Crystalline silica and risk of lung cancer in the potteries

N M Cherry, G L Burgess, S Turner, J C McDonald

Abstract

Objective—To evaluate crystalline silica as a human carcinogen.

Methods—A cohort of 5115 men, born 1916–45 and employed in the pottery, refractory, and sandstone industries of Stoke-on-Trent was identified from occupations subject to health surveillance by the local Silicosis Medical Board (now the Department of Social Security). Detailed occupational and smoking histories, and records of small parenchymal opacities on periodic radiographs were extracted from medical records. An exposure matrix was derived from some 1400 personal or static dust samples and tested against the presence of small parenchymal opacities in a subcohort of 1080 men employed for at least 10 years, who had started working in the industry before 1960.

Results—Standardised mortality ratios (SMRs) calculated against mortalities for Stoke-on-Trent, with 95% confidence intervals (95% CIs), were raised for all causes (1.15 (1.05 to 1.26)), lung cancer (1.28 (0.99 to 1.62)) and non-malignant respiratory disease (2.04 (1.55 to 2.65)). Average concentration and duration of exposure to silica were, taken together, significantly related to the presence of small opacities (>10). In a nested case-referent analysis of 52 cases of lung cancer and 197 matched referents, conditional logistic regression gave a significantly increased odds ratio (OR) for average silica concentration (µg/m³.100), after adjustment for smoking, of 1.66 (1.14 to 2.41) but not for duration of exposure nor, in consequence, for cumulative exposure.

Conclusion—The association between risk of lung cancer and quantitative estimates of silica exposure supports the SMR analysis and implies that crystalline silica may well be a human carcinogen.

Keywords: lung cancer; silica; potteries

Until recently little thought was given to the possibility that occupational exposure to crystalline silica might be carcinogenic, but largely as the result of a symposium on silica, silicosis, and cancer, held in North Carolina in 1984. This view became seriously considered. In 1986, an International Agency for Research on Cancer (IARC) working group reviewed the question and concluded in their overall evaluation that although there was sufficient evidence for the carcinogenicity of crystalline silica in experimental animals, in humans the evidence was limited. The reasons for the working group’s hesitation were essentially twofold: firstly, that the evidently high risk of lung cancer in people with compensated silicosis could be explained by biases associated with case selection and confounding; secondly, that few if any occupational cohort surveys had adequately excluded exposure from other potential carcinogens, taken account of smoking, or provided qualitative or quantitative findings on exposure-response. In the decade that followed, several stronger epidemiological papers were published, sufficient to justify the IARC in convening a second working group in 1996 to review the evidence on crystalline silica yet again. This time the group concluded that there was now sufficient evidence of human carcinogenicity; however, in their overall evaluation the working group noted that carcinogenicity was (a) "not detected in all industrial circumstances" and (b) "may be dependent on inherent characteristics of the crystalline silica or on external factors affecting its biological activity or distribution of its polymorphs".

Because of the dearth of adequate epidemiological data on workers exposed to silica available in 1986, we explored potential opportunities for research in the United Kingdom. Most promising was the existence of employment and other records of men and women in specific trades and processes exposed to dust, who from 1931 to 1984 when the legislation was revoked, were subject to periodic medical surveillance. Preliminary findings on mortality from lung cancer from a follow up of a stratified sample of the current workforce of the British pottery industry, included in a survey in 1970–1, had been published by Winter et al. Because of difficulty in ensuring a complete follow up these investigators confined their report to the mortality experience of 3669 men <60 years of age. In this cohort 60 deaths from lung cancer were observed against 42.8 expected from national rates (standardised mortality ratio (SMR) 1.40, p=0.007) and 45.6 from locally adjusted rates (SMR 1.32, p=0.023).

The study on which the present report is based was initiated after discussion with the earlier investigators. Our general approach differed in that it followed the more usual procedure of defining the cohort as subjects at the time of first exposure and in terms of date of birth. Whereas the earlier study covered pottery workers in all parts of the United Kingdom, the present cohort was recruited entirely from employees of the numerous pottery companies with workers subject to
health surveillance at Stoke-on-Trent together with a much smaller number (<10% of the total) in refractory or sandstone work. It is likely that the two cohorts had some members in common.

The cohort mortality study of Staffordshire pottery workers described in this paper is one of the very few designed to consider the risk of lung cancer in men exposed to crystalline silica in whom work histories, smoking habits, chest radiograph readings, and previous exposure to other hazardous dusts were all recorded. Also, quantitative exposure estimates, made and tested against radiographic findings, were available for a nested case-referent analysis of exposure-response. Preliminary findings from this investigation have been published, firstly on proportional mortality, then on SMRs. These both showed a substantial excess of lung cancer and non-malignant respiratory disease compared with national (United Kingdom) mortality statistics, but this was much less clear when local (Stoke-on-Trent) rates were used. Preliminary results on all aspects of the survey were recently published in abstract form, so that they could be taken into account by the IARC working group in 1996. It is these results which are now fully described.

**Materials and methods**

**STUDY POPULATIONS**

**The cohort**

From 1931 to 1984, United Kingdom employers were required to notify the Silicosis Medical Boards and their successors (now the Benefits Agency of the Department of Social Security (DSS)) of any employee who was to work in specified trades and processes exposed to dust. At the DSS Boarding Centre, Stoke-on-Trent, those thus notified had been entered on a card register which is maintained indefinitely. They were then subject to an initial medical examination and further periodic examinations every 2 years. From 1948 this examination included chest radiographs (posterior-anterior) taken when first (or next) seen and every 4 years thereafter. A standard medical record form, which changed over the years, was completed by the physician at each visit and contained the following information:

- Full name, sex, date of birth, and National Insurance Number
- Job or process for which employed
- Duration of any previous work exposed to dust—for example, coal, asbestos, foundries, quarries etc
- Smoking habit
- Classification of chest radiograph on the International Labour Office (ILO) system.

These records were supposedly destroyed, under the regulations, 10 years after last employment and not later than the age of 70, but in fact these rules were not rigorously applied. The records were also destroyed after 2 years if the Centre was informed of the subject’s death; however, no special steps were taken to learn of these deaths. During the course of the study it became apparent that, contrary to policy, some index cards as well as medical records may have been destroyed for deaths known before 1985 (see below). When medical records had been destroyed, duration of employment could not be estimated from the index cards, but there was no indication that the rules had been applied differentially for those with long or short periods of employment.

A cohort of 7064 was defined from the card register for identification and tracing to be all men born between 1916 and 1945 for whom full name and date of birth were given; no minimum period of employment was specified. Men who had worked previously with asbestos or in foundries were then excluded, as were men recorded as having been employed for >1 year in coal mining or exposed to other dusts, largely in masonry or from talc in the rubber industry. Men who had been living outside the pottery areas at the time of the first medical examination were also excluded. This was to reduce the number of men examined at the Centre for exposures other than pottery. As a result the cohort used for the present analysis was limited to 5115. For these men the date of first employment ranged from 1929 to 1992, but 80% were known to have been first employed before 1970.

**Pneumoconiosis subcohort**

A subcohort of pottery workers was selected from the main mortality cohort to test whether exposure estimates were related to radiographic changes in a reasonable way. To ensure that members of the subcohort had exposure with the potential to produce radiographic evidence of fibrosis it was restricted to men with at least 10 years in the potteries, beginning before 1960. A total of 1080 workers met these criteria.

**Nested case-referent study**

Within the 5115 cohort, 88 had a death certificate (see later) with a diagnosis of lung cancer. Records for 32 of these had been destroyed, following the policy already described. Of those whose records were available none was known to have been exposed to asbestos but three further cases were eliminated because their exposure had been to silica in the sandstone or refractory industry where exposure estimates had not been made and one case because the death from lung cancer had been within 10 years of first pottery exposure (in this case 4 years and 9 months before the death).

Each of the remaining 52 cases was matched with three or four referents (depending on availability) on date of birth and date of first exposure making a total of 247 referents. Matching to ±3 years was always achieved for date of first exposure but was extended to ±4 years of date of birth. Referents were considered ineligible if they were known never to have smoked (no case fell into this category), if they had ever been exposed to asbestos, or if their exposure to silica had been entirely outside the pottery industry, or if they had predeceased the case.
Crystalline silica and risk of lung cancer in the potteries

781

*Reported as daily 8 hour time weighted airborne concentration in µg/m³.

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North Carolina, USA. This method equated 1

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unless information was available to the con-

trary. By this means, the industry was divided

into 11 major process groups comprising, in

all, 569 job titles. Air sample results were aver-

aged, particle counts converted to gravimetric

mass, categorised by job and decade, and then

tabulated into a preliminary exposure matrix.

Published literature and unpublished reports

dust control measures or changes to the

process or work rate were then used to refine

the matrix, particularly for the periods where

no sample results were available. Judgement

was inevitably needed in taking account of

engineering changes.

The final version of the matrix is presented

in table 1. In general, it depicts an overall trend

toward reduction in exposure over the 60 year

span, with considerable variations with process

and decade.

For members of the pneumatic tuberculosis subco-

hort and the nested case-referent study full

work histories were extracted from clinical

records without knowledge of the radiographic

readings or cause of death. Duration was measured and maximum, cumulative and aver-

age lifetime exposures to crystalline silica were

calculated from the matrix. For the pneumo-

coniosis subcohort the exposures were up to the

time of the first positive reading (≥1/0) or, if all

radiographs were normal, to the end of

employment or to June 1992 if still employed.

For the nested case-referent study each expo-

sure measure was calculated to the time of

death of the case, and also to points 10 years

and 20 years before this death.

EXPOSURE ESTIMATES

Extensive records existed for airborne dust

concentration in various parts of the industry

recorded since the late 1960s. Methods
designed to collect static (breathing area) sam-

ples for particle counting were widely used in

the United Kingdom until the 1960s, when a
cyclone was introduced to collect personal

samples of respirable sized dust followed by

analysis of gravimetric silica mass. More than

1000 such personal samples were identified.

These measurements of respirable silica dust

fell in the range 0–800 µg/m³ (mostly between

50 and 200). In earlier years records were

sparse, but some 350 samples were from the

1950s and 1960s. The earlier measurements

were dust particle counts from static samplers.

All samples, personal or static, were from ran-
dom surveys carried out within the industry

and were not biased towards exceptionally high

exposures.

After a review of the issues surrounding the

conversion of results from one method to

another, it was decided to make use of that

suggested by Rice et al for the dusty trades of

North Carolina, USA. This method equated 1

million particles per cubic foot to 0.09 mg/m³ of

respirable dust. The use of respiratory

protective devices might have complicated

exposure estimates but this does not seem to

have been a practice in this industry. Job titles

were used to indicate similar levels of exposure

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trary. By this means, the industry was divided

into 11 major process groups comprising, in

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employment or to June 1992 if still employed.

For the nested case-referent study each expo-

sure measure was calculated to the time of

death of the case, and also to points 10 years

and 20 years before this death.

MEASUREMENT OF POTENTIAL CONFOUNDERS

Cigarette smoking had been recorded at each

medical examination. For the present study,

information was extracted on number of

cigarettes smoked a day either at the last medi-
cal examination, or if not a smoker at that time,
at the last examination at which the number of

cigarettes smoked had been recorded.

Date of birth was extracted from the index

card.

Work at any time in firing or a post-firing

occupation (secondary shaping or glazing) was

also recorded; these jobs potentially entailed,

particularly within earlier years, exposure to

cristobalite or tridymite. These forms of

crystalline silica, caused by sustained heating

above 1000°C, have been suspected of being

more fibrogenic than quartz.

<table>
<thead>
<tr>
<th></th>
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<td>370</td>
<td>250</td>
<td>175</td>
<td>100</td>
<td>60</td>
<td>45</td>
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<tr>
<td>Body preparation</td>
<td>400</td>
<td>300</td>
<td>225</td>
<td>170</td>
<td>115</td>
<td>60</td>
<td>50</td>
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<tr>
<td>Primary shaping (production)</td>
<td>400</td>
<td>325</td>
<td>250</td>
<td>175</td>
<td>70</td>
<td>60</td>
<td>50</td>
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<tr>
<td>Primary shaping (non-production)</td>
<td>200</td>
<td>160</td>
<td>125</td>
<td>90</td>
<td>35</td>
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<td>25</td>
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<td>Secondary shaping</td>
<td>500</td>
<td>450</td>
<td>340</td>
<td>200</td>
<td>180</td>
<td>40</td>
<td>50</td>
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<td>Firing</td>
<td>800</td>
<td>650</td>
<td>500</td>
<td>220</td>
<td>24</td>
<td>20</td>
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<td>200</td>
<td>150</td>
<td>100</td>
<td>80</td>
<td>29</td>
<td>25</td>
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<td>550</td>
<td>450</td>
<td>370</td>
<td>95</td>
<td>80</td>
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<td>90</td>
<td>50</td>
<td>40</td>
<td>30</td>
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<td>Mould making</td>
<td>150</td>
<td>110</td>
<td>70</td>
<td>40</td>
<td>30</td>
<td>20</td>
<td>15</td>
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<td>Pottery support activities</td>
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<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Pottery activity, no job details known</td>
<td>200</td>
<td>160</td>
<td>125</td>
<td>90</td>
<td>35</td>
<td>30</td>
<td>25</td>
</tr>
</tbody>
</table>

*Reported as daily 8 hour time weighted airborne concentration in µg/m³.
Table 2 Person-years analysis: observed and expected deaths 1985–92

<table>
<thead>
<tr>
<th>Cause (ICD-9)</th>
<th>Observed</th>
<th>Expected SMR (95% CI)</th>
<th>Expected SMR (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>All malignant disease (140–209)</td>
<td>150</td>
<td>104.3 1.44 (1.22 to 1.69)</td>
<td>133.5 1.12 (0.95 to 1.32)</td>
</tr>
<tr>
<td>Lung cancer (162)</td>
<td>68</td>
<td>35.6 1.91 (1.48 to 2.42)</td>
<td>53.1 1.28 (0.99 to 1.62)</td>
</tr>
<tr>
<td>Cancer of digestive organs (150–159)</td>
<td>40</td>
<td>31.8 1.26 (0.90 to 1.71)</td>
<td>41.4 0.97 (0.69 to 1.31)</td>
</tr>
<tr>
<td>Other cancers (140–149, 160–161, 163–209)</td>
<td>42</td>
<td>36.8 1.14 (0.82 to 1.54)</td>
<td>39.0 1.08 (0.78 to 1.46)</td>
</tr>
<tr>
<td>Non-malignant respiratory disease (460–519)</td>
<td>57</td>
<td>19.9 2.87 (2.17 to 3.72)</td>
<td>27.9 2.04 (1.55 to 2.65)</td>
</tr>
<tr>
<td>Heart disease (391–429)</td>
<td>171</td>
<td>125.8 1.36 (1.16 to 1.58)</td>
<td>153.3 0.98 (0.83 to 1.13)</td>
</tr>
<tr>
<td>Cerebrovascular disease (430–438)</td>
<td>17</td>
<td>18.7 0.91 (0.53 to 1.46)</td>
<td>21.3 0.80 (0.46 to 1.28)</td>
</tr>
<tr>
<td>Accidental injury (800–998)</td>
<td>9</td>
<td>15.6 0.58 (0.26 to 1.09)</td>
<td>13.9 0.65 (0.29 to 1.23)</td>
</tr>
<tr>
<td>All causes</td>
<td>470</td>
<td>321.1 1.46 (1.33 to 1.60)</td>
<td>409.1 1.15 (1.05 to 1.26)</td>
</tr>
</tbody>
</table>

RADIOGRAPHIC READINGS

The radiographs were taken either at first employment, or, for those employed before 1948, as soon as practicable after this date and subsequently every 4 years. These were read and recorded by medical officers of the Department of Social Security trained and experienced in the ILO classifications in current use. At least one chest radiograph was available for 4247 workers, 83% of the cohort. In the present study the date of the first reading on the ILO classification for small parenchymal opacities of 2/1 was recorded together with the reading at this date and at the last available radiograph.

STATISTICAL ANALYSES

Person-years analysis

Standardised mortality ratios (SMRs) were computed with two sets of rates, those for England and Wales and those for Stoke-on-Trent, standardising for quinquennia of birth and age at death. Because of the possibility that bias might have been introduced in the analysis of early deaths by the inadvertent destruction of index cards for deaths known before 1985, the analysis was limited to mortality to June 1992 in the cohort of 4822 men known to be alive at 1 January 1985. Among these men 470 deaths occurred, 68 from lung cancer.

Analysis of the pneumoconiosis subcohort

The prevalence of radiographic change (≥1/0) was calculated for each measure of exposure. With unconditional logistic regression in an unmatched case-referent design, odds ratios (ORs) were calculated for each exposure measure, with allowance for possible confounding by smoking and potential exposure to cristobalite or tridymite.

Analysis of the nested case-referent study

The relation of exposure to lung cancer was examined in case-referent matched sets by conditional logistic regression analysis, assuming multiplicative relative risks. To assist presentation of the results, cumulative exposure was divided by 1000, mean concentration by 100, and duration by 10 before entry in the regression analysis.

Results

PERSON-YEARS ANALYSIS

The observed to expected ratios based on rates for England and Wales and for Stoke-on-Trent are given in table 2. Against national rates the ratios were significantly increased for all causes, all malignancies, lung cancer, and non-malignant respiratory disease. With Stoke-on-Trent rates as reference the difference was greatly reduced. However, the SMRs for all causes, for lung cancer, and for non-malignant respiratory disease remained raised; the lower bound for the 95% confidence interval (95% CI) for lung cancer was marginally less than 1.00 but on a χ² test the observed number of cases differed significantly from expectation (χ² = 3.91; p<0.05).

RADIOGRAPHIC CHANGE AND EXPOSURE

In the subcohort of 1080 selected for this analysis, 64 (5.9%) had at least one radiograph read as ≥1/0 for small opacities on the ILO classification, for the present purpose considered abnormal. Of the 64, 21 had a reading ≥2/1. Mean dates of birth, of starting work, and of first abnormal radiograph are shown in table 3. Those with abnormal radiographs were born and started work earlier than those whose radiographs were read as normal (≤1/0). Those whose first radiograph was read as ≥2/1 had started work earlier than those first identified as having an ILO score of 1 (1/0, 1/1, or 1/2) and the opacities were detected after a shorter period of employment.

The prevalence of small opacities increased with cumulative exposure (table 4). Among those who had ever smoked the prevalence was about twice that in non-smokers. A small group of 14 with insufficient information on smoking had an unexpectedly high prevalence of abnormal chest radiographs. All but three had missed earlier radiographic screening, and despite a mean duration of exposure of some 19 years, had no history of previous smoking. Eight were found to have abnormal radiographs, seven with an ILO classification of ≥2/1. Further analyses of the subcohort excluded these 14 workers.

Table 3 Description of the pneumoconiosis subcohort

<table>
<thead>
<tr>
<th>ILO classification of small parenchymal opacities</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>Overall</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of birth:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mean</td>
<td>1933</td>
<td>1936</td>
<td>1921</td>
<td>1933</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>6.3</td>
<td>6.6</td>
<td>4.5</td>
<td>6.2</td>
<td></td>
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<tr>
<td>Date of starting:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mean</td>
<td>1940</td>
<td>1942</td>
<td>1936</td>
<td>1949</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>6.6</td>
<td>7.0</td>
<td>2.1</td>
<td>6.6</td>
<td></td>
</tr>
<tr>
<td>Date of radiograph:*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>SD</td>
<td>9.6</td>
<td>9.5</td>
<td>6.9</td>
<td>9.9</td>
<td></td>
</tr>
<tr>
<td>n</td>
<td>1016</td>
<td>43</td>
<td>21</td>
<td>1080</td>
<td></td>
</tr>
</tbody>
</table>

*First recorded as ≥1/0. Last if all recorded as normal.
Odds ratios were calculated separately for cumulative exposure, duration, and average concentration (cumulative exposure and duration) both before and after adjustment for smoking (Table 5). Cumulative exposure and average concentration entered as continuous variables were both strongly related to the presence of small opacities. The likelihood ratio statistic associated with mean concentration (35.7 on 1 df) was marginally greater than that for cumulative exposure (34.1 also on 1 df). Duration of exposure was not significantly related to radiographic reading. It did, however, add somewhat to mean concentration when both were in the model (cumulative exposure OR 3.10, 95% CI 2.19 to 4.38; duration OR 1.37, 95% CI 1.05 to 1.80). In all analyses the inclusion of smoking (which was itself associated with the presence of small opacities by an OR of 2.28 (95% CI 1.02 to 5.10) marginally reduced the size of the exposure effect without changing the conclusions drawn. In this subcohort working in firing and post-firing jobs did not seem to increase the probability of radiographic changes (OR 0.83, 95% CI 0.41 to 1.67).

CASE-REFERENT ANALYSIS

Matching on date of birth and date of starting work in the pottery industry was very close, with the mean year of birth 1930 and mean year of starting work 1950, for both the 52 cases of lung cancer and the 195 referents. Date of last medical examination in the pottery industry was somewhat earlier for cases (1969) than referents (1972). For cases, the date of the last medical examination was on average 18.4 years before the date of death.

Cases and referents differed in reported cigarette smoking (Table 6). No case was recorded as never having smoked and referents were chosen to exclude known non-smokers. Nevertheless, referents had a significantly higher proportion of ex-smokers (26.2%) than cases (9.6%). Those with unknown history of smoking (12 cases, 42 referents) had short employment in the industry (on average 4.1 years).

Only three cases and 10 referents were known to have had an abnormal radiograph (ILO ≥1/0). No radiograph was recorded for eight cases and 25 referents and again the period of employment was short (average 5.1 years).

Odds ratios calculated separately for cumulative exposure, duration, and mean concentration, lagged by 0, 10, and 20 years are shown in Table 7. Only mean concentration of exposure was positively related to lung cancer (p<0.008 at all three lag periods). Neither cumulative exposure nor duration was associated with lung cancer in the expected direction; indeed cases had shorter exposure. When duration was added to a model already including mean concentration and smoking, no significant improvement in the model was found (p=0.42).

Lagging had little effect on risk estimates, as might be expected from the long period between last medical examination (reflecting last employment in exposed jobs) and death. Further analysis was restricted to exposure variables lagged by 10 years.

It was previously reported from this study8 that both maximum exposure and exposure to processes containing heated silica were positively related to lung cancer. This was indeed the case (maximum exposure ≥400 mg/m³ OR 2.16, 95% CI 0.98 to 4.74; heated silica OR 2.19, 95% CI 1.06 to 4.51). When, as previously, mean concentration was entered as a dichotomous factor, both added to the model. However, in the present detailed analysis, with mean concentration entered as a continuous variable, neither maximum exposure nor exposure to heated silica changed the results to an important extent (maximum exposure ≥400: OR 1.29, 95% CI 0.47 to 3.55; heated silica OR 1.64, 95% CI 0.68 to 3.94), reflecting the close correspondence between heat related jobs and high exposure.

The presence of small opacities was unrelated, in the logistic regression analysis, to lung cancer either alone (p=0.78) or after adjust-

Table 5 Relation of small parenchymal opacities (≥1/0) to each exposure variable (unconditional logistic regression analysis (n=1066))

<table>
<thead>
<tr>
<th>Exposure index</th>
<th>Prevalence</th>
<th>OR 95% CI</th>
<th>Prevalence</th>
<th>OR 95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative 1000 (µg/m³ y)</td>
<td>1.38</td>
<td>1.24 to 1.53</td>
<td>1.37</td>
<td>1.24 to 1.53</td>
</tr>
<tr>
<td>Mean concentration 100 (µg/m³)</td>
<td>2.69</td>
<td>1.96 to 3.70</td>
<td>2.66</td>
<td>1.94 to 3.66</td>
</tr>
<tr>
<td>Duration/10 (y)</td>
<td>1.06</td>
<td>0.82 to 1.37</td>
<td>1.08</td>
<td>0.83 to 1.40</td>
</tr>
</tbody>
</table>

Table 6 Percentage distribution by smoking and radiographic data for cases and referents

<table>
<thead>
<tr>
<th>Cigarette smoking</th>
<th>Cases (%)</th>
<th>Referents (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>78.8</td>
<td>82.1</td>
</tr>
<tr>
<td>Yes</td>
<td>58.5</td>
<td>51.1</td>
</tr>
<tr>
<td>UK</td>
<td>13.4</td>
<td>12.8</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

n = 52

Table 4 Prevalence of small parenchymal opacities (≥1/0) by cumulative exposure and smoking

<table>
<thead>
<tr>
<th>Non-smoker</th>
<th>Smoker</th>
<th>UK Smoking</th>
<th>Overall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposure (µg/m³ y)</td>
<td>Prevalence</td>
<td>n</td>
<td>Prevalence</td>
</tr>
<tr>
<td>&lt;2000</td>
<td>0</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>2000-3999</td>
<td>0.9</td>
<td>112</td>
<td>1.8</td>
</tr>
<tr>
<td>4000-5999</td>
<td>2.9</td>
<td>70</td>
<td>6.3</td>
</tr>
<tr>
<td>≥6000</td>
<td>9.3</td>
<td>43</td>
<td>16.3</td>
</tr>
<tr>
<td>Overall</td>
<td>2.7</td>
<td>255</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Crystalline silica and risk of lung cancer in the potteries 783
Table 7  Relation of lung cancer to each exposure variable (conditional logistic regression analysis)

<table>
<thead>
<tr>
<th>Exposure Variable</th>
<th>No lag</th>
<th>95% CI</th>
<th>Lagged 10 y</th>
<th>95% CI</th>
<th>Lagged 20 y</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cumulative exposure:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unadjusted</td>
<td>0.92</td>
<td>0.79 to 1.08</td>
<td>0.93</td>
<td>0.79 to 1.09</td>
<td>0.93</td>
<td>0.77 to 1.11</td>
</tr>
<tr>
<td>Adjusted for smoking</td>
<td>1.01</td>
<td>0.85 to 1.19</td>
<td>1.02</td>
<td>0.86 to 1.21</td>
<td>1.01</td>
<td>0.84 to 1.22</td>
</tr>
<tr>
<td>Duration:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unadjusted</td>
<td>0.73</td>
<td>0.55 to 0.96</td>
<td>0.67</td>
<td>0.47 to 0.95</td>
<td>0.49</td>
<td>0.29 to 0.85</td>
</tr>
<tr>
<td>Adjusted for smoking</td>
<td>0.79</td>
<td>0.56 to 1.13</td>
<td>0.75</td>
<td>0.48 to 1.18</td>
<td>0.59</td>
<td>0.30 to 1.17</td>
</tr>
<tr>
<td>Average concentration:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unadjusted</td>
<td>1.70</td>
<td>1.18 to 2.44</td>
<td>1.67</td>
<td>1.18 to 2.35</td>
<td>1.57</td>
<td>1.12 to 2.20</td>
</tr>
<tr>
<td>Adjusted for smoking</td>
<td>1.67</td>
<td>1.13 to 2.47</td>
<td>1.66</td>
<td>1.14 to 2.44</td>
<td>1.60</td>
<td>1.11 to 2.31</td>
</tr>
</tbody>
</table>

Discussion

The findings from this cohort study show that men working in the pottery industry had more deaths than expected from lung cancer and non-malignant respiratory disease compared with the national population, or to a lesser extent, that of Stoke-on-Trent. Moreover, from the nested case-referent analysis, it seems that lung cancer was strongly related to the mean concentration of silica to which men had been exposed even after allowing for smoking and duration of exposure. These findings indicate that exposure to crystalline silica, at least in this industry, carried an increased risk of lung cancer.

The data available to us were unusual in that we had information recorded at regular intervals from first pottery exposure, on smoking, objective readings of periodic chest radiographs, and on previous occupational exposure to other hazardous dusts. Moreover, the work histories were sufficiently detailed for an exposure matrix, derived from about 1400 dust measurements, to be successfully tested for criterion validity against radiographic scores, before use in the nested case-referent analyses. Finally, the level of tracing by the DSS (99%) and of death certificate ascertainment by the OPCS (97%) would be difficult to better. Against all this is the serious possibility of non-random removal and destruction of records at the local DSS office. To minimise this possibility several strategies were adopted. Firstly, the cohort for the mortality study was confined to the period since 1984. Next, the analysis of the pulmonary subcohort was repeated in a reduced cohort in which no record was eligible for destruction, and comparable results were obtained. Finally, for the case-referent study in which all lung cancer deaths with extant records were used, evidence of possible bias was sought with information on the death certificates. For those with extant records pottery work was recorded in 52%; for those whose records were missing this was recorded in 48%. Only three workers with lung cancer, whose records had been destroyed, had mention of silicosis on the death certificate: this did not suggest important bias in destruction.

Table 7 shows that industries associated with heat processes, perhaps because of the associated high exposures, provide the strongest evidence of carcinogenicity and the most promising focus for further research. To be useful future studies must provide both quantitative and qualitative evidence on exposure in relation to risk.

This work was supported in part by a grant from the Department of Social Security, London. The views expressed are not necessarily those of the DSS or any other government department.

humans. Silica, some silicates, coal dust and para-aramid fibrils.


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