 15% inflation over the SEER incidence would be appropriate. (The 10% annual increase is virtually identical to the rate of increase in mesothelioma incidence predicted by the incidence models constructed for task 2. That model predicts annual increases of 11.2% in 1970, declining steadily to 8.4% in 1975.)

2. Since the SEER regions contain proportionately more shipbuilding areas than the United States as a whole, the incidence rates are overstated to the extent that mesothelioma occurs more commonly in shipbuilding areas. SEER data suggest that this is indeed the case. The age-standardized white male rates for Seattle and San Francisco are 1.42 and 1.36 cases per 100,000 men annually, while those for Utah and Iowa are 0.82 and 0.54 cases per 100,000 per year. A reasonable estimate as to the overstatement of mesothelioma due to nonrepresentative sampling of the United States in SEER overall would be 10%-15%, with a best guess of about 12%.

3. Finally, the diagnosis of mesothelioma is by no means easy or clear-cut. Selikoff et al. (1980) maintain that a review of all medical evidence in the deaths of U.S. insulation workers from 1967 through 1976 indicates that of 175 mesothelioma deaths only 104 (59%) had mesothelioma recorded on the death certificate. This startling figure may be due in part to the sensitivity of Selikoff and colleagues to the possibility that a difficult-to-diagnose tumor may be mesothelioma. High prior expectation would render diagnosis of mesothelioma more common than it would otherwise be, even in the most competent hands. Nonetheless, it seems likely that any general surveillance scheme will tend to produce underreporting of rare tumors, especially those with ambigous pathology. SEER diagnostic coding is generally felt to be of much higher quality than death certificate information, but the SEER data are regional and they necessarily derive in part from smaller hospitals with less sophistication in diagnosis than is available in cancer referral centers. A reasonable estimate would be that reporting in SEER is about 10% below the reporting that would result if all cases were seen in cancer referral centers and that the diagnosis rates in referral centers are perhaps 20% below the figures that would be reported by a diagnostic group with a high prior expectation of mesothelioma. For the purposes of this report, we will regard "mesothelioma" as that entity which would ordinarily be diagnosed as such in a cancer referral center.

Combining adjustments for time trends, nonrepresentativeness and underdiagnosis in the SEER data one arrives at a best guess for the number of mesothelioma cases occurring in the U.S. men in 1977 not of 854, but of (853.9) (1.15)/(1.12)/(0.90) = 974 cases. The approximate number occurring in the 1975-1979 quinquennium would be 4,870.

Table 1 – Annual Age-Specific Mesothelioma Incidence for Males

Age Group	Incident Cases per 100,000 Men per Year	Implied U.S. Total 1977
0-19	0	0
20-24	0.02	2.0
25-29	0.07	6.1
30-34	0.20	15.2
35-39	0.17	10.2
40-44	0.37	20.2
45-49	1.05	58.9
50-54	1.59	90.8
55-59	2.09	110.1
60-64	3.37	147.6
65-69	3.84	143.6
70-74	5.72	148.5
75-79	6.34	100.7
		853.9

Task 1b: Calculate the fraction of mesothelioma cases which have a documented history of asbestos exposure, and estimate what fraction of the exposed are likely to have been heavily exposed.

Not all mesothelioma occurs in men with a documentable asbestos exposure history. Assuming essentially no asbestos exposure in low incidence SEER regions and assuming that the entire difference in mesothelioma incidence is attributable to asbestos, the differences between the highest and lowest mesothelioma incidence would

suggest that 38% of mesothelioma in the high risk areas might be "background" incidence. (The annual incidence per 100,000 white males ranges from 0.54 in Iowa to 1.42 in Seattle; 0.54/1.42 = 38%.) In low incidence areas, the fraction of disease attributable to background would be even higher. Inquiries undertaken among mesothelioma patients have yielded estimates of the percent with an asbestos exposure history running from 16% to 76%, depending principally on whether cases come from areas with heavy asbestos-using industries. Table 2 summarizes the data from a number of sources.

While much of the variation in Table 2 must result from real differences in the asbestos exposure histories of mesothelioma patients from different regions, there may also be a substantial variation depending on the group interpreting the exposure history. Table 3 (from McDonald and McDonald, 1980) illustrates this phenomenon. Three hundred forty-four male cases of mesothelioma were paired with cases matched for age, sex, hospital and year of death. The comparison cases had died with lung metastases from a nonpulmonary malignant tumor. Job histories were obtained from interview of relatives, coded and submitted to four asbestos research centers for interpretation. While there was general agreement on the proportion with "definite" and "unlikely" exposure to asbestos, there was much less concordance in the interpretation of ambiguous exposure histories. One center, the Environmental Sciences Laboratory of the Mount Sinai School of Medicine, was very much more likely than the others to interpret ambiguous histories as "probable" asbestos exposure.

The consensus U.S. figures (from centers 2, 3 and 4) in Table 3, when averaged, yield an overall figure for the proportion of male mesothelioma cases with a definite or probable history of asbestos exposure of 54%. This number is in the middle of the range of Table 2, and will be used as a best estimate. The proportion with definite exposure appears to be about 20%, averaging the figures from all four centers in Table 3.

A separate line of observation and inference indicates that the proportion of mesothelioma cases attributable to relatively heavy occupational exposure to asbestos is considerably less than the 54% with a definite or probable asbestos exposure history. This is based on the observation of the relative frequencies of involvement of the two major sites of appearance of mesothelioma, the pleura and the peritoneum. As indicated in Table 4, in heavily exposed industrial cohorts, the peritoneum probably accounts for about half of all cases. The most important exception to this pattern arose in a group with what (for an industrial cohort) is an atypical exposure pattern: 75% of the observation time in the group of Australian crocidolite miners reported on by Hobbs et al (1980) was in men with a total duration of exposure of less than 12 months. There were no peritoneal tumors documented among these men. In groups less heavily exposed, the peritoneum is less frequently involved, as indicated in Table 5. The least exposed

Table 2 – Proportion of Mesothelioma Cases With Asbestos Exposure History

Reference	Region; Subjects	Source of Data	Proportion of Cases With Asbestos Exposure (%)
P ** al, 1981	Los Angeles 1974-1978; males	Case or close relative interview	69/101 (68) 69/91* (76)
Vianna et al, 1981	New York State excluding New York City; males, 1973-1978	Death certificate, occupational record	67/193 (35)
Vianna et al, 1981	New York State high incidence counties 1968-1978	Patient or first-degree relative interview	24/31 (77) 17/31† (55)
Tagnon et al, 1980	Coastal Virginia 1972-1978; white males	Patient or next of kin interview	43/56 (77)
McDonald et al, 1973	All Canada (emphasis on Quebec) 1968-1970	Relatives and friends interview	11/69‡ (16) 31/69§ (45)
Newhouse and Thompson, 1965	Patients dying at The London Hospital 1964 and earlier	Surviving relatives, medical records	40/76 (53) 31/76[b] (41)

* Excludes those for whom interviewee was unsure of work history
† Excludes indirect exposure (e.g., family member of an exposed person)
‡ "Definite" or "probable" exposures
§ Includes "possible" exposure as well

groups are the general population series of incident mesothelioma cases, and those cases determined by direct inquiry to have had no identifiable asbestos exposure. In these groups, the proportion with peritoneal disease is on the order of 10% (see Table 6).

From Tables 4-6, it appears that substantial occupational exposure results in mesotheliomas which are at least 50% peritoneal, and that moderate exposure may result in about 20% peritoneal mesotheliomas. If this is true, then only a small fraction of the total contemporary U.S.

Table 3– Distribution (%) of 185 Canadian and 159 U.S. Male Case-Control Pairs According to the Probability of Occupational Asbestos Exposure as Classified in Four Centers*

	Asbestos Exposure							
	Definite		Probable		Possible		Unlikely	
Center†	Cases	Controls	Cases	Controls	Cases	Controls	Cases	Controls
Canada (1960-72)								
1	11.9	1.1	43.8	31.4	4.3	2.7	40.0	64.9
2	11.9	1.1	20.5	14.6	21.1	15.7	46.5	68.6
3	13.5	2.7	29.7	21.1	18.9	20.5	37.8	55.7
4	11.9	1.1	22.7	13.0	22.7	27.6	42.7	58.4
United States (1972)								
1	18.2	3.8	51.6	35.2	3.8	1.9	26.4	59.1
2	18.9	3.8	31.4	18.7	20.8	18.6	28.9	58.9
3	24.5	6.3	34.0	19.5	16.4	19.5	25.1	54.1
4	18.9	3.8	33.3	15.1	22.6	27.0	25.2	54.1

* From McDonald and McDonald (1980)

† Centers. 1 indicates Environmental Sciences Laboratory, Mount Sinai School of Medicine, New York; 2, Gesondsheitsorganisatie TNO, den Haag, the Netherlands; 3, Department of Epidemiology & Health, McGill University, Montreal; 4, TUC Centenary Institute of Occupational Health, London School of Hygiene and Tropical Medicine, London

Table 4 – Relative Frequencies of Peritoneal and Pleural Mesothelioma in Heavily Asbestos-Exposed Groups

Reference	Source Population	Peritoneal	Pleural	Mixed P-P	Other	% Peritoneal or Mixed P-P
Selikoff, 1980	North American insulation workers 1/67 - 12/76	112	63	0	0	64
Newhouse, 1981	English factory workers > 2 yrs exposure	16	10	0	0	62
Newhouse, 1981	English female textile workers	8	12	0	0	40
Finkelstein, 1981	Canadian workers receiving asbestos disability benefits	4	5	0	0	44
McDonald and McDonald, 1980	Insulation workers, asbestos production and manufacture United States and Canada 1960 1972	23	29	0	0	44
Hobbs et al, 1980	Miners and millers of crocidolite W Australia 1943-1966	0	25	0	0	0
Elmes and Simpson, 1976	Mesothelioma in United Kingdom 1/60-12/69 classified from medical records as "heavily exposed to asbestos"	20	64	6	0	29

Table 5 – Relative Frequencies of Peritoneal and Pleural Mesothelioma in Less Heavily Asbestos-Exposed Groups

Reference	Source Population	Peritoneal	Pleural	Mixed P-P	Other	% Peritoneal or Mixed P-P
Elmes and Simpson, 1976	Exposed, but not heavily	10	151	13	0	13
Chovil et al, 1981	"Compensable" mesothelioma in Ontario, including exposure which was "relatively light, or short duration, in the distant past, or all of these"	9	23	0	0	28
McDonald and McDonald, 1980	Heating trades, shipyards, construction (excluding insulation workers), United States and Canada 1960-1975	19	117	0	0	16

mesothelioma incidence (9%-13% peritoneal) can be attributable to heavy occupational exposure: at most about 25% of U.S. cases (the 13% peritoneal and an equal number of pleurals) can be attributable to heavy exposure. In fact, the *true proportion of heavily exposed mesothelioma* cases must be less than 26%, since peritoneal tumors do arise in persons with little or no known asbestos exposure (see Table 6). The 20% with "definite" exposure in Table 3 may provide a more realistic upper limit to the heavily exposed proportion of persons who develop mesothelioma.

Task 1c: Estimate the timing of exposure in U.S. cases.

Allegations in J-M mesothelioma case data provide information on the timing of asbestos exposure in those persons who develop mesothelioma. There are 278 J-M mesothelioma cases who give an analyzable asbestos exposure history: a plausible age at first exposure (between 15 and 54 years of age) and a year of first exposure between 1930 and 1954. (See task 1f for an explanation of the 1954 cutoff.) By five-year age groups we have identified the alleged year of first exposure to asbestos. Applying the percent alleging first exposure at various years in J-M data to the age-specific estimates of asbestos-exposed mesothelioma incidence obtained (after adjustments) from SEER, one can estimate how many cases of mesothelioma occurred among U.S. workers who were first exposed to asbestos at any given age and any given year in the past. This procedure is carried out separately for the 20% of U.S. cases of mesothelioma with presumed heavy exposure, and for the 34% with presumed identifiable light exposure, on

Table 6 – Relative Frequencies of Peritoneal and Pleural Mesothelioma in General Populations and in Cases With No Identifiable Asbestos Exposure

Reference	Source Population	Peritoneal	Pleural	Mixed P-P	Other	% Peritoneal or Mixed P-P
Connelly, 1980	SEER 1973-1978 males	43	369	0	55	9
Breslow, 1982a	TNCS 1969-1971 males	9	83	0	0	10
Breslow, 1982a	U.S. patients entering comprehensive cancer centers 1978-1980	36	234	0	0	13
Elmes and Simpson, 1976	No known exposure	7	52	4	0	11
Baris et al, 1979	Turkish villagers in a hyperendemic area	1	20	0	0	5
McDonald and McDonald, 1980	No occupational exposure, United States and Canadian cases 1962-1975	37	119	0	0	24

the assumption that the relative frequencies of heavy and light exposures did not change greatly until the introduction of dust controls in the workplace in the 1960s and 1970s. Qualitative review of the J-M case data indicates that most current J-M cases are derived from the smaller, heavily exposed portion of the workforce (insulation workers, asbestos factory workers, etc.).

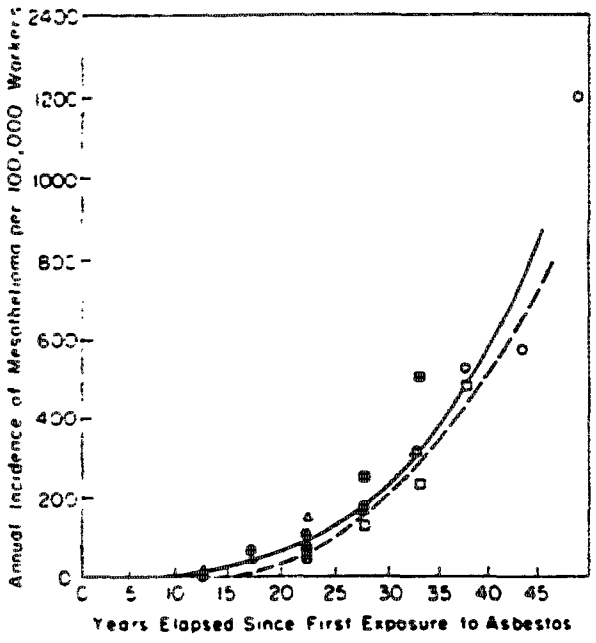
Task 1d: Calculate the number of workers now alive and exposed at different times in the past which would be required to account for the current observed mesothelioma incidence.

How many exposed workers are there? This question can be answered by combining the estimated counts of mesothelioma cases having each exposure history with data on the incidence of mesothelioma in exposed workers.

Peto (Peto et al. 1982) analyzed Selikoff et al's (1980) data on the incidence of mesothelioma in insulation workers and found that incidence could be very closely described by the equation

$$I = 4.37 \times 10^{-8} \times t^{(3.2)} \times P_t,$$

where I is the number of cases of mesothelioma occurring per year, t is the elapsed time in years since first exposure to asbestos and P_t is the size of the population of workers with first exposure t years previously. This incidence curve is graphed as a solid line on the Figure for a hypothetical population of 100,000 people.



Solid line represents Peto incidence curve (Peto et al, 1982); dotted line, Breslow incidence curve (Breslow, 1982). Incidence rates reported by Peto et al (1982) for five studies (see Table 7): open circle is Selikoff et al (1979); open triangle, Newhouse and Berry (1976), open square, Peto (1980); solid circle, Hobbs et al (1980), solid square, Seidman et al (1980). Data from Peto et al (1982).

Having derived the above equation on the basis of Selikoff's data, Peto et al (1982) examined its generalizability by fitting similar equations, with the same exponent (3.2), to data obtained in a variety of settings. Table 7 provides, for five studies, the Peto estimate of the leading constant term in the above equation, the number of mesotheliomas observed and predicted at five-year intervals from first exposure, and the total number of cases observed. Observed incidence rates from the five studies are plotted on the Figure, along with Peto's curve (with the constant term calculated from Selikoff's data). All show a sharp increase beginning 15 years from first exposure and continuing – so far as the data tell – indefinitely thereafter.

Although Peto's equation has the theoretically attractive property that its mathematical form is derivable from current theories of carcinogenesis, it is not the only possible mathematical description of the U.S. insulation worker mesothelioma incidence. Breslow (1982a) has used the same data to estimate the components of a second formula which incorporates an estimated latent period as well as the exponential and constant terms used in Peto's formula. The form of this equation was proposed originally by Newhouse and Berry (1976), and in a statistical sense it fits the observations more closely than does the Peto equation. Using the symbols as above, that incidence equation is:

$$I = 1.37 \times 10^{-5} \times (t - 15)^{1.846} \times P_t.$$

The better fit of this equation to Selikoff's data derives principally from the fact that it predicts no cases to occur in the first 15 years following first exposure; Peto's equation predicts a small number of cases. In fact, in Selikoff's data none were observed to occur. Breslow's function is plotted as a dashed curve on the Figure. The two equations give very similar estimates. Throughout the ensuing analysis, Peto's equation has been used because it appears to provide estimates more consistent with the full range of reported values (as opposed to Selikoff's data alone). Nonetheless, projections carried out using the Peto equation have all been verified using the Breslow equation.

As suggested in task 1a, Selikoff's figures might lead to estimates of more mesothelioma occurrence than would be detectable by competent cancer specialists under ordinary circumstances. We have provisionally adopted a correction factor of 0.6 in Peto's and Breslow's equations relating mesothelioma incidence to asbestos exposure. This has the effect of expanding the size of the exposed population required to account for currently observed mesothelioma cases.

Given the number of cases which have occurred and knowing their alleged elapsed interval since first exposure, one can solve the equations above for P_t. We carried out this procedure for all five-year categories of age at diagnosis of mesothelioma in 1975-1979, and for all elapsed times since first exposure, giving a matrix of P_t's which corresponds to the distribution of asbestos workers alive in 1975-1979, who gave rise to mesothelioma, cross-tabulated by age and year of first exposure to asbestos.

The size of the exposed population calculated in this step is an artificial figure corresponding to "insulation worker equivalents." That is, the number is the number of asbestos workers as heavily exposed as the insulation workers studied by Selikoff who would be required to

Table 7 – Numbers of Pleural (Pl) and Peritoneal (Pt) Mesotheliomas, Both Combined (N), and Man-Years (MY) of Observation in Various Studies. Expected Numbers (Exp) Are Obtained by Fitting Death Rate=b (Time Since First Exposure)$^{3\cdot 20}$ Where b is Constant*

Study		Years Since First Exposure 10-	15-	20-	25-	30-	35-	40-	45-	50+	Total
Selikoff et al (1979), North American insulation workers (mixed exposure, $b=4\cdot37\times10^{-9}$)	Pl			2	8	15	20	6	12	2	65
	Pt			1	14	32	26	19	16	7	115
	N			3	22	47	46	25	28	9	180
	Exp			4·58	22·59	44·28	41·64	31·17	23·59	12 17	180 00
	MY			4,939	12,815	14,711	8,756	4,391	2,328	872	48 812
Newhouse and Berry (1976), factory workers (mixed exposure, $b=4\cdot95\times10^{-8}$)	Pl	1	3	7	5	7					23
	Pt	0	3	8	6	5					22
	N	1	6	15	11	12					45
	Exp	2·59	6·32	10·37	12·84	12·87†					45 00
	MY	16,167	3,438	9,862	6,423	3,772					49,662
Peto (1980) chrysotile textile factory ($b=2\cdot94\times10^{-8}$)	Pl	0	0	1	2	2	2	0			7
	Pt	0	0	0	0	0	0	0			0
	N	0	0	1	2	2	2	0			7
	Exp	0·16	0·52	1·10	1·77	1·69	1·32	0·44			7·00
	MY	1,633	1,860	1,761	1,496	837	414	92			8,093
Hobbs et al (1980) Australian crocidolite miners ($b=5\cdot15\times10^{-8}$)	Pl	1	12	13							26
	Pt	0	0	0							0
	N	1	12	13							26
	Exp	4·53	8·32	13·5‡							26 00
	MY	27,172	17,012	12,028							56,212
Seidman et al (1979), U.S amosite factory ($b=4\cdot91\times10^{-8}$)	Pl	0	0	1	3	3	0				7
	Pt	0	0	1	2	4	0				7
	N	0	0	2	5	7	0				14
	Exp	0·58	1·48	2 73	4·01	4·68	0·52				14·00
	MY	3,628	3,174	2,618	2,026	1,383	98				12,927

* From Peto et al (1982).
† 30 or more years; 32 5 assumed in calculating expected number
‡ 20 or more years; 22 5 assumed in calculating expected number

explain the current mesothelioma experience. As outlined in task 1b, it is likely that only some 37% of exposed mesothelioma cases (20% of the 54%) actually arise in persons with heavy exposure. The remaining cases derive from larger populations with less intense exposure. For the purposes of mesothelioma incidence projections, there is no need to distinguish between the two situations. A population of 100,000 workers at one exposure level can be expected to give rise to the same number of cases as a population of 200,000 at half the exposure. Therefore the "worker-equivalent" has an interpretation which is independent of the actual distribution of intensities of exposure. For lung cancer, the distinction does make a difference: the larger population will have a larger "background" number of lung cancers to which the asbestos-attributable cancers must be added. In either case, the impression of J-M's legal staff at present is that most lawsuits are coming from heavily exposed plaintiffs, indicating that the distinction may be relevant for a person's propensity to sue.

Task 1e: Using actuarial techniques, calculate the size of the originally exposed worker population which would yield the estimated numbers of currently living, previously exposed workers.

Every group of workers now alive with first exposure at some time in the past corresponds to an originally exposed population, some members of which have died with the passage of time. We have used white male actuarial survival tables covering the years 1930-1979 to calculate the originally exposed population as follows: call the population alive in year y, of age a, with time t since first exposure, $P_{a,t,y}$. Call the same population t years previously (when they were $a-t$ years old), $P_{a-t,O,y-t}$. If the actuarial probability for survival from age $a-t$ to age a, starting in year $y-t$, is $S_{a-t,a,y-t}$ then

$$P_{a-t,O,y-t} = P_{a,t,y}\ S_{a-t,a,y-t},$$

where $P_{a-t,O,y-t}$ is the number of workers entering the asbestos-exposed work force in year $y-t$ at age $a-t$ who would be required to produce in year y a surviving exposed population of size $P_{a,t,y}$. If that surviving exposed population has already been derived (task 1d) as the one large enough to produce the estimated number of new exposed cases of mesothelioma of age a who report having been first exposed to asbestos t years previously, then $P_{a-t,O,y-t}$ is the size of the new workforce t years earlier which would be required to account for the current mesothelioma experience.

A modification of the actuarial survival figures was necessary before carrying out the above calculations. As noted in task 1b, some 20/54=37% of the insulation-worker equivalents estimated here derived from heavily exposed individuals. Selikoff has noted that insulation workers have a 37% higher overall mortality rate than the general population. As a result, a group consisting of 37% heavily exposed workers has approximately a (37%)(37%) = 14% higher mortality rate than the general population. This

correction factor has been introduced into all calculations of the survival of nondiseased, asbestos-exposed groups of insulation-worker equivalents.

Task 1f: For exposure in the more recent past which would give rise to no current disease, estimate the quantity of exposure, since this could still give rise to future disease.

The procedures of task 1d and 1e begin breaking down when first exposures less than 20 years prior to the 1975-1979 period are considered. Few cases of mesothelioma would have as yet arisen from this period, because of the delayed rise in the mesothelioma incidence curve; thus it is impossible to work backwards to the exposed population with any reliability. Instead, we have used the reported distribution of age at first entry into an asbestos-related industry from a survey of men aged 40 and above conducted for JM by the firm of Elrick and Lavidge. Although that survey does not allow us to calculate the absolute number of heavily exposed asbestos workers entering the workforce each year, it does allow us to calculate the relative number entering. Altogether the Elrick and Lavidge survey identified 214 individuals who had worked in an asbestos-using industry, of whom 79 were aware of actual exposure to asbestos dust. The results of the survey were as shown in Table 8, from which it is apparent that the distribution of years of entry into asbestos-using industries is essentially identical for men who did recall and those who did not recall direct asbestos exposure. We have based our adjustments on the larger, statistically more stable numbers of all entrants into asbestos-using industries.

The workforce was calculated directly from the mesothelioma incidence data through 1954. From 1955 on we assigned numbers proportional to the number of men in the Elrick and Lavidge survey reporting entry into the workforce in each quinquennium. Adding the post-1955 workers generally resulted in a small increase in the predicted numbers of mesotheliomas for 1975-1979. Both pre- and post-1955 figures were then iteratively adjusted until: (1) the pre-1955 figures maintained the year of first exposure distribution implied by the J-M cases, (2) the post-1955 figures stood in the proportion to the pre-1955 that was dictated by the survey, and (3) the 1975-1979 mesothelioma predictions derived from the resulting distribution of exposed workers equaled the number actually thought to have occurred.

From 1965 on, it is probable that exposed workers faced diminishing amounts of ambient asbestos fiber. We have accounted for this by recalculating the overall workforce size (as above) but with smaller fractions of the exposed workforce assigned to the post-1955 period. (In effect this amounts to modeling the health effects of an unchanged number of workers exposed to less and less asbestos by assuming smaller and smaller numbers of workers exposed to essentially the same amount of asbestos.) Workforce discounts used to compensate for recent improvements in the workplace were: 1960-1964, 10%; 1965-1969, 50%; 1970-1974, 75%; 1975-1979, 100%.

Table 9 gives the number of insulation-worker equivalents entering the workforce for each quinquennium 1930-1974, as estimated from J-M data directly through 1954, and with adjustment of the post-1955 figures to match the survey data in their calendar year distribution. Of particular interest is the general conformity of the worker distribution for earlier years (as inferred from J-M data) to that actually observed in the Elrick and Lavidge survey.

Table 9 also gives the number of insulation-worker equivalents entering the workforce in each quinquennium from 1930 to 1979, according to intensity of exposure. For the heavily exposed group, one equivalent can be taken to equal (more or less) one worker. For the less heavily exposed group, there may be as many as five or 10 actual workers making up each insulation-worker equivalent.

Task 2a: Adjust exposed population and calculate future incidence of mesothelioma.

For every five-year period in the future, we calculated the number of mesothelioma cases that would be expected to arise out of each group of workers we estimated to have entered the workforce at each age-of-entry in each calendar-

Table 8 – Year of Entry Into the Asbestos-Exposed Workforce

Year	Workers Who Recalled Asbestos Exposure			All Workers In Asbestos-using Industries		
	Number	%	Cumulative %	Number	%	Cumulative %
Before 1930	5	6.3	6.3	16	7.5	7.5
1930 1934	1	1.3	7.6	9	4.2	11.7
1935-1939	6	7.6	15.2	19	8.9	20.6
1940 1944	17	21.5	36.7	45	21.0	41.6
1945 1949	14	17.7	54 4	29	13.6	55.1
1950 1954	5	6.3	60.8	19	8.9	64.0
1955 1959	10	12.7	73.4	29	13.6	77.6
1960 1964	9	11.4	84.8	21	9.8	87.4
1965 1969	7	8.9	93.7	14	6.5	93.9
1970 1974	1	1.3	94.9	5	2.3	96.3
1975 1979	4	5.1	100.0	8	3.7	100.0

Table 9 – The Dissemination of Asbestos Exposure Insulation-Worker Equivalents Entering the U.S. Labor Force

	Heavily Exposed*	Lightly Exposed†	Total‡
1930-1934	2,700	3,700	6,400
1935-1939	13,800	18,100	31,900
1940-1944	55,900	74,900	130,800
1945-1949	35,400	49,900	85,300
1950-1954	38,100	59,400	97,500
1955-1959	34,900	49,300	84,200
1960-1964	22,700	32,100	54,800
1965-1969	8,600	12,200	20,800
1970-1974	1,400	2,100	3,500

* In the heavily exposed, each insulation-worker equivalent corresponds roughly to a single worker

† Many lightly exposed individuals are required to make up a single insulation-worker equivalent (listed in the table)

‡ The total number of insulation-worker equivalents, *not* the total of exposed workers

quinquennium in the past. Using the notation of previous sections, call a the age in 1975-1979, and t the number of years elapsed since first exposure in year y. Call p the number of years into the future for which a projection is being made. Then the age at first exposure is $(a-t)$, age in the projected future year is $(a+p)$, and elapsed time from first exposure in the future is $(t+p)$. The components of the projection equation (Peto et al, 1982) are:

$I_{a+p,t+p}$ – The number of new cases of mesothelioma p years from 1975-1979 among persons then aged $(a+p)$ with time elapsed since first exposure $(t+p)$.

$P_{a-t,O,y}$ – The number of persons entering the asbestos workforce t years prior to 1975-1979, at age $(a-t)$, in year y.

$S_{a-t,a+p,y}$ – Actuarial survival from age $(a-t)$ in year y to age $(a+p)$, taking into account recorded actuarial survival for calendar years prior to 1979, and assuming age-specific mortalities after 1979 to be unchanged from their late 1970s values.

K – A constant term derived from Selikoff's observation of insulation workers (Peto et al, 1981), 4.38×10^{-8} for one-year incidence, 2.19×10^{-7} for five-year incidence, multiplied by a correction factor (0.8) for higher diagnosis rates in Selikoff's data.

The projection equation is:

$$I_{a+p,t+p} = P_{a-t,O,y} \times S_{a-t,a+p,y} \times K \times (t+p)^{3.2}.$$

The estimated populations of exposed workers presented at the end of task 1 in Table 9 yield projections of mesothelioma incidence shown in the first column of Table 10 for the years 1980-2009.

Use of Breslow's projection equation to derive the exposed population and the resultant mesothelioma incidence leads to very similar projected counts, as seen in the second column of Table 10. Redefining K to equal 1.37×10^{5}, again multiplied by an 0.8 correction factor, the Breslow projecting equation is:

$$I_{a+p,t+p} = P_{a-t,O,y} \times S_{a-t,t+p,y} \times K \times (t+p-15)^{1.846}.$$

Table 10 – Projected Numbers of New Mesothelioma Cases 1980-2009 in Men With Plausible Asbestos Exposure Using Two Models of Incidence

	No Latency Period (Peto)	Latency Period (Breslow)
1980-1984	3,200	3,400
1985-1989	3,500	3,900
1990-1994	3,600	4,200
1995-1999	3,400	4,000
2000-2004	2,900	3,500
2005-2009	2,100	2,500
Total 1980-2009	18,700	21,500

Task 2b: Estimate the sensitivity of mesothelioma projections to the assumptions involved.

Assumptions underlying the mesothelioma analysis fall into two categories, depending on whether they are reflected in the final mesothelioma projections in a linear or nonlinear fashion. The linear factors affect the height of the projected curve, whereas the nonlinear factors affect its shape.

The linear factors are those of task 1a (corrections of trend in incidence, nonrepresentativeness of the SEER populations, general underdiagnosis of mesothelioma) and task 1b (fraction of mesothelioma cases exposed to asbestos). While the net effect of uncertainties in these elements may be as much as 30% either way, it is crucial to bear in mind that the ultimate projections of mesothelioma lawsuits must be tied to the number of suits currently occurring in relation to the number of cases of disease occurring ("propensity to sue") so that these variations in absolute incidence have no final effect on projections for numbers of lawsuits.

Nonlinear effects, because they affect the shape of the future mesothelioma curve, are highly relevant to projections of suits. The shape of the curve is relatively robust to large variations in the nonlinear parameters. Assuming that the reported years of first exposure to asbestos in the J-M files were off by five years in either direction gives very distorted year of entry distributions (with peak employment coming before or after the war) and only shifts the incidence peak forward or backward five years, but does not change its broad, relatively flat character. Changing the age distribution of current mesothelioma [illegible] (in the SEER data) by assigning 30% more cases to [illegible] and older or to the under 50-year-old age groups shows similar five-year shifts in the incidence peak. Assuming that the workplace was entirely cleaned up by 1965 slightly increased the short-term projections for mesothelioma and decreased the long-term ones, since the effect of recent exposures (or nonexposure) can be expected to be felt only many years in the future. Assigning all worker-equivalents the higher mortality of insulation workers leads to slightly faster decline in the pool of exposed workers, and a 5%-10% drop in late (post-year 2000) estimated mesothelioma incidence. Assuming that mortality of exposed workers is that of the general population leads to a 5% increase in late mesothelioma incidence.

Task 3a: Adjust the size of the exposed population and calculate future incidence of lung cancer.

The incidence of lung cancer among asbestos workers has been reasonably well documented by Selikoff et al (1980) and others (Berry 1980, McDonald et al 1980, Henderson and Enterline 1979) to be the product of two terms: the "underlying risk" for lung cancer that would hold in the absence of asbestos exposure, and a multiplication factor resulting from exposure. The underlying lung cancer risk is a sharply rising function of age. From the 1973-1978 NCI report of the SEER program the underlying risk for white males is as given in Table 11.

The asbestos-multiplier calculated by Selikoff et al varies not with age, but with elapsed time since first exposure. Values for the multiplier are given in Table 12.

Although the data which Selikoff has assembled on insulation workers represents the largest, statistically most reliable source of follow-up information, there have been a number of other studies of exposed cohorts. These are summarized in Table 13. Among all occupational groups, insulators are matched only by factory workers for their levels of lung cancer risk. Miners and, even more so, shipyard workers have much lower risk multipliers, the former possibly because ambient fiber concentrations are lower in mining than in processing jobs, the latter almost certainly because the category "shipyard worker" includes many people with minimal exposure.

The multipliers observed by Selikoff are unlikely to be purely the result of asbestos exposure. To the extent that the asbestos-exposed workers studied by Selikoff differed in their smoking habits from the general population, the multipliers include this effect as well. If part of the purpose of the projections was to estimate what fraction of cases in exposed workers were actually attributable to asbestos exposure, lack of smoking data from Selikoff's workers would represent a serious lack. In fact, the purpose of the projection is to decide how many cases of lung cancer occur in toto among exposed workers. For this purpose, it is sufficient to assume that the workers observed by Selikoff have approximately the same fraction of smokers as do asbestos workers in general. This appears to be a reasonable assumption, even for future projections. Although there has been a decrease in adult male smoking in the United States, the trend appears to include blue-collar workers to a smaller extent than others (Surgeon General 1979).

Table 11 – Incidence of Lung Cancer – Underlying Risk

Age (yrs)	New Cases of Lung Cancer per 100,000 White Men per Year
20-24	0.2
25-29	0.6
30-34	2.6
35-39	7.4
40-44	22.8
45-49	58.3
50-54	106.8
55-59	181.7
60-64	284.2
65-69	400.9
70-74	481.5
75-79	519.0

Table 12 – Selikoff Asbestos-Multiplier*

Time Since First Exposure, yrs	Multiplication Factor
10-14	2.55
15-19	3.40
20-24	3.48
25-29	5.00
30-34	6.08
35-39	5.68
40-44	4.93
45-49	3.89

* From Selikoff et al (1980)

Selikoff's multipliers above describe the experience of a cohort of workers with lifetime exposure to asbestos, and may not correctly predict the future experience of workers, after occupational exposure to asbestos has been curtailed. Observations in chrysotile miners (Berry 1980; McDonald et al 1980) and asbestos factory workers (Henderson and Enterline 1979) have lent strong support to the idea that relative risk for lung cancer (i.e., the multiplier) may be nearly linearly related to accumulated asbestos exposure over a fairly wide range. Selikoff's multipliers can be interpreted as reflecting a reasonably steady rise through working life with a decline beginning around the time of retirement, that is about the time of cessation of asbestos exposure. We have incorporated this phenomenon into the projection equations by constraining the lung cancer multipliers for each exposure cohort to decline from their 1975-1979 value at a rate of 10% per quinquennium. It should be noted that while this discounting of later multipliers fits the Selikoff data most closely, there is no a priori reason to expect a decline, and mathematical modeling of other, smaller bodies of data does not suggest a decline. While the values used represent our "best estimate" for projections, experts who disagreed would probably choose somewhat higher multipliers and consequently would project somewhat larger numbers of cases.

The projection equation has the following components:

$I_{a+p,t+p}$ – The number of new cases of lung cancer p years from 1975-1979 among persons then aged $(a+p)$ years with time elapsed since first exposure $(t+p)$.

$P_{a-t,O,y}$ – The number of persons entering the asbestos workforce t years prior to 1975-1979, in year y at age $(a-t)$

$S_{a-t,a+p,y}$ – Actuarial survival from age $(a-t)$ to age $(a+p)$, beginning in year y.

L_{a+p} – The underlying risk of lung cancer as determined from NCI tables for white males of age $(a+p)$.

M_t – Lung cancer risk multiplier for elapsed time since first exposure through 1975-1979 (t), reduced by 10% for each subsequent quinquennium.

The projecting equation is

Table 13 – Risk Multipliers for Lung Cancer From Cohort Studies*				
Source	Minimum	(Years Following Exposure)	Maximum	(Years Following Exposure)
Insulators,				
Selikoff et al (1980)	0	(<10)	6.03	(30-34)
Factory workers				
Henderson and Enterline (1979)	1.8	†	7.78	†
Newhouse and Berry (1979)	2.42	(<2)‡	5.38	(>2)‡
Peto et al (1977)	1.25	(10-14)	1.71	(>20)
Cement workers				
Huges and Weill (1980)	0.77	(10-15)	3.33	(30-35)
Shipyard workers (except insulators),				
Kolonel et al (1980)	1.1	(<10)	1.3	(>10)
Miners				
McDonald et al (1980)	0.80	(<1)‡	2.65	(>20)‡
Nicholson et al (1979)	...	...	4.19	(40-49)
Hobbs et al (1980)	2.10	(0-9)	2.46	(>15)

* In each study, if several exposure levels were given, the highest is reproduced here
† Time data not given separately from accummulated dust exposure
‡ Time figures are for years of employment

$$I_{a\to p,t\to p} = P_{a-t,0} \times S_{a-t,a\to p} \times L_{a\to p} \times M_{t\to p}.$$

The projected incidence is calculated for each worker group entering the workforce at every age in every past year, and the projected number of cases occurring in every five-year period are summed.

The projection procedure described above is by itself correct only for a heavily exposed worker cohort (such as insulation workers or factory workers). For a less heavily exposed cohort such as shipyard workers, the projection predicts only the asbestos-attributable disease, plus the background lung cancers which would be found in a population whose size corresponds to the number of insulation worker equivalents. When the insulation-worker equivalent exposures are spread out over a larger number of persons, more background disease needs to be recognized in order to project the total burden of lung cancer (both spontaneous and asbestos-attributable) in asbestos-exposed persons. Table 14 presents projections of lung cancer for a worker population which on the average is about one half as intensely exposed to asbestos as insulation workers. Since our best estimate is that 37% of the "insulation worker-equivalents" are indeed heavily exposed, this implies that the remaining 63% of equivalents arise in workers whose exposure intensity is 2.6 times less than that of an insulation worker

Task 3b: Compare projected and observed lung cancer figures.

Since no part of the model used to predict lung cancer incidence is based on data from lawsuits coming in to J-M, it is possible to test partially the validity of the projections by comparing details of the J-M litigation file against the model's projections. Table 15 displays the distribution of alleged year of first exposure to asbestos among the 349 J-M cases aged 40-79 who filed suit claiming lung cancer in the years 1975-1981, and who further gave a sufficiently detailed exposure history to allow them to be classified. The percent distributions are further cross-classified by the age at which suit was filed. In parallel are the age-specific distributions of years of first exposure to asbestos for the 22,248 male lung cancer cases for the period 1975-1979 predicted by the model developed in tasks 1 through 3. Lung cancer is less well connected with asbestos exposure than is mesothelioma, both in the medical and in the legal communities, and so there may be an increased element of serendipity in bringing cases of disease to litigation. Nonetheless, there appears to be a fair correlation between the observed and predicted distribution of years of first exposure, particularly in the overall figures. Although the lawsuits tabluated do not represent the total number coming in to J-M (most do not have detailed asbestos exposure data), their distribution over age categories reflects a plausible pattern of litiginosity when

Table 14 – Projected Numbers of New Lung Cancer Cases 1980-2009 in U.S. Men Plausibly Exposed to Asbestos	
Year	No. of New Cases
1980-1984	17,800
1985-1989	13,600
1990-1994	10,200
1995-1999	7,000
2000-2004	4,300
2005-2009	2,200
Total	55,100

Table 15 – Lung Cancer. Percent Distribution of Year of First Exposure to Asbestos Products Alleged in Lawsuits (1975-1981) and Predicted by Model (1975-1979)

Age at Diagnosis /Lawsuit		1930-1934	1935-1939	1940-1944	1945-1949	1950-1954	1955-1959	1960-1964	1965-1969	1970-1974	Total %	Count
40-49	L*	2.7	2.7	13.5	8.1	35.1	18.9	8.1	8.1	2.7	100.0	37
	M*	0	0	0	19.7	30.2	29.2	15.5	4.6	0.7	100.0	698
50-59	L	1.6	9.0	30.3	23.0	18.0	9.0	5.7	2.5	0.8	100.0	122
	M	0	2.7	20.3	19.5	20.7	23.0	11.5	2.1	0.1	100.0	3770
60-69	L	4.2	15.5	33.1	22.3	10.1	6.8	4.7	1.4	1.4	100.0	148
	M	3.9	11.0	35.1	16.3	14.5	15.4	3.6	0	0	100.0	8313
70-79	L	7.1	16.7	33.3	14.3	7.1	7.1	7.1	7.1	0	100.0	42
	M	0.6	10.4	56.0	20.3	12.4	0	0	0	0	100.0	9443
Total	L	3.7	12.0	30.1	20.1	15.2	8.9	5.7	3.2	1.1	100.0	349
	M	1.8	9.0	40.3	18.7	15.1	10.6	3.9	0.5	0.0	100.0	22,248

* L: lawsuits with analyzable exposure data registered at JM

* M: model projections of total number of lung cancer cases arising in asbestos-exposed men in the United States

compared to the projected distribution of lung cancers. The highest propensity to sue appears to be in the 40-49 year age group, with a gradual tailing off to age 69, and a precipitous drop thereafter.

Task 4: Estimate current and future asbestosis prevalence.

Unlike persons with mesothelioma or lung cancer, persons with asbestosis are likely to live many years after the onset of their disease. Much or all of that time they may be unaware that their symptoms are due to asbestosis. From the point of view of medical and legal awareness of the disease, then, the key event in the progression of a case of asbestosis is not the date of onset, but rather the date of diagnosis. For predicting the rates of diagnosis (and hence suit), the key underlying figure to examine is the prevalence of potentially diagnosable cases in the general population.

There are no direct measures of the prevalence of diagnosable asbestosis in the United States. There are, however, methods of arriving at educated guesses. One depends on the occurrence of mesothelioma in persons with asbestosis; another depends on an equivalence between asbestosis mortality rates and mesothelioma mortality rates.

Task 4a: Predict asbestosis using mesothelioma mortality rates in asbestotics.

Elmes and Simpson (1976) have reviewed the clinical, pathologic and radiographic records of 327 cases of mesothelioma occurring in the United Kingdom between 1960 and 1969. They found that 70/247 cases with chest radiographs (28%) had clear radiographic evidence of concurrent asbestosis. *This figure is not a biological constant; rather it* probably reflects the particular distribution of intensities and durations of exposure to asbestos which U.K. mesothelioma cases had undergone in the 1960s. If the general historical pattern of asbestos exposure in the United States is similar to that in the United Kingdom, then one may estimate that about 28% of the cases of mesothelioma in the United States, about 273 developed mesothelioma each year.

Three studies give rates of occurrence of mesothelioma in persons with asbestosis which are of the same order of magnitude. Berry (1981) provides the most extensive data: 25 cases of mesothelioma occurred in 665 Englishmen with asbestosis certified for the purpose of disability insurance, followed for 4,165 man-years of follow-up between 1952 and 1976. Thus, he found a rate of one case per 166 man-years. A total experience about three fifths as large was reported by Edge (1979) who observed seven cases of mesothelioma in 2,637 man-years of observation in 429 men who had been identified by chest radiographs showing pleural plaques taken between 1964 and 1971 in an English shipyard community. His observed rate is one case per 377 man-years of observation. Least informative because of its small amount of observation is the report of Finkelstein et al (1981) who studied mortality among 172 workers receiving workman's compensation for asbestosis in Ontario between 1942 and 1979 followed for 733 man-years. There were three death certificate records of mesothelioma (one per 244 man-years) and six further cases identified by review of other records (total of one case per 81 man-years of observation). Totaling the experience recorded in the three studies, one obtains reports of 41 cases in 7,535 man-years of observation, or one case in 184 man-years of observation. Exclusion of the six Finkelstein cases discovered only after record review would give an overall rate of one case of mesothelioma per 215 man-years. We have chosen a figure of one per 200 man-years as a summary figure.

As with the 28% figure for the fraction of mesothelioma cases with asbestosis, *the one per 200 man-years estimate* for mesothelioma in asbestosis should not be taken to be a biological constant. It too probably reflects the distribution the United States in the late 1970s, or about 273 cases annually, had concurrent diagnosable asbestosis. Put another way, of all the people with diagnosable asbestosis

Table 15 – Lung Cancer Percent Distribution of Year of First Exposure to Asbestos Products Alleged in Lawsuits (1975-1981) and Predicted by Model (1975-1979)

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	M*	0	0	0	19.7	30.2	29.2	15.5	4.6	0.7	100.0	698
50-59	L	1.6	9.0	30.3	23.0	18.0	9.0	5.7	2.5	0.8	100.0	122
	M	0	2.7	20.3	19.5	20.7	23.0	11.5	2.1	0.1	100.0	3770
60-69	L	4.2	15.5	33.1	22.3	10.1	6.8	4.7	1.4	1.4	100.0	148
	M	3.9	11.0	35.1	16.3	14.5	15.4	3.6	0	0	100.0	8213
70-79	L	7.1	16.7	33.3	14.3	7.1	7.1	7.1	7.1	0	100.0	42
	M	0.6	10.4	56.0	20.3	12.4	0	0	0	0	100.0	9443
Total	L	3.7	12.0	30.1	20.1	15.2	8.9	5.7	3.2	1.1	100.0	349
	M	1.8	9.0	40.3	18.7	15.1	10.6	3.9	0.5	0.0	100.0	22,248

* L: lawsuits with analyzable exposure data registered at JM
* M: model projections of total number of lung cancer cases arising in asbestos-exposed men in the United States

compared to the projected distribution of lung cancers. The highest propensity to sue appears to be in the 40-49 year age group, with a gradual tailing off to age 69, and a precipitous drop thereafter.

Task 4: Estimate current and future asbestosis prevalence.

Unlike persons with mesothelioma or lung cancer, persons with asbestosis are likely to live many years after the onset of their disease. Much or all of that time they may be unaware that their symptoms are due to asbestosis. From the point of view of medical and legal awareness of the disease, then, the key event in the progression of a case of asbestosis is not the date of onset, but rather the date of diagnosis. For predicting the rates of diagnosis (and hence suit), the key underlying figure to examine is the prevalence of potentially diagnosable cases in the general population.

There are no direct measures of the prevalence of diagnosable asbestosis in the United States. There are, however, methods of arriving at educated guesses. One depends on the occurrence of mesothelioma in persons with asbestosis; another depends on an equivalence between asbestosis mortality rates and mesothelioma mortality rates.

Task 4a: Predict asbestosis using mesothelioma mortality rates in asbestotics.

Elmes and Simpson (1976) have reviewed the clinical, pathologic and radiographic records of 327 cases of mesothelioma occurring in the United Kingdom between 1960 and 1969. They found that 70/247 cases with chest radiographs (28%) had clear radiographic evidence of concurrent asbestosis. This figure is not a biological constant; rather it probably reflects the particular distribution of intensities and durations of exposure to asbestos which U.K. mesothelioma cases had undergone in the 1960s. If the general historical pattern of asbestos exposure in the United States is similar to that in the United Kingdom, then one may estimate that about 28% of the cases of mesothelioma in the United States, about 273 developed mesothelioma each year.

Three studies give rates of occurrence of mesothelioma in persons with asbestosis which are of the same order of magnitude. Berry (1981) provides the most extensive data: 25 cases of mesothelioma occurred in 665 Englishmen with asbestosis certified for the purpose of disability insurance, followed for 4,165 man-years of follow-up between 1952 and 1976. Thus, he found a rate of one case per 166 man-years. A total experience about three fifths as large was reported by Edge (1979) who observed seven cases of mesothelioma in 2,637 man-years of observation on 429 men who had been identified by chest radiographs showing pleural plaques taken between 1964 and 1971 in an English shipyard community. His observed rate is one case per 377 man-years of observation. Least informative because of its small amount of observation is the report of Finkelstein et al (1981) who studied mortality among 172 workers receiving workman's compensation for asbestosis in Ontario between 1942 and 1979 followed for 733 man-years. There were three death certificate records of mesothelioma (one per 244 man-years) and six further cases identified by review of other records (total of one case per 81 man-years of observation). Totaling the experience recorded in the three studies, one obtains reports of 41 cases in 7,535 man-years of observation, or one case in 184 man-years of observation. Exclusion of the six Finkelstein cases discovered only after record review would give an overall rate of one case of mesothelioma per 215 man-years. We have chosen a figure of one per 200 man-years as a summary figure.

As with the 28% figure for the fraction of mesothelioma cases with asbestosis, the one per 200 man-years estimate for mesothelioma in asbestosis should not be taken to be a biological constant. It too probably reflects the distribution the United States in the late 1970s, or about 273 cases annually, had concurrent diagnosable asbestosis. Put another way, of all the people with diagnosable asbestosis

of intensities and durations of exposure to asbestos holding roughly over the two decades ending in 1975.

If, however, we accept the rate of one case of mesothelioma per 200 asbestotics per year, and combine this with the expected number of mesothelioma-asbestosis cases derived before, i.e., 273, we arrive at an overall estimate of about 55,000 persons with diagnosable asbestosis in the United States in the late 1970s.

Expressed algebraically, the line of reasoning above is as follows. Let I be the annual incidence of mesothelioma in asbestotics; let A be the number of asbestotics in the United States; let M be the annual number of new mesothelioma cases in the United States; and let P be the proportion of those with concurrent asbestosis, then $A \times I = M \times P$ and $A = M \times P/I$.

Substituting known or estimate values. $A = (974)(0.28)/(1/200)$; $A = 54{,}544$ men with asbestosis.

At present it is not known for how long new cases of asbestosis will continue to develop among currently healthy workers previously exposed to asbestos, assuming that workplace contamination has been essentially eliminated since 1975, and greatly reduced prior to that. J-M's worker experience indicates that there has been a precipitous decline in new cases of asbestosis over the last decade (Chase 1981). This would argue in favor of not projecting the occurrence of new cases beyond 1985. As a best estimate then, we have based asbestosis prevalence projections on an assumption of continued new occurrence through the first half of this decade. Starting from the projected mesothelioma incidence in 1980-1984, we have projected asbestosis prevalence in each age group for 1980-1984 using the projection equation described above.

For projections beyond 1984, we have aged the populations using modified 1977 white male actuarial survival figures. The modification is based on strong evidence of very much higher mortality rates in men with asbestosis than in the general population. Berry (1981) reports on 283 deaths in asbestotics with only 108.6 expected; Finkelstein et al (1981) report 66 deaths in asbestotics with only 16.6 expected. Together these give an overall mortality for asbestotics 2.79 times that which would otherwise be expected. Table 16 provides our projections of annual diagnosable asbestosis prevalence for each quinquennium through the year 2009.

Of particular importance in interpreting Table 16 (and Table 18 in the following task) is that the prevalence figures are for clinically diagnosable (not necessarily diagnosed) asbestosis which would qualify for workman's compensation in the United Kingdom or Canada. This is inescapable, because the only detailed survival figures available on men with asbestosis derive from these registered and monitored groups. Depending on the criteria used, very much more "asbestosis" can be diagnosed on the basis of minimal radiologic changes. Table 17 (Selikoff 1976) illustrates the problem. Chest x-rays of 1,117 men were graded according to the degree of asbestosis, classified on a four-point scale ranging from 0 (no disease) to 3 (severe asbestosis). The readings were cross-classified by time since first exposure to asbestosis. It is very unlikely that workers with Selikoff's minimal (grade 1) asbestosis would qualify for workman's compensation. If such workers were to be included in prevalence estimates, however, the projections of Tables 16 or 18 (task 4b) would have to be roughly tripled.

Task 4b: Estimate asbestosis prevalence using the equivalence between asbestosis and mesothelioma mortality.

A second line of reasoning about asbestosis prevalence can lead to an independent estimate by which to gauge the results of the previous task. This is based on the near perfect identity of the time course and magnitude of asbestosis mortality and mesothelioma mortality in Selikoff et als (1980) insulation worker data, combined with independent estimates of mortality in men with asbestosis.

It is of particular importance that the asbestosis mortality recorded by Selikoff is not simply an estimate of mortality in men with asbestosis, but rather specifically of mortality from deaths due to asbestosis. Berry (1981) found that 56 of 263 deaths (21.3%) in British men with asbestosis were actually attributed to asbestosis. Finkelstein et al (1981) found for the more inclusive category "non-malignant respiratory disease" 23 of 61 deaths (37.7%) in Canadian men receiving workmen's compensation for asbestosis. This figure is consistent with Berry's, which is based on larger numbers and more specific reporting.

Independent estimates of mortality rates among asbestosis sufferers place them at about 2.8 times the corresponding age-specific rates in the general population (see task 4a). For any given age group, write the mesothelioma deaths among men exposed to asbestos as M_a, and the corresponding count of all deaths in men with asbestosis as

Table 16 – Projections of the Number of Prevalent Cases of Asbestosis in U.S. Males 1980-2009, Projection Based on the Incidence of Mesothelioma in Asbestotics

Years	No. of Men Alive With Asbestosis
1980-1984	65,800
1985-1989	35,400
1990-1994	19,000
1995-1999	9,600
2000-2004	4,400
2005-2009	1,700

Table 17 – X-Ray Changes in Asbestos Insulation Workers*

Years Since Onset of Exposure	No.	Percent Distribution by Asbestos Grade			
		0	1	2	3
40+	121	5.8	28.9	42.1	23.1
30-39	194	12.9	52.6	25.3	9.3
20-29	77	27.2	45.5	22.1	5.2
10-19	379	55.9	41.7	2.4	0.0
0-9	346	88.6	11.4	0.0	0.0

* From Selikoff (1976)

D_g. Then the Selikoff finding of an equality in the numbers of mesothelioma deaths and asbestosis deaths in insulation workers, combined with Berry's finding that 21.3% of all death is due to asbestosis, is $M_g = 0.213 \times D_g$. If the general death rate for men is G, and the number of asbestotics is A, then the total number of deaths in asbestotics is $D_g = 2.8 \times G \times A$. A is the number of interest. Combining the above equations,

$$A = Mf_g/(0.213 \times 2.8 \times G).$$

Mf_g is available for every age and future year from the mesothelioma projections (task 2) and G is estimable for each age group from current vital statistics data.

Selikoff's data apply to insulation workers exposed to asbestos essentially all their working lives, and cannot, therefore, be expected to give a reasonable estimate of asbestosis mortality for into the future, after the workplace has been largely cleared of significant asbestos exposure. (Mesothelioma mortality, by contrast, is affected almost entirely by age at first heavy exposure, and is not changed greatly by workplace clean-up, at least as far as concerns already exposed workers.) The problem is that discussed at the end of task 4a: new asbestosis probably stops occurring (with some lag, perhaps 10 years) after the cessation of asbestos exposure. Thereafter mesothelioma asbestosis relations observed previously (under conditions of extended exposure) became inapplicable to future projection. As in task 4a, we have handled this problem by estimating prevalence based on continued new incidence through the 1980-1984 quinquennium, and have estimated subsequent prevalence by aging the 1980-1984 population as described in task 4a. Table 18 gives the projected asbestosis prevalence figures for U.S. males 1980-2009, using this second projection procedure.

Task 4c: Other methods of projecting asbestosis prevalence.

There are several "quick and dirty" estimates of asbestosis prevalence which give estimates of the same order of magnitude as one another.

1. Berry (1981) reports that 133 workers were certified annually by U.K. pneumoconiosis panels in 1973-1976 and that the median survival of the least disabled certified workers was 15 years. This gives a maximum steady-state prevalence of 15 x 133 = 2,000 workers in the United Kingdom with certified pneumoconiosis (essentially all asbestosis). The United States is about four times the size of the United Kingdom. Historical exposure patterns being equal, this implies the existence of about 8,000 asbestotic workers or former workers in the United States. Apart from the looseness of the analogy between the United Kingdom and the United States, this projection suffers from its dependence on the number of workers actually certified in the United Kingdom. This is a lower limit to the number actually ill.

2. Burnham (1982) cites an unpublished estimate of the National Center for Health Statistics (NCHS) that there were 427,000 (range 248,000 to 606,000) pneumoconiosis sufferers in the United States in 1980. He also points out that the Mortality Statistics Branch of the NCHS noted 1,422 deaths ascribed to pneumoconiosis in the United States, of which 72 were ascribed specifically to asbestos. Applying the death proportionality to the pneumoconiosis prevalence gives an estimate of (72/1422)(427,000) = 21,000 asbestotics (range 12,000 to 30,000). The pneumoconiosis prevalence figure, however, was based on only a questionnaire and is therefore likely to be an underestimate, and the reporting of asbestosis on death certificates is notoriously low.

3. The prevalence of x-ray changes in workers listed in Table 17 can be multiplied by our estimates of the size of the heavily exposed workforce (Table 9), to obtain estimates of asbestosis prevalence ranging from about 8,000 to 120,000 depending on whether radiologic grade 1, 2, or 3 is used as the minimal criterion for a diagnosis of asbestosis. Although the correlation between x-ray changes and symptomatology is imperfect, the low end of this projection (8,000 grade 3 cases) would certainly represent symptomatic individuals in every case. The upper end of the projection (120,000) would include many people with few or no symptoms, whose asbestosis would be detectable by physical or radiologic examination only.

Table 18 – Projections of the Number of Prevalent Cases of Asbestosis in U.S. Males 1980-2009, Projection Based on the Equivalence of Asbestosis and Mesothelioma Mortality Rates

Years	No. of Men Alive With Asbestosis
1980-1984	64,000
1985-1989	45,300
1990-1994	31,000
1995-1999	19,700
2000-2004	11,400
2005-2009	5,700

Task 4d: Derive a general methodology for predicting lawsuits as a function of asbestosis prevalence.

Although it is not the purpose of the present work to derive estimates of a person's propensity to bring suit given that he has disease, the difference between asbestosis and the cancers insofar as diagnosability and survival times are concerned calls for some comment.

Mesothelioma and lung cancer come to diagnosis fairly rapidly and reliably, and as a result the propensity to sue can be related directly to disease incidence in order to derive an expected number of lawsuits. Asbestosis is not diagnosed nearly as reliably or as quickly, so that the pathway leading from prevalent disease to a lawsuit involves two probabilistic steps: diagnosis and decision to sue. Men with asbestosis live for decades, and so may be diagnosed for the first time and sue years after the onset of diagnosable disease.

Perhaps the best way to interpret overall propensity to sue for an asbestotic man is to calculate an annual probability of suing. The pool of prevalent, asbestotic men who are potential litigants can then be thought of as being diminished with the passage of time through two effects: first through their own mortality, and second through their bringing suit, thus removing themselves from the pool of

potential litigants by becoming active litigants. Over years, then, a constant propensity to sue acts on a diminishing pool of potential litigants to produce a declining annual number of lawsuits. By way of illustration, Table 19 gives the expected number of lawsuits by quinquennium, assuming asbestosis prevalence pools as listed in Tables 16 and 18, with cases appearing (and being removed from the pools of potential litigants) at a rate corresponding to suits from 9% of all potential litigants appearing each year.

The 9% figure was chosen for Table 19 so as to yield current lawsuit rates for the present quinquennium. Bear in mind that the rapid decline of lawsuits in Table 19 is the product of two factors, which hold true only for workers with symptomatic asbestosis. The first is the high mortality rate in these men, discussed in task 4a; the second is the finite (though large) size of the pool of potential litigants. From Table 17 it should be apparent that the number of workers with minimal disease (grade 1) is very much larger than the number of genuinely ill workers. If in fact a large number of lawsuits derive from the relatively well, exposed population, neither of the conditions on which Table 19 is predicted would hold: mortality in the minimally diseased is not much elevated, and the number of minimally diseased persons is so large that current litigation rates will not result in any meaningful depletion of the pool of potential litigants. Limited J-M data suggest that in fact lawsuits from asbestotics do not decline as rapidly after last exposure as one would anticipate from Table 19. In effect Table 19 represents minimal projection. If only a fraction of current cases are coming from symptomatic cases, then the symptomatic pool is being depleted more slowly than projected in Table 19. Symptomatic cases will come in over a larger period, and the remaining, minimally diseased cases will continue to flow in at a rate (determined by sociolegal factors) which is unlikely to be bounded by purely medical or epidemiological factors such as population mortality rates or depletion of a pool of injured workers. Taking all of these factors into consideration, a reasonable central projection of the number of lawsuits stemming from all diseases seen from 1982 on is likely to be about 45,000, with a reasonably firm lower bound of 30,000 and a very indefinite upper bound on the order of 120,000.

Task 5: Estimate the amount of asbestos-related disease occurring in women.

Approximately 5% of the lawsuits being filed with J-M derive from women. This number is consistent with an estimate from a variety of sources of about 10% of the asbestos-exposed World War II workforce being female, with a diminished fraction after the war. Exposed female workers still alive can be expected to have an age-at-first exposure distribution which is even more concentrated in the war years than that of men. The consequence of this is that asbestos-related disease will have reached its peak in women earlier than in men, and is probably past that point already. The number of female cases in J-M is too small to make to a direct test of this hypothesis. Probably the most reasonable projection of female cases would involve accepting the current 5% figure and projecting and proportion of female cases to taper off gradually to a negligible number by the year 2000.

Table 19 — Projections of Asbestosis Lawsuits Assuming 9% of Prevalent Cases (Nonlitigants) Bring Suit Each Year

Years	Method of Projecting Asbestosis	
	Meso Incidence in Asbestotics	Meso-Asbestosis Mortality Equivalence
1980-1984	24,800	24,100
1985-1989	8,300	10,600
1990-1994	2,800	4,500
1995-1999	900	1,800
2000-2004	200	700
2005-2009	100	200

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The Music of Nature

The challenge to humanism . . . is . . . to find some new point of view that will accommodate both the findings of science and a sense of commitment to mankind.

Instead of viewing ourselves as incidental byproducts of the matter and energy of the universe, we could just as easily think of ourselves as artists creating our own lives, using the material of the universe to do so.

There is nothing fanciful or unscientific about this. It is not "incorrect" to see ourselves as creative processes using the materials of nature, any more than it is "correct" to take the reverse view. It's a matter of perspective.

Indeed, the gulf between science and humanism may be no more than the gulf that would exist between printers and authors if the printers suddenly insisted that all literature was merely a byproduct of the chemistry of ink.

The perspective I am suggesting puts the emphasis on conscious life, much as a novel puts the emphasis on the story. The physical universe is the means by which our lives are expressed, the medium through which our stories are told.

In adopting this point of view, we can look back over the vast history of the cosmos and see that billions of years were needed to create small amounts of matter complex enough to serve as this medium. Only the incredible intricacy of the material that makes up the human brain could be used to tell the stories of human beings and their loving, caring, hating, fearing relationships with each other. Eons of cosmic trial and error were necessary before that material could exist.

There are undoubtedly people who will feel that such a perspective would be demeaning to science. But that would not necessarily be the case. One can cherish physical nature as one would cherish a fine violin, not so much for its shape and color as for the music it produces.

– From "Science and You: New Humanism Must Deal With Science's View of Man" by Hen. y W. Pierce in *Pittsburgh Post-Gazette*, October 30, 195[illegible].