Mortality experience of haematite mine workers in China

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Abstract

The mortality risk of iron ore (haematite) miners between 1970 and 1982 was investigated in a retrospective cohort study of workers from two mines, Longyan and Taochong, in China. The cohort was limited to men and consisted of 5406 underground miners and 1038 unexposed surface workers. Among the 490 underground miners who died, 205 (42%) died of silicosis and silicotuberculosis and 98 (20%) of cancer, including 29 cases (5.9%) of lung cancer. The study found an excess risk of non-malignant respiratory disease and of lung cancer among haematite miners. The standardised mortality ratio for lung cancer compared with nationwide male population rates was significantly raised (SMR = 3.7), especially for those miners who were first employed underground before mechanical ventilation and wet drilling were introduced (SMR = 4.8); with jobs involving heavy exposure to dust, radon, and radon daughters (SMR = 4.2); with a history of silicosis (SMR = 5.3); and with silicotuberculosis (SMR = 6.6). No excess risk of lung cancer was observed in unexposed workers (SMR = 1.2). Among current smokers, the risk of lung cancer increased with the level of exposure to dust. The mortality from all cancer, stomach, liver, and oesophageal cancer was not raised among underground miners. An excess risk of lung cancer among underground mine workers which could not be attributed solely to tobacco use was associated with working conditions underground, especially with exposure to dust and radon gas and with the presence of non-malignant respiratory disease. Because of an overlap of exposures to dust and radon daughters, the independent effects of these factors could not be evaluated.

Several epidemiological studies from the United Kingdom, Sweden, France, and the USSR have shown associations between haematite mining and lung cancer.¹⁻¹² One large study of haematite miners from the United States did not show an excess risk for lung cancer.¹³ Recently, in a mortality study of haematite miners in Cumbria followed up from 1939 to 1982 Kinlen found no excess risk for lung cancer.¹⁴ In a previous study from 1948 to 1967 in these mines an excess of lung cancer was found.² Kinlen indicated that the risk for lung cancer in these mines had largely disappeared in recent years with the introduction of improved industrial hygiene measures. Most of these surveys suggested that the increased risk of lung cancer is generally attributed to exposure to radon gas. In China we undertook a retrospective cohort study to assess the risk of lung cancer among employees at two haematite mines, Longyan mine in Hebei province and Taochong mine in Anhui province. Limited environmental monitoring data and information on work history and cigarette use of study members were available.

Materials and methods

EXPOSURE ASSESSMENT

The ore mined at Longyan and Taochong has been predominantly haematite. Mining has been carried out at Longyan mine since 1917 and at Taochong mine since the 1940s. The potential for exposure has changed with the modification of mining procedures. The introduction of mechanical ventilation and wet drilling at the Longyan mine in 1955 and the Taochong mine in 1963 reduced the concentration of total airborne dust, measured gravimetrically, from several hundred mg/m³ to less than 10 mg/m³ on average. Monitoring data from Longyan mine from 1971 to 1979 found average dust concentrations of 3.8 mg/m³ (n = 4655; 1.8-9.2 mg/m³) for mining and drilling operators and 2.7 mg/m³ (n = 167; 1.2-3.0 mg/m³) for loading machine operators.

During the period of the present survey, environmental measurements were made for chemical elements in settled dust by plasma spectrography, for 3,4-benzo[a]pyrene (BaP) by high performance liquid chromatography, and for radon and radon daughter content. In Longyan mine 28% of the settled dust and in Taochong mine 23% of the settled dust was iron. Titanium was found at greater than

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Table 1 Environmental levels of radon and radon daughters in air in Longyan and Taochong haematite mines, 1984

Mine	No of samples	Radon		Radon: daughters potential energy		Annual effective dose equivalent (mSv)
		Bqm ⁻³	pCi/l	10 ⁻⁸ Jm ⁻³	WL	
Longyan mine						
Underground:	38	1028 ± 594	27.8	317 ± 232	0.2	21
Working face	13	1329 ± 559	35.9	442 ± 267	0.2	
Other areas	22	808 ± 464	21.8	260 ± 189	0.1	
Air being exhausted from underground	2	1930 ± 14	52.2	270 ± 155	0.1	
Air entering underground	1	60	1.6	21	0.0	
Above ground	3	19 ± 0	0.5	3 ± 0	0.0	
Taochong mine						
Underground:	32	1479 ± 1338	40.0	428 ± 634	0.2	30
Workface	15	1519 ± 946	41.1	405 ± 382	0.2	
Other areas	17	1402 ± 1544	37.9	449 ± 801	0.2	
Standard occupational limit ¹⁶		3700	100.0	640	0.3	50
Standard residential limit ¹⁶						5

trace levels, 0.1% for Longyan mine and 0.04% for Taochong, whereas only traces (<0.01%) were found of the 25 other elements measured, including arsenic, chromium, nickel, cobalt, cadmium, and beryllium. The level of airborne BaP in the mines was generally low, with only occasional measurements beyond the maximum allowable concentration for occupational exposure (0.15 µg/m³).¹⁵ The average of BaP for Taochong mine was 0.08 µg/m³ (n = 6; 0.015–0.36 µg/m³) and for Longyan 0.03 µg/m³ (n = 7; 0.007–0.16 µg/m³). Concentrations among medium and heavy dust exposed workers in the two mines corresponded to BaP values of 0.04 (n = 4) and 0.07 = g/m³ (n = 6).

Table 1 shows the air levels of radon and radon daughters in the two mines in 1984. The annual effective dose equivalent (mSv) based on potential energy, breathing velocity (1.2 m³/h) and annual working time (2000 hours) for underground miners was lower than the allowable occupational limit for one year for related mines classified as having radiation exposure (mSv = 50), but was about four-fold higher than those recommended for residential exposure (mSv = 5) in China.¹⁶ The concentration of radon (Bgm⁻³) and radon daughters (Jm⁻³) under-

ground (1028 Bgm⁻³ and 317 × 10⁻⁸Jm⁻³; n = 38) in Longyan mine was much higher than the above ground concentration (19 Bgm⁻³, 3 × 10⁻⁸Jm⁻³; n = 3). The air entering the underground mine was 60 Bgm⁻³ and 21 × 10⁻⁸Jm⁻³ n = 1, respectively, for radon and its daughters, whereas the air being exhausted from the mine (n = 2) was 32-fold higher for radon and 13-fold higher for radon daughters. The level of radon and radon daughters at the working face was higher than at other areas underground. The calculation for low, medium, and heavy dust exposure, although based on few samples, indicated that the radon concentrations approximately paralleled dust exposure (table 2).

The study cohort was grouped by job title into unexposed and low, medium, and heavily dust exposed workers. The unexposed group consisted of above ground workers including office staff, non-ore transport workers, and electricians and mechanics who do not go underground. Workers, based on the job held for the longest period of time underground, with low exposure had jobs underground such as safety worker, ventilation worker, and storekeeper. Workers with medium exposure had jobs such as loading machine operator, conveyor operator, elec-

Table 2 Exposures and SMRs for lung cancer at Longyan mine. (Number in parentheses refers to number of samples)

Longyan mine	Dust (mg/m ³)	Radon		Radon daughters		BaP (µg/m ³)	No of subjects	Person-years	Lung cancer		
		Bqm ⁻³	pCi/l	10 ⁻⁸ Jm ⁻³	WL				Obs	Exp	SMR ^a
Unexposed	—	19 ± 0 (n = 3)	0.5	3 ± 0 (n = 3)	0.0	—	897	11379.4	2	1.51	1.3
Exposed:		1028 ± 594 (n = 38)	27.8	317 ± 232 (n = 38)	0.2	—	4824	60491.6	26	7.17	3.6
Low	—	512 ± 706 (n = 3)	18.8	257 ± 397 (n = 3)	0.1	—	700	8943.8	2	1.08	1.9
Medium	2.7 (n = 167)	741 ± 339 (n = 9)	20.0	241 ± 132 (n = 9)	0.1	0.049 (n = 2)	987	12618.9	3	1.30	2.3
Heavy	3.8 (n = 4655)	1329 ± 559 (n = 13)	35.9	442 ± 267 (n = 13)	0.2	0.015 (n = 2)	3137	38928.8	21	4.79	4.4

^aSMR based on nationwide male population in China, 1973–1975, by age.

tric train operator, and track maintenance. Heavily exposed workers were all directly involved in drilling and mining at the mine face.

STUDY POPULATION

Personnel files of the two mining companies were reviewed and 8641 men were identified who were employed on 1 January 1970. Vital status on 31 December 1982 was determined by individual tracing interviews and, when necessary, by mailed questionnaire to subjects or next of kin. Vital status was ascertained for 8534 (99%) of the study subjects. The 107 people lost to follow up were excluded from the study.

Information on occupational history at the mines, personal health conditions, and smoking habits were obtained by questionnaire from the study subjects or, if dead, from next of kin. For the present analysis, we excluded 2090 (24%) workers as ineligible for study: those who had been employed at the mines for less than one year before 1 January 1970; who had worked in taconite (Fe_2O_3) mining; or who, based on job title, had been exposed to silica dust above ground. This last exclusion was made to create a group of above ground workers not exposed to silica. By these criteria, 6444 subjects (Longyan mine = 5721, Tachong mine = 723), including 1308 non-exposed above ground and 5406 underground exposed miners (low exposure = 772, medium exposure = 1197, heavy exposure = 3437) were included for study.

Cause of death was generally obtained from the records of the pension department. For deaths from cancer, hospital medical records were reviewed to verify the primary site of the tumour and to determine the methods used for diagnosis, relying on the criteria for malignant tumour investigation in China.¹⁷ Causes of death were recorded according to the ninth revision of the International Classification of Disease.¹⁸

In China routine physical examinations including a chest radiograph have been offered since 1963 on an annual or semiannual basis to mine workers. According to criteria for diagnosis established in China in 1963, 1335 (24.7%) of the study group mine workers

were diagnosed as having silicosis by review panels of specialists in occupational medicine and radiology. Of these silicotic subjects, 560 (42%) were diagnosed as having silicotuberculosis. Of the 4071 non-silicotic subjects, only seven (0.2%) had tuberculosis.

STATISTICAL METHODS

For the statistical analysis, person-years were accumulated from the study entry date (1 January 1970) until the date of death or 31 December 1982, whichever occurred first. Age adjusted expected numbers of deaths were computed¹⁹ from the age specific death rates for men in China, 1973-5.^{17,20} The SMR was obtained by dividing the observed number of deaths by the expected number. Ninety five per cent confidence intervals (CI) for the SMR were calculated using Fisher's exact method when the observed number was less than eight and an approximate method when the observed number was more than eight.²¹ Tests for homogeneity and for trend of SMRs followed Breslow *et al.*²²

Results

ALL CAUSES OF DEATH

The 6444 study subjects provided 80 905 person-years of follow up. A greater proportion of miners (82%) than above ground workers (64%) were aged 30-49 at the start of the study follow up. The above ground workers group had proportionally more younger (<30) and older (>50) members than the mine worker group (table 3). For the entire study group as of 31 December 1982, 5894 (91.5%) were alive and 550 (8.5%) were dead. Of the dead, 227 (41%) had died of non-malignant respiratory disease, 111 (20%) of malignant neoplasms including 31 (6%) of lung cancer, 77 (14%) of circulatory causes, and 135 (25%) of other causes. Table 4 shows the crude death rates for underground and above ground workers for all and selected causes of death. Death rates were comparable for the two mines. Silicosis and silicotuberculosis were the major causes of death in both mines, being about eight times more frequent than lung cancer. The crude death rates for the

Table 3 Number (%) of study cohort members by age in 1970, mine, and exposure status

Age (y)	Longyan mine				Tachong mine				Two mines			
	Exposed		Unexposed		Exposed		Unexposed		Exposed		Unexposed	
	No	%	No	%	No	%	No	%	No	%	No	%
<20	3	0.1	5	0.6	0	—	2	1.4	3	0.1	7	0.7
20-	557	11.5	196	21.9	99	17.0	31	22.0	656	12.1	227	21.9
30-	2308	47.5	364	40.6	309	53.1	55	39.0	2617	48.4	419	40.4
40-	1662	34.5	204	22.7	141	24.2	39	27.7	1830	33.4	243	23.4
50-	243	5.0	99	11.0	32	5.5	14	9.9	275	5.1	113	10.9
60-	45	0.9	29	3.2	1	0.2	0	—	46	0.9	29	2.8
≥70	6	0.1	0	—	0	—	0	—	6	0.1	0	—
Total	4824	100.0	897	100.0	582	100.0	141	100.0	5406	100.0	1038	100.0

Table 4 Number of cases and crude death rate (CR)* for selected causes of death at two haematite mines, 1970–82

Mine	No of subjects	Person-years	All causes		All cancer		Lung cancer		Silicosis†	
			No	CR	No	CR	No	CR	No	CR
Underground workers:										
Longyan	4824	60491.6	435	719.1	87	143.8	26	43.0	203	335.6
Taochong	582	7244.7	55	759.2	11	151.8	3	41.4	23	317.5
Two mines	5406	67736.3	490	723.4	98	144.7	29	42.8	226	333.6
Above ground workers	1038	13168.8	60	455.6	13	98.7	2	15.2	0	—

*CR per 1/10⁵ person-years.

†Including silicotuberculosis.

selected causes of death for unexposed above ground workers were considerably lower than for underground miners.

CANCER AMONG MINERS

Pathological and radiological information was reviewed for 107 (96%) of the 111 deaths from cancer. Nineteen (61%) of the 31 cases of lung cancer, including the two cases among the unexposed, were based on a pathological diagnosis, although the cell type was available for only eight cases (three squamous cell, two undifferentiated, and three adenocarcinoma). Eleven cases (35%) were based on radiological diagnosis and one on signs and symptoms (bloody hydrothorax followed shortly by death).

In table 5 SMRs are shown for all cancer and for selected cancer sites for the 5406 miners. All cancer mortality among miners was similar to that expected, based on Chinese national rates. No excesses were found for stomach, liver, or oesophageal cancer, which are more frequent causes of death than lung cancer in China.^{17 20} A statistically significant excess of lung cancer (29 cases) was observed, SMR = 3.7 ($p < 0.05$). For lymphosarcoma there were four cases (cause specific death rate from China not available); for leukaemia the SMR = 1.5 ($n = 3$) and for other cancer sites SMRs were not calculated due to small numbers.

Mortality results for lung cancer are presented in table 6 by mine, by level of exposure, and by first employment before and after the introduction of ventilation and wet drilling. The risk of lung cancer among unexposed workers was not raised, SMR = 1.2, although the result was based on only

two cases. Among all exposed miners, the risk of lung cancer was raised among Longyan (SMR = 3.6) and Taochong (SMR = 4.2) mine workers and rose for both mines combined with level of exposure for low (SMR = 2.6), medium (SMR = 2.6), and heavily (SMR = 4.2) exposed miners. When the trend in risk is examined among the unexposed, low, medium, and heavily exposed, the increase in risk with exposure category was of borderline significance ($\chi^2 = 1.93$, $p \approx 0.05$). When the trend was examined among the low, medium, and heavily exposed, ignoring the unexposed, the increase in risk with level of exposure was only moderate and statistically not significant ($\chi^2 = 1.06$, $p = 0.29$). When considering the risks associated with changes in ventilation, the numbers of cases are small, particularly among those initially employed after the introduction of ventilation. The risk for workers initially employed before the introduction of ventilation, SMR = 4.8, is higher than the risk for those employed after its introduction, SMR = 2.4, although the difference was not statistically significant ($p = 0.08$). For mine workers in jobs with heavy dust exposure, the SMRs are 4.8 ($p < 0.05$) and 3.5 ($p < 0.05$), respectively, for those ever and never employed before the introduction of ventilation. Environmental monitoring results for Longyan mine were available for dust, radon, radon daughters, and BaP. These results with the associated risks of lung cancer by exposure category are presented in table 2. Exposure levels for radon and radon daughters, but not for BaP, were higher in high dust level jobs.

Table 7 presents the lung cancer mortality rates with respect to the presence of other pulmonary diseases. Silicotics had a more than fivefold risk of

Table 5 Number of deaths and SMRs for cancer by site at two haematite mines, 1970–83

Tumour site (ICD-9)	Longyan	Taochong	Two mines			
	No of deaths	No of deaths	Obs	Exp	SMR*	95% CI
All cancer (140–239)	87	11	98	89.88	1.1	0.9, 1.3
Lung (162)	26	3	29	7.89	3.7	2.5, 5.3
Stomach (151)	16	2	18	22.33	0.8	0.5, 1.3
Liver (155)	15	2	17	22.48	0.8	0.4, 1.2
Oesophagus (150)	9	2	11	18.13	0.6	0.3, 1.1

*SMR for nationwide male population in China, 1973, by age.

Table 6 SMRs for lung cancer at two haematite mines, 1970-82

Mine	Dust exposure	No of subjects	Person-years	Obs	Exp	SMR*	95% CI
Longyan miners		4824	60491.6	26	7.17	3.6	2.4, 5.3
Taochong miners		582	7244.7	3	0.72	4.2	0.9, 12.2
Two mines:		6444	80905.2	31	9.62	3.2	2.2, 4.6
Unexposed		1038	13168.8	2	1.73	1.2	0.1, 4.2
Exposed		5406	67736.3	29	7.89	3.7	2.5, 5.3
	Low	772	9862.4	3	1.16	2.6	0.5, 7.6
	Medium	1197	15278.3	4	1.55	2.6	0.7, 6.6
	Heavy	3437	42495.3	22	5.19	4.2	2.7, 6.4
Before ventilation†		2110	35435.7	20	4.17	4.8	2.9, 7.4
	Low	233	2951.1	2	0.48	4.1	0.5, 15.1
	Medium	428	5364.1	4	0.78	5.1	1.4, 13.1
	Heavy	1449	17120.4	14	2.91	4.8	2.6, 8.1
After ventilation		3296	42300.0	9	3.72	2.4	1.1, 4.6
	Low	539	6911.3	1	0.67	1.5	0.0, 8.3
	Medium	769	9914.3	0	0.77	—	0.0, 4.8
	Heavy	1988	25474.8	8	2.28	3.5	1.5, 6.9

*SMR based on nationwide male population in China, 1973-5, by age.

†Workers with first exposure underground before the introduction of ventilation and wet drilling, which were introduced in Longyan mine in 1955 and in Taochong mine in 1963.

lung cancer (SMR = 5.3, $p < 0.05$) although, among non-silicotic subjects, the risk for lung cancer was also significantly raised (SMR = 2.9, $p < 0.05$). The difference in SMRs between silicotic and non-silicotic subjects was not statistically significant. Silicotic subjects with tuberculosis were at high risk for lung cancer (SMR = 6.6; $p < 0.05$). For silicotic subjects with heavy dust exposure, which comprised almost all of them the SMR = 5.0. Among miners without silicosis, the risk by level of dust was SMR = 1.2 for the unexposed, SMR = 2.8 for low, SMR = 1.5 for medium, and SMR = 3.6 for heavily exposed workers. The trend was not statistically significant ($\chi^2 = 1.5$, $p = 0.14$).

Among all cohort members, 4830 (75%) were current smokers, 1426 (22%) had never smoked, and 188 (3%) were ex-smokers (table 8). Among exposed miners who never smoked, one death from lung cancer was observed whereas 1.7 were expected based on national rates. Among current smokers, the SMRs by level of dust exposure were 1.6 (based on two cases), 2.4 (based on two cases), and 3.3 and 4.9,

respectively, for unexposed, low, medium, and heavily exposed workers. The trend was of marginal statistical significance ($\chi^2 = 1.89$, $p = 0.06$).

Discussion

This study of mortality at two haematite mines in China shows an excess risk for non-malignant respiratory disease and a 3.7-fold excess for lung cancer among workers employed underground at the mines. Death due to non-malignant respiratory disease, particularly pneumoconiosis and pneumoconiosis with tuberculosis, was a major health hazard in these mines, being the cause of 46% of deaths. It was only possible in the present analysis to assess crude rates for death due to silicosis. Further detailed analyses are being planned.

The risks for total cancer and selected cancers other than lung cancer were not raised in the study group. The excess of lung cancer was limited to those working underground and was higher among those ever employed underground in the mines before the introduction of ventilation. Overall the risk for lung

Table 7 SMRs for lung cancer by history of lung disease at two haematite mines, 1970-82

Lung disease	Dust exposure	No of subjects	Person-years	Obs	Exp	SMR*	95% CI
Silicosis:		1335	15543.1	14	2.67	5.3	2.9, 8.8
	Low	32	391.4	0	0.07	—	—
	Medium	77	898.4	2	0.18	11.1	1.3, 40.1
	Heavy	1226	14253.3	12	2.41	5.0	2.6, 8.7
Non-silicosis:		4071	52193.3	15	5.23	2.9	1.6, 4.7
	Low	740	9471.0	3	1.09	2.8	0.6, 8.0
	Medium	1120	14380.1	2	1.37	1.5	0.2, 5.3
	Heavy	2211	28342.0	10	2.77	3.6	1.7, 6.6
Tuberculosis		567	6102.7	7	1.08	6.5	2.6, 13.4
Non-tuberculosis		4839	61633.7	22	6.82	3.2	2.0, 4.9
Silicotuberculosis		560	6032.9	7	1.07	6.6	2.6, 13.5
Siliosis with non-tuberculosis		775	9510.2	7	1.60	4.4	1.8, 9.0
Non-silicosis with tuberculosis		7	69.8	0	0.0	—	—
Non-silicosis with non-tuberculosis		4064	52123.8	15	5.22	2.9	1.6, 4.7

*SMR based on nationwide male population in China, 1973-5, by age.

Table 8 SMRs for lung cancer by history of cigarette smoking at two haematite mines, 1970-82

	Dust exposure	No of subjects	Person-years	Obs	Exp	SMR*	95% CI
All workers:							
Never smoked		1426	17721.7	1	2.14	0.5	0.0, 2.6
Current smoker		4830	60870.7	27	7.13	3.8	2.5, 5.5
Unexposed†		745	9439.9	2	1.22	1.6	0.2, 5.9
Exposed:							
Never smoked		1173	14505.3	1	1.70	0.6	0.0, 3.3
Current smoker†		4085	51430.8	25	5.90	4.2	2.7, 6.3
	Low	574	7350.6	2	0.85	2.4	0.3, 8.5
	Medium	937	11957.8	4	1.20	3.3	0.9, 8.5
	Heavy	2574	32122.3	19	3.85	4.9	3.0, 7.7
Ventilation:†							
Before		1555	18903.7	17	3.07	5.5	3.2, 8.7
After		2530	32527.0	8	2.84	2.8	1.2, 5.6
Silicosis:†							
Yes		962	11357.1	13	1.93	6.7	3.6, 11.5
No		3123	40073.7	12	3.98	3.0	1.6, 5.3
Tuberculosis:†							
Yes		389	4234.7	7	0.75	9.3	3.8, 19.2
No		3696	47196.0	18	5.16	3.5	2.1, 5.5

*SMR based on nationwide male population in China, 1973-5, by age.

†Analysis performed in current smoking group.

cancer also increased with level of dust exposure from low to heavy, although it was only a moderate increase in risk. This may be attributable to small numbers, particularly for the low and medium exposed groups, or to the failure of job title to differentiate between dust exposure groups clearly. It is also important that workers who became ill while working in heavily exposed jobs may have been moved to other lower exposed duties. The observed association was probably not solely due to tobacco use since the risk increased with level of exposure, even when the analysis was restricted to smokers. Radford and Renard found an excess risk for lung cancer in Swedish iron ore miners among both smokers and non-smokers.⁶ Owing to the limited number of non-smokers in this study in China, and the finding of only one case among non-smokers, we could not evaluate this result.

The presence of lung cancer in this study may be due to exposures other than dust, in particular to radon gas and radon daughters. Environmental measurements from the Longyan mine indicated that dust levels seemed to parallel the concentration of radon and radon daughters, making it impossible to evaluate the independent effect of these exposures. In both mines iron oxide and silica were the major components of airborne and settled dusts. Current concentrations of radon and radon daughters occurred at levels about fourfold the acceptable limit for inhabitants of China. Undoubtedly levels for all exposures had been considerably higher in the past, particularly before the introduction of ventilation controls. Radford and Renard found a fourfold excess risk of lung cancer among Swedish iron miners exposed to radon daughter concentrations close to the accepted occupational limit (4WLM/year), with a clear dose response relation.⁶ In addition, other studies of iron miners and of uranium

miners have established that exposure to radon gas increases the risk of lung cancer.²³ Recently, Mur reported findings from a proportional mortality study of French iron ore miners employed in the Lorraine basin.⁹ Geologically, he reports, this area was formed from sediments with no detectable radioactivity in the mines. Nevertheless, excesses of lung cancer of similar magnitude to that of the present study were found. Although radioactive decay products of uranium present a significant risk of lung cancer, it is essentially difficult to sort out independent and combined effects of the multiple disease causing agents found in most iron and other types of mines.

Silicotic subjects, particularly those with silico-tuberculosis, were at somewhat higher risk of lung cancer than were non-silicotic subjects. The presence of these diseases may increase the risk of developing lung cancer as has been suggested by limited evidence from studies of silicotic subjects who had been employed as miners, quarry workers, foundry workers, ceramic workers, granite workers, and stone cutters.^{9,12}

In this study an excess risk for lung cancer was shown to be associated with underground employment in haematite mines. Those with heavier dust exposure, those who had worked before the introduction of ventilation and wet drilling dust control measures, and those who had non-malignant respiratory diseases appeared to be at excess risk. Although the differences in risk were pronounced, tests for homogeneity of risk of lung cancer or for trend in risk of lung cancer often did not reach the established level of statistical significance ($p < 0.05$). Statistical differences in risk for lung cancer may, to some extent, have been attenuated by competing risk—that is, death due to silicosis, although small numbers of study subjects in some

comparison groups undoubtedly decreased the power of these tests.

In summary, the present study has shown a clear excess risk for death due to silicosis and to lung cancer in two Chinese haematite mines. The risk for lung cancer could not be attributed solely to tobacco use. Risk was associated with working conditions underground, especially with exposure to dust, radon, and radon daughters, and with the presence of non-malignant respiratory disease.

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