A group of over 68,000 men in various occupations was followed for an average period of seven years per man to determine causes of mortality. Lung cancer deaths were examined, and after correction for smoking practices a group of asbestos workers was found to have an excessive amount of lung cancer. The possibility of such excesses in other groups is taken up and examined in the light of further prospective study.

CANCER EXPERIENCE OF SEVERAL OCCUPATIONAL GROUPS FOLLOWED PROSPECTIVELY

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On the basis of the findings in an earlier investigation,[1] a prospective study of suspicious occupational groups began in 1954. Populations of workingmen engaged in these occupations were assembled and data collection continued through 1957. The mortality experience of these groups in the following years has been determined by a search of California death records. In the early years of the study, this death search was a clerical task of matching state death certificates and an alphabetical listing of the study. Later, a computerized system was made available, and in subsequent years the death search has been carried out by machine matching on discriminating variables.

A preliminary report of cancer mortality experience of these groups for the time period through 1958 has been presented.[2] In that report the basis for selecting the occupational groups included in the prospective study are given along with information about the manner in which the data was collected. This later report is based on the mortality experience of the study population for the period 1954-1962.

At the time of the 1958 report there were no appropriate general population rates available with which to compute expected numbers of death due to specific causes. Rates now available for use in this report are based on all male deaths during the triennium 1959-1961 and on the 1960 California male population enumeration. The expected numbers in this report were based on these 5-year-age-specific death rates.

The short observation period completed in 1958 did not necessitate the depletion, due to known mortality, of the study population's observed person-years. The increased scope of this report and those to follow has required such depletion. This has been accomplished by a computer program which automatically "ages" each man and assigns each month of his risk exposure to the appropriate age group until such time as the man dies or the follow-up period is ended.

The occupational groups listed in Table 1 are greater in number than those in the earlier report because some of the original groupings have been subdivided and the public utility work-

Table 1—Number of Men in Each Study Occupation, Deaths Observed through 1962, Total Person Years of Observation, and Average Observation Period for the Men in Each Group

Occupational Group	Number of Men	Total Number Dead	Total Person Years of Observation	Average Time of Observation in Years
Welders and burners	10,234	592	81,623.27	7.98
Sheet metal workers (not welding)	3,013	174	23,193.50	7.70
Controls (public utility employees)	8,569	607	66,536.86	7.76
Suspect controls*	1,360	66	10,807.58	7.95
Marine engineers and firemen	1,380	132	10,816.33	7.84
Electric bridge crane operators	318	18	2,282.33	7.18
Painters and decorators	12,512	1,000	84,799.14	6.78
Asbestos workers	529	41	3,851.83	7.28
Plumbers (asbestos exposed)	2,451	177	16,891.16	6.89
Plumbers (no asbestos)	7,910	491	55,059.55	6.96
Boilermakers (asbestos exposed)	4,854	370	32,388.57	6.67
Cooks	6,571	502	42,513.41	6.47
Culinary workers (never cooks)	3,028	282	19,612.41	6.48
Printers	5,424	371	34,909.91	6.44
Total	68,153	4,823	485,285.85	7.12

* Public utility employees engaged in suspect job classifications.

ers engaged in suspect job classifications have been added. Culinary workers who reported any experience as cooks are now reported separately from those reporting no such experience. Three distinct groups of men who appeared together in the original class of asbestos workers are now grouped apart into: those who are members of asbestos workers unions; plumbers reporting any asbestos exposure; and boilermakers reporting asbestos exposure.

In Table 1 the number of men in each study group is given together with the total number of deaths observed, the total person-years of life observed, and the average observation period for the men in each study group. Since collection of questionnaires was begun in 1954 and completed in 1957, all men had the opportunity for a minimum period of about five years' observation and a maximum of about eight years. The average figure for all men included in the study was 7.12 years of exposure. Of the 68,153 men in the total population, 4,823 are known to have died. Thus, 92.9 per cent of the study population were presumed to be living at the end of 1962. Had the total population survived they would have been under observation for 500,738 person-years. The figure reported in Table 1 of 485,286 person-years is 96.9 per cent of the undepleted figure. The person-years loss then, due to all known deaths during the period of observation, is 3.1 per cent.

Results

The observed and expected deaths from lung cancer, all other cancer, and all causes except cancer, are reported for each occupational group in Table 2. It is notable that the ratio of observed to expected deaths for the three categories of death are quite different. The mortality ratio for lung cancer is a little greater than 1.00 indicating that, for the entire study group, the lung cancers observed were a little in excess of that to be expected on the basis of the experience of the California male population in comparable age groups. For death from cancer other than lung cancer, however, the study population has a deficit of 12 per cent; and, for causes other than cancer, the study population has a deficit of 28 per cent.

Upon reflection, such findings are not surprising. One must remember that the total male population of California provided the age-specific death rates from which the expected number of deaths in the study population were obtained. Certain factors of selection distinguish the study population from the general population. The study populations were largely working populations at the time of collection and were engaged in occupational activities requiring at least a moderate amount of physical activity. Thus, the study design effectively excluded from consideration the disabled and the chronically ill. Few men who die today of a long-term chronic disease were performing their job a few weeks or even months ago. Such is not so likely the case when death is due to the acute, the accidental, the rapidly fatal.

Lung cancer is one condition which runs a rapidly fatal clinical course. The selection bias against chronic disabling illness is of little consequence in this disease, and one would expect to find little if any deficit. Cancer of all tissue sites except lung would include many that run a more protracted course than does lung cancer, and they could be expected to be found more frequently in a disabled, ill, or physically restricted population than in a working population. Support for this expectation was found by examination of those tissue sites with better survival records and shows a number of major sites with substantial deficits. Cancer of the bladder, colon, and rectum, for instance, have respective deficits of 27 per cent, 24 per cent, and 19 per cent. Further,

Table 2—Observed and Expected Deaths for Lung Cancer, All Other Cancer, and All Causes Exclusive of Cancer

Occupational Group	Lung Cancer		Other Cancer		All Deaths Other Than Cancer	
	Obs.	Exp.	Obs.	Exp.	Obs.	Exp.
Welders and burners	50	43.34	104	103.53	438	664.81
Sheet metal workers (not welding)	10	16.27	42	38.45	122	237.13
Controls (public utility employees)	47	52.37	81	122.26	479	743.42
Suspect controls	6	6.99	7	16.59	53	103.22
Marine engineers and firemen	11	8.95	19	20.84	102	126.12
Electric bridge crane operators	1	1.65	6	3.80	11	23.43
Painters and decorators	91	70.34	153	162.96	756	986.80
Asbestos workers	10	2.83	3	6.58	28	40.51
Plumbers (asbestos exposed)	16	11.57	21	27.12	140	167.75
Plumbers (no asbestos)	33	38.41	73	89.89	385	555.23
Boilermakers (asbestos exposed)	25	26.61	47	61.58	298	373.12
Cooks	39	37.42	74	85.53	389	515.74
Culinary workers (never cooks)	22	15.83	43	36.47	217	221.64
Printers	13	26.26	65	60.97	293	373.65
Total	374	358.84	738	836.57	3,711	5,132.57
Ratio Obs./Exp.	1.04		0.88		0.72	

data on gastric and pancreatic cancers both of which, like lung cancer are rapidly fatal, exhibit no deficit of cases in the study population. On this basis, an observed mortality ratio difference of 12 per cent between a general and a working population for death due to cancer other than lung does not seem unreasonable.

All causes of mortality other than cancer include many major causes of death, notably some of the heart diseases, which are long-term chronic and disabling conditions. This category might reasonably be expected to show a greater differential mortality ratio between a general and a working population, and is suggested by the observed 28 per cent deficit for the study population versus the general male population. This expectation is supported by the finding of a 34 per cent deficit for hypertension with heart disease, 47 per cent for chronic endocarditis and myocardial degeneration, 38 per cent for cerebrovascular disease, and 34 per cent for chronic bronchitis and emphysema.

A related line of inquiry, begun only recently, has involved a comparison of mortality experience in the study population through 1958 with the period 1959-1962, which effectively divides the present follow-up period into halves. The considerations presented above imply that, generally, the more rapidly fatal the disease, the less should be the difference for the mortality ratio of that disease in the early half of the follow-up period when compared to that for the latter half. Such detailed study of specific causes of mortality should help to assess the adequacy of the explanations offered here for the different observed to expected mortality ratios appearing in Table 2.

Lung Cancer

The primary objective of this prospective study was to determine the occurrence of lung cancer in men who were engaged in occupations under suspicion of having an excess risk for this cancer site. As pointed out in the earlier report, the greatly increased risk of lung cancer among cigarette smokers requires that the cigarette smoking pattern of any group being observed for lung cancer experience be known. This is done in order that smoking standardized comparisons can be made with other groups. The public utility employees not engaged in suspect job classes are again, as in the earlier report, utilized as a smoking control group because the cigarette smoking pattern of these men most closely resembles the general California male population in the comparisons made. In general, the specific occupational groups being studied had fewer nonsmokers and more heavy smokers than did the smoking control group.

The relative risk for lung cancer associated with nonsmokers and for different amounts of smoking was determined in the earlier report without correcting for differences in the distribution of this characteristic for various age groups. In this report the greater number of lung cancer deaths made correction for age distribution of smoking categories possible, and the longer observation with concommitant aging of the population made it desirable. Cigarette smoking-lung cancer gradients were determined for person-years before age 55 and for years at age 55 and older. When the lung cancer risk for those that did not smoke cigarettes is expressed as unity, these gradients are as follows:

Person-Years	Nonsmokers	About ½ Pack or Less	About 1 Pack	About 1½ Packs or More	Not Stated
Under age 55	1	3.6	7.5	11.0	4.5
55 and over	1	3.4	7.6	7.9	4.3

A weighted relative risk was computed for each occupational group for person-years under age 55 and for person-years 55 and older using age-specific percentage distributions of person-years in the various smoking categories. Correction factors for differences in the smoking habits of each occupation and in the two age groups were calculated by the same method as in the earlier report.[2] The factor chosen for the control group was unity. These age group factors are presented in Table 3 along with the expected numbers of lung cancer deaths, E, as they appeared in Table 2. When these correction factors are applied to the unadjusted expected numbers, the result is a smoking adjusted expected number, É. The ratios of observed to adjusted expected numbers indicate whether or not an excess or deficiency of lung cancers was observed. The last column of Table 3 is the normally distributed characteristic: observed number minus the adjusted expected number divided by the square root of the adjusted expected number. This column indicates those observed deviations from expectation that occur outside a chance probability of 95 per cent when the value of the statistic is greater than 1.96, and those outside a chance probability of 99 per cent when the value is greater than 2.58. Only two such values are found. Both are significant at the 0.01 level. One, for asbestos workers, is positive suggesting a significant excess of observed lung cancer deaths. The other, for printers, is negative, suggesting a significant deficit.

Asbestos Workers

Exposure to asbestos is the one occupational exposure included in this study which is known to be associated with an increased risk of lung cancer.[3,4] In the preliminary report,[2] the group of asbestos workers included members of the asbestos workers union together with all plumbers and boilermakers who indicated in their questionnaires that they had, at some time, worked with asbestos. The small membership of the asbestos unions (529) and the short term of the earlier report made it desirable to include them with those plumbers and boilermakers, numbering 7,305, who had some occupational exposure to asbestos.

At the time of the first report these three groups showed a total adjusted lung cancer excess of approximately 22 per cent which, based on only 19 observed lung cancer deaths, did not approach statistical significance. If we sum the appropriate figures in Table 3, these three groups had a total of 51 lung cancer deaths through 1962 compared to a smoking adjusted expected number of 45. The ratio of these observed to expected numbers is 1.13 and this excess of six cases is well within the confines of chance.

However, when these groups are examined separately, as is done in Table 3, the outcome is strikingly different. The plumbers exposed to asbestos have a small surplus and the asbestos-exposed boilermakers enjoy a small deficit. The asbestos union group, however, has three times the expected number of lung cancers and, although the number is small, the excess is so great as to reach significance with ease.

Death certificates were examined and certifying physicians were queried in deaths which occurred among asbestos exposed workers. Evidence of asbestosis was found in the lungs of five of the ten asbestos union members dying of lung cancer. One asbestos worker who died of asbestosis was also suffering from lung cancer, although it was not reported as a primary cause of death. No asbestosis was reported in the 41 lung cancer deaths occurring among the asbestos-exposed plumbers and boilermakers.

One can make more finely drawn assessments in the amount of occupational

Table 3—Smoking Adjustment Factors by Broad Age Groups for Each Occupational Group. The Smoking Adjusted Expected Number of Lung Cancers and the Ratios of Observed to Expected Numbers

Occupational Group	Smoking Adjustment Factors		Unadjusted Expected Number E	Adjusted Expected Number É	Observed Number O	Ratio O/É	$\frac{O-É}{\sqrt{É}}$
	Under Age 55	Over Age 55					
Welders and burners	1.11	1.15	43.34	49.02	50	1.02	0.14
Sheet metal workers (not welding)	0.98	1.02	16.27	16.39	10	0.61	−1.58
Controls (public utility employees)	1.00	1.00	52.37	52.37	47	0.90	−0.74
Suspect controls	1.07	1.07	6.99	7.46	6	0.80	−0.53
Marine engineers and firemen	1.24	1.16	8.95	10.57	11	1.04	0.13
Electric bridge crane operators	1.21	1.02	1.65	1.77	1	0.56	−0.58
Painters and decorators	1.15	1.13	70.34	79.85	91	1.14	1.25
Asbestos workers	1.15	1.10	2.83	3.16	10	3.16	3.84
Plumbers (asbestos exposed)	1.20	1.17	11.57	13.66	16	1.17	0.63
Plumbers (no asbestos)	1.15	1.12	38.41	43.40	33	0.76	−1.58
Boilermakers (asbestos exposed)	1.10	1.06	26.61	28.49	25	0.88	−0.65
Cooks	0.98	0.95	37.42	35.84	39	1.09	0.53
Culinary workers (never cooks)	1.01	0.95	15.83	15.31	22	1.13	1.71
Printers	1.04	1.02	26.26	26.92	13	0.48	−2.68
Total	1.09	1.06	358.84	383.64	374	0.97	−0.49

asbestos exposure than those available from a knowledge of the type of union to which a man belongs. These distinctions might well lead to greater understanding of the types, lengths, and amounts of asbestos exposure which are most central to the genesis of asbestos-inspired lung cancer. Such categories are now being applied in the hope that more precise analyses are feasible with these data.

It may be of some interest to consider whether or not cigarette smoking and asbestosis are independent in their causation of lung cancer. In Table 4 the three cases of lung cancer expected from general population rates applied to the asbestos union group are distributed by weighted relative risks of the various smoking categories. The seven lung cancer cases attributed to asbestos are distributed within the population proportions in the various smoking categories without regard to smoking practice. The total theoretical distribution is compared to the observed distribution by categories of smoking. The observed distribution is shifted more to the left than is the theoretical, suggesting that the two carcinogenic factors are acting independently.

Printers

An unexpected finding for the men employed in the various trades of the printing industry was the appearance of a significant deficit of lung cancer deaths rather than an excess. The mortality ratios from cancers other than lung cancer, and from all causes other than cancer, were comparable to other occupational groups. The lung cancer deficit does not seem due, then, to any general failure to identify deaths in the printing group. Nor has preliminary examination of occupational and exposure subgroups within the occupation suggested that any of these are particularly responsible for the observed deficiency of the total group in this cause of mortality.

If one balks at assuming the existence of an anticarcinogenic factor in the face of no supporting evidence, there is left only one likely alternative. The most probable explanation is that this is an unusual chance occurrence rather than an exciting finding with important possibilities. In each year of follow-up there had been only one lung cancer death up through 1961 except for one year, 1959 when there were three. Then in 1962 there were six and for 1963 we have found eight. With such a trend continuing, it would appear that we have followed one group too long and serendipity is giving way to the laws of probability.

Other Occupations and Lung Cancer

None of the other occupation groups show a significant excess of lung can-

Table 4—Theoretical Distribution of Lung Cancer Cases Attributed to Cigarette Smoking and Asbestos if These Are Independent Compared to Observed Distribution by Smoking Categories

	Smoking Categories					
Cases Attributed to	None	Less Than 1 Pack	1 Pack	More Than 1 Pack	Not Stated	Total Cases
Cigarette smoking	0.1	0.3	1.8	0.8	0.0	3
Asbestos	1.2	1.2	3.2	1.2	0.1	7
Total theoretical distribution	1.3	1.5	5.0	2.0	0.1	10
Observed distribution	1	3	6	—	—	10

Table 5—Number of Observed and Expected Deaths from Cancer Other Than Lung Cancer for Each Occupational Group, the Obs./Exp. Ratios, and A Ratio Statistic

Occupational Group	Cancer Deaths Other Than Lung Cancer			
	Obs.	Exp.	O/E	$\frac{O-E}{\sqrt{E}}$
Welders and burners	104	103.53	1.0045	0.05
Sheet metal workers (not welding)	42	38.45	1.0923	0.57
Controls (public utility employees)	81	122.26	0.6625	−3.73
Suspect controls	7	16.59	0.4219	−2.36
Marine engineers and firemen	19	20.84	0.9117	−0.40
Electric bridge crane operators	6	3.80	1.5789	1.13
Painters and decorators	153	162.96	0.9389	−0.78
Asbestos workers	3	6.58	0.4559	−1.39
Plumbers (asbestos exposed)	21	27.12	0.7743	−1.17
Plumbers (no asbestos)	73	89.89	0.8121	−1.78
Boiler makers (asbestos exposed)	47	61.58	0.7632	−1.86
Cooks	74	85.53	0.8652	−1.25
Culinary workers (never cooks)	43	36.47	1.1791	1.08
Printers	65	60.97	1.0661	−0.52
Totals	738	836.57	0.8822	−3.41

cer deaths, according to Table 3. In the previous report painters and cooks appeared to have some excess of lung cancer deaths. The former now has a 14 per cent excess, although this falls short of significance. As mentioned above, the culinary workers who have never cooked are separated from the cooks in this report and they both show nonsignificant excesses. The excess, however, is not greater for cooks as we might expect from the original case-control study.[1]

These occupational groups still must be examined as subgroups by length of occupational exposure and by exposure to specific occupational agents. It is possible that some of these will show a concentration of excess mortality where none now appears. This was the case with the asbestos workers, where the excess risk associated with those having maximum exposure was lost in the much larger number with minimal exposure.

Cancer Deaths Other than from Lung Cancer

In Table 2 the observed and expected deaths from cancers other than lung cancer were presented, and we have suggested some reasons for the 12 per cent deficit of such causes of death found for all occupational groups combined. In Table 5 these are again shown for each occupational group together with each group's mortality ratio and statistic. It is evident that there is a highly significant deficit of these cancer deaths for all groups combined. This deficit is greatest in the control groups. In a few groups the deficit is minimal or nonexistent.

Quite obviously, further analysis of these data will require internal comparisons because of the general deficit of these cancer deaths. Also, the comparisons will need to be on a site specific basis. The fact that the control population shows the greatest deficit, and some of the specific occupations little or none, suggests the possibility that there may be some specific cancer site excesses to be found in the detailed analyses now under way.

Summary

A group of 68,153 men engaged in various occupations have been followed for periods of time, averaging 7.12 years per man, to determine causes of mortality. There have been 4,823 known deaths of which 374 were from lung cancer, 738 from other cancer sites, and 3,711 noncancer deaths. The lung cancer deaths were found to be related to cigarette smoking with a gradient reflecting the daily consumption of cigarettes. The lung cancer experience of the various occupational groups was corrected for smoking practices, and comparisons made with the lung cancer experience of all California males for comparable age groups. In this analysis one occupational group made up of members of an asbestos workers union was found to have a threefold excess of lung cancer. A significant deficit was also found among printers, but this is now believed to be the result of an unusual chance distribution over time of their lung cancer deaths.

The possibility exists that some other lung cancer excesses will appear as occupational groups are further examined in terms of length of time in the occupation and specific exposures.

Deaths from cancer other than lung cancer and from all causes other than cancer show deficits for all the occupational groups as compared to all California males.

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Urgently Needed

Single copies of the following issues of the American Journal of Public Health are needed: February, March, May, September, and October, 1964, and January, 1965. These are needed to fill out sets for libraries and other institutions.

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