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DUST EXPOSURE, SMOKING HABIT AND RESPIRATORY CONDITION OF WORKERS IN IRON AND STEEL FOUNDRIES

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ABSTRACT

Between 1960 and 1970 3 559 workers in nine iron (IF) and steel foundries (SF) were examined. By means of thermal precipitator, filter apparatus, and a high volume sampler, 14 000 dust measuring data were collected. The aim of the study was to relate respiratory condition to dust exposure.

In SF numbers of particles were very high (iron oxides), weight content of dust was relatively low. Quartz content of the inhalable fraction was globally 10 ± 3 per cent of the heat resistant particles in $\mu g/m^3$. The number and weight concentrations of dust show log-normal frequency distributions with a g.s.d. of 1.8–2.5. For quartz particles the g.s.d. is double. A well defined sampling strategy in relation to technical sampling procedures is necessary.

The mean prevalence of silicosis was in the order of 1–4 per cent, higher in SF than in IF, and bound to particular occupations, being highest among fettlers. Symptoms of bronchitis were related to smoking and occupation. Lung function was influenced by both smoking habit and dust exposure. The impact was estimated in terms of loss of function, equivalent to number of years of accelerated aging. At exposures ≥ 2.5 mg/m^3 the mean loss in FEV_1 and FVC may amount to 7–10 functional years.

Paradoxical findings raise questions of the value of cross-sectional investigation, a mechanism of self selection and survival of the fittest, and drop out.

Under the auspices of the Netherlands Organization for Applied Scientific Research (abbreviated in Dutch: TNO) a working group on respiratory disease among workers in iron and steel foundries started its activities in 1959. One aim of the study was to make an inventory of the sort and amount of dust to which workers are exposed in various occupations: qualitative analysis of dust, exposure levels or exposure characteristics for defined working conditions or occupations, and development of representative sampling strategies.

The second part of the study concerned the worker's health and was aimed at the detection of lung disease and functional disturbances of airways and lungs in workers with different levels of exposure: prevalence of silicosis and other roentgenological abnormalities, bronchitic symptoms, and functional condition of airways and lungs. Special attention was given to smoking habit.

Finally efforts were made to qualify and to quantify possible relationships between exposure characteristics and medical findings: significance of quartz, acid resistant and heat resistant dust particles, exposure time, different lung function parameters, and a comparison with existing threshold limit values or guides was made. A detailed lay-out of the study plan was given by Jongh in 1963[9] and can be found in the final report by TNO of 1977[18]. The present paper discusses a limited number of relevant findings that are of general interest.

SUBJECTS, MATERIALS AND METHODS

A description of the methods of air sampling and the equipment used in the study of the working environments of nine iron and steel foundries was given in 1963 by Hartogensis and Van Zuilen[8]. More specified information can be found in the final report by TNO[18].

The main component of dust in foundries is quartz. Further the dust contains silicates (mainly clay) and iron oxides. In the original stage the quartz particles are very coarse. By temperature changes and mechanical operations, the particles are fractionated into fine dust. This means a shift in the distribution of particle sizes that can be found, dependent on sand mixture, casting temperature, and fettling procedures.

In steel foundries a conversion of quartz into cristobalite may take place and quartz particles may be broken up into fine splinters under the influence of high temperature. The size of quartz particles is up to about 200 μm in diameter, the range of cristobalite particles is up to about 5 μm.

Usually silicate dust is much smaller in particle size than quartz. The size of the elementary particles is not larger than about 2 μm. Iron oxides present themselves in agglomerated particles, which consist of numerous networks of chainlike particle rows. Although such particles may be present in a large number (e.g. 200 000 particles per ml of air), their total weight is low because of their small size.

Although in foundry dust the coarse particles mainly consist of quartz, the content of clay and iron oxides is relatively large in the respirable fraction (<5 μm diameter). Below a size of about 0.5 μm this phenomenon is still more evident so that in those cases the quartz content is relatively small and iron oxides may happen to be present in very large proportions.

The following dust sampling equipment was used:

- Standard thermal precipitator (number of particles <5 μm, sampling time 10 minutes, used in all foundries since 1959).
- Hamilton thermal precipitator (number of particles <5 μm, sampling time 8 hours, used since October 1961).
- Filter apparatus (weight content of dust, sampling time 3–4 hours, used in all foundries, since 1959).
- High Volume Air Sampler (USA) and dito GROMOZ (IG-TNO) for analysis of the chemical composition of the smallest fractions (a.o.

assessment of quartz content, sampling time $^1/_2$–4 hours, used since 1961 and 1963, respectively).

The sampling apparatus were located at defined spots in the working environment as close to the workers as practicable, dependent on their activities and on the possibility to control the equipment. Because all sorts of air movement (caused by heat sources, ventilation, open doors) can make measuring data less representative and thus less reliable, large numbers of samples were taken, as well as series of samples at the same spot under various conditions.

In the first three foundries, measurements were made without a definite schedule or layout, without strict outlines for measuring spot, sampling time and hour of the day. In the next foundry a selective procedure was applied: every run was simultaneously made at four different locations and occupations. The location of the equipment per type of work and per day was selected at random. Finally, a sampling strategy was developed in which samples were taken at a restricted number of locations (about 15). Per occupation these were randomly selected (Latin square method). By this procedure the topical dependence of sampling data could be eliminated so that the influence of time of the day could be studied per location.

Data were pooled according to occupational groups, i.e. groups of comparable occupations through the works. Eleven groups could be taken into consideration because of availability of a satisfactory amount of data, and by the fact that those occupations could be found and were performed in a comparable manner in most foundries.

The study covered nine foundries of which seven were iron foundries (IF); one was a large steel foundry (SF), and one works had combined but alternating activity. A total of 14 000 data was gathered and it was possible to detect specific distribution characteristics for numerical and gravimetric dust data[3,7,8,15,16].

For the study of the workers' health condition, the method of a transversal cross-section was chosen. It was expected that differences in environmental conditions would be reflected by differences in health parameter values among people investigated in such a sense that the findings would also allow a dynamic interpretation (dose-effect and dose-response relationships).

When the study started, the opinion existed that silicosis could be found in Dutch iron and steel foundries, indeed, but not in great numbers. It could be relevant to look for lung function disturbances among people without manifest clinical symptoms. Since the study aimed at checking only a limited number of functions that could be tested by a mobile team of investigators, the following records were made: personal and anthropometric data, smoking habits, bronchitis and asthma history, physical and X-ray examination of the thorax, spirometry: forced vital capacity (FVC) and forced expiratory volume in one second (FEV_1), helium wash-out curve (assessment of unequal distribution of alveolar ventilation), carbon dioxide curve (assessment of alveolar CO_2 pressure and ventilation-perfusion ratio) and urine test.

Specifications of the screening procedures used can be found in the literature[4,5,6,19]. At the beginning of the study there was not yet enough insight in the relationships between spirometric data, body stature, and age for Dutch population groups. During the studies the best fitting model turned out to be:

$$\log(\text{spirometric value}) = b_1 \log(\text{height}) + b_2(\text{age}) + a \qquad 1$$

In this formula the spirometric value reads in litres, body height in metres, and age in years. The best fit for the parameter values turned out to be:

$$\log FVC = 2.27 \log(\text{height}) - 0.0021(\text{age}) + 0.244 \qquad 2$$

$$\log FEV_1 = 2.27 \log(\text{height}) - 0.0043(\text{age}) + 0.181 \qquad 3$$

The promulgation of these models and formulas can be found in literature[1,12,13,14]. In each foundry the multiple correlation coefficient was in the order of 0.7. For the purpose of the analysis of the influence of smoking habit, various types of dust, and exposure time, the term "a" in formula 1 was replaced by a constant b_0 plus a series of additional terms as $b_3(A) + b_4(B) + b_5(C)$ ...$b_n(Z)$ of which each represents the contribution of an environmental or other particular aspect to the actual individual spirometric value recorded.

In total 3559 people, employed in iron and steel foundries, were investigated. Many of them worked in dusty environments. Outdoor workers, administrative and laboratory staff and others were screened too, as they could be used as a control group. For the purpose of linking medical to environmental data, only a part of the total population investigated could be covered (2400 individuals). Forthcoming hypotheses were tested on the total set of data from nine foundries.

Based on the distributions of dust measuring data per occupational group, the best fitting approximation in terms of a mean value per parameter was made. Application of an occupational group code rendered it possible to link exposure data to individual functional data. The latter could be grouped as well.

The following magnitudes of dust exposure were entered in the analysis:

a. number of heat resistant particles per ml (thermal precipitator);

b. number of acid resistant particles per ml (thermal precipitator);

c. milligrams of heat resistant dust per m^3 (filter apparatus);

d. milligrams of heat resistant dust < 5 μm per m^3 (high volume sampler);

e. micrograms of quartz < 5 μm per m^3 (high volume sampler).

Exposure time was introduced as such, as well as the product of exposure time and the number of heat resistant particles per ml.

Great attention was given to the handling of smoking data. The number of cigarettes consumed was classed in three categories, the fourth being reserved for smoking habits different from cigarette smoking.

Finally, an extra variable was entered in order to assess an aspect that could be called specific for each foundry, whatever the kind of that influence might be.

RESULTS AND DISCUSSION

Dust measurements

In Table 1 the ranges of mean exposures to seven dust parameters are given for four main occupational groups in IF and SF. On the basis of these indicative data and information present in the final report[18], the following observations can be made.

TABLE 1

Exposure ranges of seven dust parameters for four occupational groups in iron and steel foundries.

Dust parameters	Occupational group			
	Core making	Moulding, all in	Fettling, all in	General exposure
Thermal precipitator heat resistant particles (per ml × 1000)	7 – 40	7 – 25	5 – 137	9 – 24
Thermal precipitator acid resistant particles (per ml × 1000)	2.0 – 14	0.9 – 7.4	1.0 – 7.8	2.2 – 7.0
Hamilton t.p. heat resistant particles (per ml × 1000)	5 – 38	6 – 26	4 – 150	7.5 – 18
Filter apparatus heat resistant particles (mg/m^3)	1.9 – 6.9	2.1 – 17	4.8 – 23	2.2 – 13
High volume sampler total dust content (mg/m^3)	2.9 – 9.3	2.0 – 29	4.1 – 35	2.3 – 20
High volume sampler acid resistant particles $< 5 \mu m$ (mg/m^3)	0.7 – 2.8	0.5 – 3.2	0.6 – 6.8	0.6 – 2.6
High volume sampler quartz + cristobalite in particles $< 5 \mu m$ ($\mu g/m^3$)	68 – 365	42 – 300	46 – 990	62 – 305

Differences in dust exposure exist between foundries and occupations. In most cases (particularly in IF) the difference per occupation between foundries did not amount to more than a factor two. If different occupations were performed in one workshop, the range of exposure over the occupations decreased. If different occupations were performed in separate workshops, the range of exposures per foundry increased and amounted roughly to a factor four. In IF there is no evidence that particular occupational exposures were systematically heavier than others. In general, core makers' exposure patterns tended not to be heavier than others, but there is hardly any occupation with an exposure pattern that would be heavier than the one of fettlers.

In SF things were different. The numerical dust concentrations in those works were exceedingly high among fettlers. This holds true for heat resistant particles, not for acid resistant particles. Only a very small fraction of the large numerical dust concentrations consisted of quartz or cristobalite. In one steel foundry, where iron was cast one day each week, this phenomenon could be checked. On "iron" days the number of heat resistant particles amounted to only about one-tenth of the levels on "steel" days, whereas the number of acid resistant particles then happened to be several times higher than on "steel" days.

As to the gravimetric dust concentration, there are indications that the over--all dust levels in SF may be lower than in IF if both total and heat resistant dust are compared. This does not hold for fettlers.

In the inhalable fraction (<5 μm) the quartz and cristobalite content amounted globally to 10 per cent (range 8 – 14) of the mean weight in mg/m^3 of heat resistant particles in SF. For IF the mean ratio was in the order of 8 per cent, with a wider range (3 – 15). From this one may conclude that the gravimetric dust content of particles <5 μm in terms of mg/m^3, would represent a rather good prediction about the amounts of respirable quartz in the working environment.

Exposure of furnace repair workers to quartz and cristobalite was four to five times higher than this 8 to 10 per cent ratio. About 45 per cent of the acid resistant fraction <5 μm of the lining dust of cupola turned out to consist of quartz.

The quartz content of particles <0.8 μm is lower than of particles in the order of 0.8 – 3.2 μm and >3.2 μm. After acid treatment of heat resistant dust, the size distribution of the sample generally shows a shift towards relatively more coarse particles.

Distribution of measuring data, gathered at one or more locations that together can be considered representative of a given occupation, in general, showed an asymmetrical form. It turned out that a logarithmic normal frequency distribution fairly fits the description of such series of data. This holds true for numerical as well as for gravimetric dust concentrations.

Differences between the distributions show themselves in differences in arithmetic mean and, particularly, in the geometric mean. Another typical feature is the difference in range and standard deviation of the data. The great influence of a running furnace or cupola could be observed: the overall and peak levels could be doubled particularly of the finest particles.

In groups of extreme exposure, e.g. fettlers or moulders in an automatized or mechanical process, the geometric standard deviation of data appeared to be relatively small: in the order of 1.5 – 1.8. This may imply a high background level. For the greater part of occupations, however, the geometric standard deviation (g.s.d.) appeared to be larger, in the order of 1.8 – 2.5, for number concentrations and weight concentrations of dust as well. The quartz content of the dust generally showed a larger range than the other parameters. Cristobalite, in the end, showed the largest range: the g.s.d. for particle numbers may be in the order of a factor four.

Occupational groups who work during night at a time that there are no other activities in the works (e.g. sand removers) meet exposures that are 5 to 10 times lower than of day workers. The distribution of their exposure data, however, is in the same order as for the others: the g.s.d. is about two.

Various above statements and conclusions induce the need to assess the quality of the working environment of iron and steel foundry workers not by single but by means of series of measurements per occupation or group of workers. It should be put forward as a pertinent condition, that air sampling should be performed on the basis of statistical schedules. In these the influences of the season, day of the week, and moment of the day, should be taken into account in such a way that fluctuations or combinations of those factors are mirrored in the data. This applies to measurements with a short sampling period (thermal precipitator) and long running equipment as well. It is impossible to give an exact outline in this respect, since local conditions play an important role.

Comparison of series of measuring data has made obvious, however, that at least 20 data per occupation or group should be available in order to get a frequency distribution of a representative character. This holds true for a parameter in terms of mg/m^3, or quartz < 5 μm in terms of $\mu g/m^3$. For the standard thermal precipitator one needs at least 40 to 50 samples before the frequency distribution of data may be considered representative. It is obvious that the range of data obtained in a series of measurements depends on the sampling time: the former and the latter are inversely proportional to each other. If these conditions are met, the arithmetic mean of longer and shorter sampling times is more or less equal. The same holds true, to some extent, for the geometric mean. The latter tends to be somewhat higher if shorter sampling times are used.

Medical findings

A great part of the findings was already published at a stage where it was still impossible to investigate any overall associations between dust exposure and health parameters. Most of the publications dwell on the subject of the influence of dust inhalation and smoking habit on lung function parameters, e.g. references 10 and 11. On this subject the newer findings will be presented in the following chapter. Here only some remarks will be made regarding silicosis and bronchitis.

Prevalence of silicosis

The X-ray screening yielded a number of indisputable cases of silicosis. On the other hand, abnormal pictures were met that neither could be diagnosed as a real silicosis, nor could exclude any developmental stage of silicosis (comparable with Z-stage of the ILO nomenclature).

In the total of 3 559 people screened, 52 cases of distinct silicosis were found. As the total study population incorporated also employees who were not specifically engaged in the foundry process (office, laboratory forwarding), the number of found cases of silicosis should be related to an actually smaller foundry population in order to get realistic prevalence rates. The probable population at risk was estimated to amount to 2700 workers. Thus the found 52 cases of silicosis represent a prevalence in the order of 2 per cent (N.B. this figure does not give any information about the incidence per year of freshly diagnosed silicosis).

Looking at the distribution of silicosis over the nine works, the greater part of the cases appeared to be recorded in a large steel foundry (36 out of the 52 cases). This implies a higher prevalence for that foundry, viz. in the order of 3 to 4 per cent. The prevalence in the iron foundries figures in the order of 1.5 per cent. This finding is in agreement with experience from other countries: the prevalence of silicosis has been higher in steel foundries than in iron foundries, until recently. A dubious X-ray picture was found in 79 cases. Most of them (57) were met in the big steel foundry. The ratio compares with the prevalence rate of indisputable silicosis in that works.

Eighty per cent of silicosis cases were found among fettlers, ten per cent among moulders. The distribution of silicosis among fettlers was as follows: half of them were engaged in de-burring, trimming, and grinding, one sixth did the shaking and clearing out or beating the cast, and one sixth had been engaged in sand blasting and stone grinding. The rest of the silicosis cases among fettlers had performed various activities. Among furnace builders and repairers no silicosis was found in the present study. Among these, however, there were no workers with an exposure time over 15 years. Likewise, one third of cases of dubious silicosis was found among fettlers, one quarter among moulders, and about one tenth of cases among furnace repairers.

The overall prevalence of indisputable silicosis was in the order of 14 per cent among fettlers all in, 25 per cent in shaking out, beating, sand and steel grit blasting or stone grinding, and 18 per cent in deburring and trimming. Among moulders silicosis was diagnosed in only 3 per cent of the workers. A corresponding pattern was found for the distribution of dubious silicosis. Macronodulation and tumour phase silicosis were found in three cases, two of them having been engaged in sand blasting in former days.

The influence of exposure time is obvious, particularly among fettlers and moulders. In these two sub-populations with an outspoken risk, one sees the number of healthy people decreasing at increasing duration of exposure, in absolute and relative terms as well. For moulders the smaller risk is mirrored by a moderate decrease of healthy workers among those engaged already a long time, and silicosis was only found among moulders with a very long duration of exposure (35 years and over). Among fettlers, the number of workers with an indisputable or dubious silicosis manifested itself from an exposure time of ten years on. The prevalence increased rapidly at growing exposure so that half of the workers who were engaged more than 10–15 years, showed roentgenologically abnormal pictures. These patterns are mainly based on the findings in a large SF[9]. The findings from the IF's were so scattered that no trends could be recognized. The individual cases on the other hand, were not in disagreement with the observations made in the SF.

These results are in agreement with findings from other countries[2,17]. The incidence of silicosis (i.e. detection and registration of new cases per unit of time) turns out to be rather high among fettlers in steel and iron foundries, and among moulders in iron foundries as well, the former rate being about twice as high as the latter.

If one compares those incidence data with the prevalence rates from the present investigation, it is remarkable that the ratio between the prevalences in fettlers and in moulders (14–25 per cent versus 3 per cent) tends to be in the order of five to eight against a factor two, derived from incidence rates in literature.

Prevalence of bronchitis

Most people with a positive anamnesis of bronchitis or asthma smoked moderately or heavily. In about one half of these smokers with a positive history, no rhales could be observed. In about 40 per cent of all people with a positive history of bronchitis, rhales were observed. In people with a positive asthma history, this percentage amounted to about fifty. In healthy people rhales were heard on auscultation in 8 per cent of the population. In both healthy workers and people with respiratory symptoms, the prevalence of rhales was relatively high among furnace building and repairing people (indoor climate of cupola?), moderate among fettlers, moulders, and smelters (hot environment?).

About one third of the workers gave positive answers to the questionnaire (cough and phlegm) to such an extent, that their complaints could be appreciated as indicative of a mild or manifest bronchitis in the present or past. The prevalence was highest among furnace building and repairing people (36%), being twice as high as among fettlers, smelters, and moulders who exceeded the average (15%) with only two to three per cent. Among the people working inside the works, a positive history of bronchitis was about one and a half to twice as high as among the people who worked outside closed working premises, or who belonged to administrative and laboratory staff of the foundry. If one would give an interpretation of this finding from an environmental point of view, one should not point to a possible exposure to dust only, but take into account the influence of high and changing temperatures and draughts and the stress of heavy working loads as well. These parameters were not the subject of the study.

Influence of smoking habit and dust exposure on lung function

Four lung function parameters were thoroughly investigated with regard to the significance of smoking habit, exposure to various dust parameters, and possible additional factors (i.e. "home" factor of each foundry). These are helium wash-out curve, CO_2 curve, forced vital capacity (FVC), and forced expiratory volume in one second (FEV_1).

The relationship between dust and smoking habit on one hand, and the slope of the helium curve and CO_2 curve on the other, was investigated by means of a parameter-free analysis of variance. The latter data cannot be considered as elements from a continuum and must be treated as discrete quantities. This reduced the possibilities of analysis in comparison to the spirometric data.

The associations between FVC or FEV_1, dust parameters and smoking, were investigated by means of a multiple regression analysis. To both FVC and FEV_1, the same technique was applied that was based on the finding that the parameter values showed a continuous distribution. The applied model is presented in the chapter on materials and methods.

Helium curve and CO_2 curve

The analysis of helium and CO_2 data was confined to the influence of age by class, smoking habit by class, and three dust parameters, viz. items a, c and d, mentioned in the chapter on materials and methods.

This was done for each foundry separately, because it had become clear that large differences between the works might exist. As a condensed result the following generalized statements can be made:

a. In relatively young people, viz. 20–35 years of age, the mean slope of the helium curve was in the order of 2% sec^{-1}.

b. The slope of the helium curve increased at climbing age. The average increment amounted to 1% sec^{-1} per 15 years.

c. There was a positive association between the slope of the helium curve and smoking habit: on an average, the consumption of tobacco was mirrored by a helium gradient in the order of 1% sec^{-1} per pack of cigarettes smoked per day.

d. There was no association between the slope of the helium curve and the magnitude of the three dust parameters tested.

e. The distribution of the slope of the helium curve was not influenced by a foundry specific "home" factor.

f. For the carbon dioxide curve, the same tendencies were found, although less clear and less consistent. The rules of thumb, as are given here under a, b, and c with respect to the slope of the helium curve, could not be found for the CO_2 curve. An association between CO_2 curve and dust exposure could not be found.

g. The hypothesis that a combination of smoking and dust inhalation could have a synergistic or cumulative effect on the slope of the helium or CO_2 curve, could not be substantiated by the present data.

In conclusion it may be stated that the smoking of cigarettes plays an important role in bringing about unequal distribution of alveolar ventilation. Only under extreme conditions an association between the level of dust exposure and deterioration of the helium curve could be demonstrated[11].

FVC and FEV_1

Although a number of new parameters were entered in the analysis in the form of terms like $b_3(A)$, $b_4(D)$, etc. for smoking habit and various dust exposure magnitudes, the fit of the original model (formulas 1, 2 and 3) could not be improved substantially. Body height and age remained as significant as they were already; the values of b_1 and b_2 did not change. At a level of 0.70, the multiple correlation coefficients increased, if so, with only 0.01–0.03. Further, it turned out that a significant weight must be attributed to "local conditions" as such (home factor), that could not be explained on the basis of dust and exposure data. This held true for both FVC and FEV_1.

The magnitude of the constants b_3, b_4 etc., in the extended model and, particularly, the ratio between the various b-values, is indicative for the importance of an agent or a condition. Their reliability could be assessed from the ratio between the estimated mean b-value and the standard error of the mean.

Smoking turned out to be of prime importance. The phenomenon was pronounced and consistently present for FEV_1, as is shown in Table 2. Looking at the data that stem from the eastern part of the country, for FEV_1 there is a clear shift in the b-values of smoking habit. The log FEV_1 of a moderate smoker is $0.0065-0.0006 = 0.0059$ smaller than the log FEV_1 of a matching non-smoker. Among heavy smokers the influence is still more pronounced: the log FEV_1 is $0.0065-(-0.0083) = 0.0148$ lower.

TABLE 2
Estimated b-value for smoking in a multiple regression model of FVC and FEV_1.

Smoking habit		0	+	++
Number of cigarettes smoked per week		0	1–50	50–125 and > 125 (70%) (30%)
West	FVC	−0.0016	−0.0030	−0.0004
	FEV_1	+0.0048	+0.0005	−0.0112
East	FVC	+0.0028	+0.0024	−0.0013
	FEV_1	+0.0065	+0.0006	−0.0083

It is interesting to compare this finding with the impact of other variables in the model. From formula 3 it can be learned that in the case of FEV_1, the b_2-value (of age) figures at a level of -0.0043 for each year lived. As this value did not change in the extended model, the following example of a judgement of the practical significance of these parameter values in the model may be given.

If two workers, aged 25 and 55 respectively, are compared, their difference of predicted log FEV_1 amounts to 30 times $-0.0043 = -0.129$. If one realizes that -0.129 is the log of 0.74, one may translate the log difference of -0.129 into a ratio of 74 per cent, or a reduction in the order of 26 per cent (roughly 0.9 per cent per year). This would apply to mean data.

If individual or group data deviate from the predicted values, the difference of FEV_1 and log FEV_1 may be expressed in terms of a positive or negative deviation from any of the promulgated b-values. One of the possibilities is to express the deviation in equivalent terms of gain or loss of "functional age years". Parameter values that contribute negatively in the model, may be interpreted as an acceleration of the process of aging. If the contribution turns out positive, the individual or group behaves younger than expected from the mean. In the following discussion a trial is made to translate the influences of smoking and dust exposure in terms of "aging".

From Table 2 the net influence of moderate smoking (+) on log FEV_1, can be estimated to be in the order of − 0.0059, which may be compared with 0.0043 for each year of age. For heavy smokers (++) the latter compares with − 0.0148. This could imply that, in the average, the FEV_1 is reduced by about 1.35 per cent to a level of a person about 1.5 years older in the case of moderate smokers, whereas heavy smokers show a loss of FEV_1 in the order of 3 per cent or an "age loss" of about 3.5 years.

Comparison of these findings from the foundries in the eastern part of the country with those from the western (and central) part, shows a close correspondence. The reduction of the b-value for smoking is $0.0048 - 0.0005 = = 0.0043$ and $0.0048 - (-0.0112) = 0.0160$ for moderate and heavy smokers, respectively. This equals an "age loss" of about 1 and 4 years.

The congruence of both patterns from different parts of the country clearly indicates that the loss of functional years under the influence of smoking is general and essential. Particularly, the effect of heavy smoking is significant, both from the statistical point of view (ratio between estimated b-values and its standard error in the order of 3), and from the health point of view.

A consistent influence of smoking upon FVC seems absent in the central and western part. In the east there is a tendency of decreased log FVC in heavy smokers: $0.0028 - (-0.0013) = 0.0041$ reduction of the log. Taking into account a b_2-value for log FVC of − 0.0024 for each year of age, the reduction of FVC among heavy smokers rates a functional age loss of about two years or about one per cent of FVC. Compared to FEV_1, this finding indicates that the effect of heavy smoking upon FEV_1 is about four times greater than upon FVC.

In all foundries, dust in the air was assessed with simple filter apparatus and thermal precipitator so that a spectrum of data over most of the works was available. As these data were checked, no consistent pattern of contributing b-values was found for log FVC and log FEV_1 either. The eastern part of the country did not differ from the western and central parts. Yet some indications of possible associations were found, e.g. between the number concentration of particles (t.p. data) and FEV_1. On the other hand the standard error of the parameter value in the formula turned out to be so large that the reliability of any statement or conclusion would be minimal.

In the eastern part of the country a poor association between the number concentration of dust particles and FEV_1 seemed to exist. If exposure levels with a difference in the order of a factor 20 were compared, in the worst case a tendency was found that such a difference of exposure could be associated with a functional age loss of two or three years at most. If, nevertheless, this poor phenomenon would bear any meaning, it should be observed that data from other parts of the country did not give any indication of the kind. For FVC such an indication was not found either, nor any association with weight content of dust as measured by filter apparatus.

In contrast to the above findings, the weight concentration of dust with a particle diameter <5 µm (sampled with a high volume sampler) seemed to bear real significance. It should be observed, however, that this equipment was not yet in use in the first works. So, the data pertain to the works in the eastern part of the country. In a manner, comparable to the procedure outlined above, b-values for three degrees of dust exposure were estimated. They are presented in Table 3.

TABLE 3
Estimated b-value for weight class of dust $<$ 5 µm in a multiple regression model of FVC and FEV_1.

Dust category	+	++	+++	Difference		b_2-value for age
Dust level (mg/m³)	0.3–0.8	0.8–1.6	>1.6	++ vs +	+++ vs +	
FVC	+0.0180	+0.0029	−0.0058	−0.0151	−0.0238	−0.0024
FEV_1	+0.0231	+0.0011	−0.0083	−0.0220	−0.0314	−0.0043

Both FVC and FEV_1 seem to show an association with the weight of dust particles <5 µm diameter. For log FVC the decrement is $0.0180 - 0.0029 = = 0.0151$ and $0.0180 - (-0.058) = 0.0238$, respectively. If both these differences are related to a b_2-value for log FVC of 0.0024 per year of age, one could say that exposure to medium and high concentrations of fine dust may be associated with a loss of ventilatory function equivalent to an acceleration of aging in the order of 6 or 10 years, respectively. On account of the range of the dust categories applied, one may assume that a FVC decrement in the order of a functional loss of 6 years aging can be a sequel of exposure to fine dust at mean levels of about 1.2 mg/m³. A loss of function equivalent to 10 years aging, could then be associated with exposure levels in the order of 2.5 mg/m³.

For log FEV_1 the differences in the parameter values turned out to be in the order of 0.0220 and 0.0314 for moderate and heavy exposures, respectively. If these are compared with the b_2-value for aging of 0.0043, one could say that the loss of lung function equals an aging of 5 or 7 years. It should be observed that the phenomenon of acceleration of aging showed itself less in FEV_1 than in FVC. The order of magnitude of both effects is, however, comparable.

It is difficult to discuss how far the above findings bear a significant and realistic meaning. The problem is that the standard error of the b-values presented is very large: about four to ten times the standard deviation of the b_2--values for age or smoking, which each are significant from a statistical point of view. This implies that predictability of readings in individual cases is minimal. Only for large collectives it may be said that the observed tendencies really exist.

It should be added that in a non neglectible number of cases, the effect would be much greater than the mean parameter values in the formulas suggest. On the contrary, a number of individuals would behave in a way opposite to the observed tendency.

In Table 4 an unexpected and very remarkable phenomenon is presented. For quartz (in terms of weight concentration of particles <5 μm) an inverse pattern of associations with both FVC and FEV_1 was found: the b-values and their differences turned out positive instead of negative at increasing exposures. For log FVC the differences were in the order of 0.0121 and 0.0255 at the given exposure levels. For log FEV_1 the differences figure at a level of 0.0220 and 0.0495, respectively. Expressed in terms of aging, these differences amount to 5 and 10 years for FVC, and to 5 and 11 years for FEV_1, respectively. But the tendency is opposite to those observed in the case of non-specific dust and smoking habit. Under the conditions of this investigation, exposure to increasing quartz levels turns out to be associated with spirometric readings that will be met, in general, among people who are many years younger.

TABLE 4
Estimated b-value for weight class of quartz particles <5 μm in a multiple regression model of FVC and FEV_1.

Quartz category	+	++	+++	Difference		b_2-value for age
Quartz content (μg/m³)	64	65–125	>125	++ vs +	+++ vs +	
FVC	−0.0139	−0.0018	+0.0116	+0.0121	+0.0255	−0.0024
FEV_1	−0.0326	−0.0106	+0.0169	+0.0220	+0.0495	−0.0043

It should be observed, however, that in the quartz case the standard error of the b-values was very large. Although the differences between the estimated mean b-values are impressive, they can by no means be labelled statistically significant.

If, however, one would seek an explanation of the observed controversal phenomenon, the most plausible inference could be that it is a question of self--selection and "survival of the fittest". Particularly in those environments where the hazard of acquiring a respiratory disease is great, one may expect a number of supra-normals whose quality is superior to the average. They may be resistant towards the environmental impact. In other words: the finding is not relevant from the point of view of seeking associations between quartz and lung function. If one reverses the way of reasoning, however, the finding could be very important and indicative: an indirect evidence of the possibly fatal effect of inhalation of quartz containing dust by people who do not belong to a most resistant and supra-normal species, and who are forced to drop out.

If one would look at things this way, Table 4 gives an indication that exposures to levels of quartz particles < 5 µm in the order of 50–100 µg/m³ should be prevented, because such exposures possibly contribute to the supposed drift of people out of the population at risk. This hypothesis, however, cannot be proven by the material of the present study. But the forwarded hypothesis is more or less in agreement with the order of magnitude of the quartz guide issued in 1971 by the German Research Association (Deutsche Forschungsgemeinschaft) which figures at a level of 150 µg/m³.

CONCLUDING REMARKS

Most of the findings in this study are in agreement with the knowledge already existing. The prevalence of silicosis in SF turned out to be twice to three times as high as in IF. Silicosis is bound to definite jobs, among which fettlers form the group with the highest risk. The risk is appreciably lower among moulders.

About the prevalence of bronchitis and bronchitis symptoms, only few pertinent features became clear. Exposure to dust and to extreme climatic conditions seems to play a pertinent role.

In the studied foundries, differences in spirometric data (FVC and FEV_1) were observed. They could be associated with the number concentrations of inhalable particles, to some extent, and to the weight concentration of dust particles < 5 µm to which workers were exposed at the time of the investigation. The associations showed a large variance and some inconsistencies. For most of the foundries sometimes significantly discriminating "home"-factor could be found, to which, in some cases, the absolute meaning of the other parameters was related to appreciable extent.

The influence of smoking, however, turned out to be real and consistent. The meaning of the associations between inhalable dust and FVC or FEV_1 should be appreciated as real, too. About any interactions between smoking and an effect of dust exposure or other environmental and situational factors, nothing can be concluded. It is highly probable that exposure changes through the years and drop out of population members at risk, contribute to false statements and conclusions, if based only on the data from the present study. Further it is probable that the real impact of dust exposure is appreciably greater (particularly in individual cases) than the mean findings suggest.

The results of the present study clearly demonstrate the limitations of the method: cross-sections of population groups render insufficient possibilities to clarify phenomena that are evoked by complex interactions of multiple factors and conditions. Example of it may be the large regional variation in the distribution of the phenomena and the great variance of the possible associations between the independent and dependent variables. The relative lack of appropriate interpretability of findings, and the dimensions of the problems inherent to the method of a transversal study, has come to light convincingly.

In spite of these shortcomings, the present study has brought about a number of important conclusions and statements: the relative significance of various dust parameters has become clear. Important aspects of sampling strategy (in order to get representative exposure characteristics) has become evident. Various health parameters were tested as to their capacity to discriminate with regard to the impact of inhalable dust. Both influences, dust inhalation and smoking, could be expressed in terms of an acceleration of the process of aging of the lungs, which among healthy workers may amount to ten years loss of functional capacity on an average at the given exposures.

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