SILICOSIS HAZARDS IN ENAMELLING

A MEDICAL, TECHNICAL, AND EXPERIMENTAL STUDY

BY

LARS FRIBERG and HARRY ÖHMAN

From the Institute of Hygiene, Karolinska Institute, and the Department of Industrial Health, the National Institute of Public Health, Tomtebodavägen, Stockholm, Sweden

(RECEIVED FOR PUBLICATION JULY 20, 1956)

Silicosis in enamel workers has been reported by Gaubatz (1940), Bruce (1945), Meures and Gräf (1949), and Troisi (1952). One of Bruce's cases had third-stage silicosis (International Labour Office, 1930) and was completely disabled. A search of the literature, however, has revealed no further reports of advanced silicosis in such workers, even after long exposure to enamel dust. The cases described in the literature were attributed to inhalation of silicates, although Bruce discussed the possibility that certain types of enamel could contain free silica. Except for occasional analyses of the quartz content of enamel, dust studies in enamelling processes were not found in the available literature.

The exact prevalence of silicosis in Swedish enamel workers is not known, chiefly because medical inspection is not compulsory in that occupation. In a general survey of silicosis in Sweden during the period 1931 to 1953, however, 11 cases accepted by the insurance boards were found in enamelling workers and had had no other known exposure to silica (Ahlmark, Bruce, and Nyström, 1956, personal communication).

The present paper reports the prevalence of silicosis in a Swedish enamelling shop and the investigations performed in order to assess the silicosis risk.

The occurrence of silicosis among the employees in a workshop shows that unsatisfactory hygienic conditions have existed. In order to determine the current silicosis hazard dust studies are necessary. As a rule these include estimation of the atmospheric concentration of dust and of its content of quartz, but they are not completely reliable guides to the injurious properties of the dust. Tests on laboratory animals of the fibrogenic potency of the dust may provide a valuable complement to more technical investigations, especially for comparison of different dusts. In the shop we investigated, technical dust

studies and animal experiments were therefore performed for appraisal of the silicosis hazard and of the need to introduce further prophylactic measures.

Enamelling Processes

The three main processes of enamelling are preparation of the enamel, spraying or dipping, and firing of the enamelled articles.

Preparation of Enamel.—The composition and technical properties of the enamels used in the shop investigated varied greatly. The method of preparation, however, was usually as follows. The powdered ingredients, including quartz feldspar, borax, metal oxides, and carbonates, were mixed in a rotating mixer and then heated in a furnace for some hours to about 800 to 1,200° C. The fused or sintered product (frit) was tapped in running water to produce an easily ground, granulated substance. This was ground while wet in a ball mill, sometimes with added substances such as quartz, clay, metal oxides, and carbonates. The aqueous mass thus obtained was ready for dipping or spraying various articles.

The enamel powder was weighed and mixed in a special shed with good general ventilation but without local exhausts. The dust produced in the various processes, therefore, spread into the atmosphere. Respirators were used by the men working in the mixing shed. Dust-reducing measures by mechanization and enclosure of the dusty operations with local exhaust ventilation are planned. The powder mixtures were fused and sintered and the wet enamel was ground out in a separate shed. In recent years exhaust devices have gradually been installed above the furnaces in this shed.

Enamelling.—Cast-iron and sheet-metal articles were enamelled by dipping or spraying. Dipping was common formerly, but spraying was mainly used at the time of investigation.

In dipping, the article was rotated in the wet enamel so that an even coating was obtained. Spraying was undertaken with special guns in booths fitted with exhaust ventilation. The enamelled surfaces were allowed to dry before firing.

Enamelling has always been carried out in a special shed. The spraying booths were rebuilt and their exhaust system improved about 15 years ago. In 1952 there were 19 such booths along one wall. The velocity of air movement in the apertures of the various booths was then 0.7 to 2.0 metres per second when spraying was not in progress, and fell 0.1 to 0.2 metres per second during spraying.

Firing.—The enamelled articles were fired in a conveyor oven, through which they were transported on a moving band. Some articles were cleaned with compressed air before firing. The passage through the oven took several hours, during which the temperature was 800 to 900° C. Before 1952 firing was undertaken in 10 small ovens situated in the enamelling shed. These are gradually being dismantled, but two remained in 1954 and were used occasionally.

Prevalence of Silicosis

On January 1, 1954, there were 35 men employed in the shop we investigated. Nine of them had been enamel workers for more than five years, 13 for more than 10 years, four for more than 20 years, and two for more than 30 years. Seven men had less than five years' exposure.

Routine medical inspection was not carried out before 1950. Since then, however, all the men have had at least two chest radiographs.

Up to the end of 1953 silicosis was demonstrated in six men and was suspected in two more. Of the six established cases (Table 1), two were then classified as third-stage, two as second-stage, and two as first-stage silicosis (Johannesburg definition, 1930). Three of these men were partially disabled and their degree of disablement was assessed by insurance boards as 33½%, 20%, and 15%, respectively.

As periodic radiological examinations began so recently, the length of exposure required to produce silicosis is not known. In the four silicotic enamellers, however, normal pulmonary radiographs were obtained two to nine years before silicosis was diagnosed. From the beginning of exposure to the last normal radiograph, the minimum "incubation period" for silicosis in these men was nine years (probably much more), 21, 22, and 26 years, respectively. On the other hand, an enamel grinder (Case 6) was found to have second-stage silicosis after no more than 17 years' exposure. In no case were tuberculous lesions coexistent with silicosis as judged from the appearance of the radiograph.

Technical Dust Studies

The technical studies included determination of dust concentrations in the inhalation zone during various operations and analysis of the quartz content of dust and enamels. The samples for dust counts were collected from the breathing zone of the workers for five to 10 minutes with a midjet impinger. For chemical analysis air-borne dust was collected on filters. The quartz content of this dust and of the various enamels was determined by radiological diffraction of the particle fraction smaller than 5 μ .

The dust counts are presented in Tables 2, 3, and 4. Manual operations with the raw constituents of the enamels yielded by far the highest dust counts (Table 2). In the production of frit the mean dust concentration was considerably lower, although very high counts were registered when the powder mixtures were transferred to the furnaces. This operation lasted only a few minutes, however, and was performed only five or six times per shift. In spray enamelling and in the firing process the dust concentrations varied greatly, but the mean value was relatively low.

Table 3 shows dust counts in spray enamelling under various conditions. The surface to be coated, for example, on washbasins and cooking utensils, is important. Spraying of inner surfaces produced

TABLE 1
SILICOSIS IN ENAMEL WORKERS*

Case	Age	Chief Occupation	Total Exposure	Negative Chest Radiograph	Silicosis			Percentage Disablement
					Stage I	Stage II	Stage III	
					Years from Start of Exposure			
1	47	Enameller	28	9	18	27		
2	49	„	22	21	23-25			
3	66	„	28	22	26	30		20
4	67	„	28	26	23			
5	59	Various jobs in enamelling	33	14	16	22	29	15
6	49	Enamel grinder	16			17	19	33½

* Some data in the table were obtained from the survey of Ahlmark, Bruce, and Nyström (Personal communication).

TABLE 2
DUST COUNTS IN ENAMELLING PROCESSES BY
IMPINGER METHOD*

Operation	No. of Samples	Dust Count			
		Minimum	Maximum	Median	Mean
<i>Preparing enamel</i>					
Weighing and mixing	10	28	145	82	75
Transferring powder to furnace; wet grinding	23	1	64	4	10
<i>Enamelling</i>					
Spraying	46	< 1	37	3	6
Dipping	11	1	7	2	2
<i>Firing enamelled articles</i>	18	1	21	6	8

* Counts are expressed in million particles per cu. ft.

TABLE 3
DUST COUNTS IN SPRAY ENAMELLING BY THE
IMPINGER METHOD*

Type of Enamelling Operation	No. of Samples	Dust Count		
		Minimum	Maximum	Mean
<i>Ground coat</i>				
Inner surfaces, large articles	3	31	37	35
Outer surfaces, large articles	3	1	6	2
Outer surfaces, small articles	3	1	1	1
<i>Cover coat</i>				
Inner surfaces, large articles	2	15	16	16
Inner surfaces, small articles	12	1	24	9
Outer surfaces, large articles	8	1	3	2
Outer surfaces, small articles	6	2	3	2
<i>Single coat</i>				
Outer surfaces, large articles	7	< 1	2	1
Outer surfaces, small articles	2	1	3	2

* Dust counts expressed in million particles per cu. ft.

TABLE 4
COMPARISON BETWEEN DUST COUNTS MADE IN 1952
AND 1954 BY THE IMPINGER METHOD*

Operation	1952		1954	
	No. of Samples	Mean Dust Count	No. of Samples	Mean Dust Count
<i>Dip enamelling</i>	3	2	3	2
<i>Spray enamelling</i>				
Inner surfaces	4	12	7	12
Outer surfaces	10	2	29	2
<i>Firing enamelled articles</i>	8	6	10	8

* Dust counts expressed as million particles per cu. ft.

much higher dust counts than did spraying of outer surfaces. This was because the enamel aerosol has a greater tendency to "rebound" from inner surfaces and because the enameller as a rule must lean into the spraying booth, which is unnecessary in spraying outer surfaces. Dust counts during the latter operation were on the whole independent of the size of the coated article.

Enamelling by dipping (Table 2) gave the lowest mean dust counts of all, although no special exhaust ventilation was in use.

Work at the firing ovens involved three dusty

processes—cleaning with compressed air, brushing the inside of the articles, and handling the boards on which the spray-enamelled goods were placed for transport to the ovens. These boards gathered a deposit of dry enamel powder, which was readily whirled up into the atmosphere.

In certain processes the dust counts made in 1954 could be compared with counts which had been made in 1952. The dust concentrations were similar (Table 4). This tallied with the lack of change in working methods and in ventilation.

Quartz Analyses.—Quartz analyses were made on air-borne dust, on deposited dust, and on various enamels.

The results are presented in Tables 5, 6, and 7.

TABLE 5
QUARTZ CONTENT IN THE PARTICLE FRACTION < 5 μ
OF AIR-BORNE DUST

Operation	No. of Samples	Mean Quartz Content (%)
<i>Preparing enamel</i>		
Weighing and mixing	2	43
Transferring powder to furnace; wet grinding	1	46
<i>Spray enamelling</i>		
Ground coat	1	58
Cover coat	2	< 5
<i>Firing enamelled articles</i>	2	11

TABLE 6
QUARTZ CONTENT IN THE PARTICLE FRACTION < 5 μ
OF VARIOUS ENAMELS

No.	Type of Enamel	No. of Samples	Mean Quartz Content (%)
1	Ground coat	1	52
2	" "	3	57
3	" "	2	39
4	Cover coat	3	> 5
5	" "	1	> 5
6	" "	2	15
7	" "	2	> 5
8	Single coat	2	13

TABLE 7
QUARTZ CONTENT IN PARTICLE FRACTION < 5 μ OF
DEPOSITED DUST

Site of Dust Deposit	No. of Samples	Quartz Content (%)
Spraying booth	1	6
Space above conveyor oven	1	21
Beams of conveyor oven, ball mill and smelting furnace	1	18
Locker in enamelling hall	1	5

In the air-borne dust (Table 5) quartz could not be demonstrated during spraying of cover-coat enamel. The other processes, however, with the exception of firing the enamelled articles, produced dust with high quartz contents. Of the enamels studied (Table 6), those used for the ground coat had the highest content of quartz (39, 52, and 57%). Of

FIG. 1.—Epithelioid-cell granuloma (omentum) with fibrosis and concentrically-layered collagen fibrils nine months after injection of enamel No. 2. Weigert haematoxylin-Hansen. $\times 150$.

FIG. 2.—Epithelioid-cell granuloma (omentum) with severe fibrosis and concentrically-layered collagen fibrils two months after injection of pure quartz powder (No. 9). Weigert haematoxylin-Hansen. $\times 150$.

FIG. 3.—Necrotic granuloma (omentum) with infiltration of lymphocytes and leucocytes and severe fibrosis with concentric collagen lamellae two months after injection of enamel No. 7. Weigert haematoxylin-Hansen. $\times 150$.

FIG. 4.—Epithelioid-cell granuloma (omentum) with mild fibrosis nine months after injection of enamel No. 8. Weigert haematoxylin-Hansen. $\times 150$.

four types of cover coat only one contained quartz, and that in low concentration (15%). A single-coat enamel (an enamel sprayed without ground coat on sheet metal or cast iron) contained 13% quartz.

Animal Experiments

The fibrogenic potency of six of the enamels reported in Table 6 (Nos. 2, 3, 4, 6, 7, and 8) was tested in rats. These were the enamels most commonly used during the period of our investigation. Control tests were undertaken with pure quartz powder (No. 9). The approximate percentages of quartz in the enamel powders were 57 (No. 2), 39 (No. 3), < 5 (Nos. 4 and 7), 15 (No. 6), and 13 (No. 8).

Enamel powder was suspended in sterile physiological saline solution in a concentration of 3.7 g. per 100 ml. The fibrogenic potency was estimated from the tissue reaction after a single intraperitoneal injection (2 ml. = 75 mg. enamel powder) according to the method of Miller and Sayers (1934).

Each type of enamel was tested on about 30 rats, the groups being numbered in conformity with the enamels. In each group four rats were killed after two weeks, one, two, three, six, and nine months. The peritoneum and omentum were examined macroscopically and in about half of the rats microscopy was also performed.*

Macroscopic Changes.—These were invariably most severe in the omentum, but frequently occurred also in the peritoneum. Changes appeared from two to four weeks after the injection and consisted of white or green (some of the enamels were green) pinpoint- to pinhead-sized, more or less firm, nodules. The largest and firmest nodules were seen in groups 2 and 9, and the smallest in groups 4 and 7, where the lesions had an almost floury appearance. Progression was clearly observed only in group 9 and occurred two months after the injection. Some apparent regression of the lesions was seen in groups 6 and 7.

Microscopic Changes.—These were observed in all the groups, but there were some distinct differences.

In groups 2, 3, and 9 (57, 39, and 100% quartz respectively) the microscopic findings were nearly the same. The lesions were granulomatous with moderately abundant epithelioid cells. After two to three months fibrosis also developed, which intensified and gradually took on a typical silicotic appearance with concentric layering (Fig. 1 and 2). Such changes first occurred in group 9.

Groups 4 and 6 both showed granulomatous lesions with abundant foreign bodies, but with insignificant numbers of epithelioid cells. Fibrosis developed, especially in group 6. It was not silicotic in type, however, but most closely resembled foreign-body granuloma.

In groups 7 and 8 (Fig. 3 and 4) the lesions were more heterogeneous. Group 7 showed small granulomata with scanty epithelioid cells. Small fibrous lesions with concentric layering were observed, two, six, and nine months after the injection, but in some sections the fibrous lesions displayed central necrosis with some leucocytic infiltration. In group 8 a section two months after the injection showed epithelioid-cell granuloma with fairly typical silicotic fibrosis. Subsequently, however, epithelioid-cell granuloma was the only demonstrable lesion in this group, except for mild, non-silicotic fibrosis in the rats killed after nine months.

Enamels 2 and 3 (57 and 39% quartz respectively) and the pure quartz powder thus gave rise to severe silicotic lesions and enamels 7 and 8 (< 5 and 13% quartz respectively) produced changes of suspected silicotic type. Silicosis was not demonstrated in the rats injected with enamels 4 and 6 (< 5 and 15% quartz respectively).

Discussion

In the past 20 years six established and two suspected cases of silicosis have occurred in a Swedish enamelling shop which now employs 35 men. The true attack rate of silicosis cannot be determined, chiefly because it is not known how many of the men who left this occupation subsequently developed the disease. Periodic medical inspection has only recently been introduced.

That silicosis is an important medical problem in enamel workers is nevertheless shown by its partially disabling effects in three of the men. The period of exposure required to produce silicosis was probably at least 15 to 20 years, except in preparing enamel powder, where one man showed second-stage silicosis after (probably) less than 17 years' exposure. In no case was silicosis complicated by tuberculosis.

It is not possible solely from the known cases of silicosis to determine accurately which processes are dangerous. The composition of the enamel varied and many of the men had taken part in more than one process. The rapidly progressive silicosis in the man mainly engaged in preparing enamel powder, may, however, indicate special risks in this work.

The dust studies indicate the aetiology of the silicosis and provide a good estimate of the future risks. Thus, men engaged in preparing enamel and

* The microscopic examinations were carried out by Professor Gösta Hultquist, of the Institute of Pathology, Uppsala.

in spraying ground-coat enamel on inner surfaces are exposed to fairly high concentrations of a dust containing about 50% quartz, and presumably in former years they were even more severely exposed. By themselves these investigations strongly suggest that such work has entailed and still entails considerable silicosis hazards. Confirmatory evidence was furnished by the animal experiments, in which the two ground-coat enamels tested (containing 57% and 39% quartz) displayed distinct fibrogenic potency and produced lesions differing relatively insignificantly from those in control tests with pure quartz.

It is considerably more difficult to determine how far spraying with cover-coat and single-coat enamel contributed to the development of silicosis and whether such work now carries a risk of the disease. Fairly high dust concentrations undoubtedly occur—and in earlier years probably were substantially higher—in enamelling of inner surfaces. On the other hand, quartz could not be demonstrated (< 5%) in three of the cover-coat enamels. The fourth contained 15% quartz. The single-coat enamel contained only 13% quartz.

If one appraises the silicosis hazard from the dust concentrations found and the generally accepted maximum allowable concentrations (50 and 20 million particles per cu. ft., respectively, for dust containing < 5 and 5 to 50% quartz), cover-coat enamelling carries a minimal risk. Certain factors, however, indicate that a more cautious approach may be advisable. Thus, as mentioned in the introduction to this paper, silicosis has been reported to result from exposure to enamel dust containing little or no quartz. Nor do we know whether the permissible concentrations of dry dust should be applicable to the aerosol formed in spray enamelling. Finally, in our animal experiments lesions of suspected silicotic appearance were produced by one of three cover-coat enamels, although quartz could not be demonstrated (< 5%). Similar changes were evoked by the single-coat enamel (only 13% quartz).

Hence it is not unlikely that at least two of the enamels were more toxic than their quartz contents indicated, and we consider that attention should be directed to the operations (spraying of inner surfaces) in which relatively high dust concentrations occur. This opinion is in conformity with the views expressed by Hatch (1955). On the basis of an extensive investigation he criticized the current rule of automatically relating the silicosis hazard to the amount of quartz in the dust. Hatch suggested the following norms for maximum allowable concentrations: < 5 million particles per cu. ft. in

occupations with a well-documented risk of silicosis, 5 to 10 million particles per cu. ft. when the risk is less pronounced, 25 to 50 million particles per cu. ft. for dust which has given rise only to simple pneumoconiosis, e.g., anthracosis, and < 100 million particles per cu. ft. for dust which has not produced demonstrable pathological changes. This interesting principle must, of course, be limited to occupations from which satisfactory clinical experience is available.

Summary

Medical, technical, and experimental investigations of the silicosis hazards in a Swedish enamelling shop which now employs 35 men are described.

In the last 20 years six established and two suspected cases of silicosis have occurred in men exposed to no other similar risk. In three of the men the disease caused partial disablement.

The most dangerous operations appeared to be the preparation of enamel powder and spraying ground-coat enamel on inner surfaces. The men were exposed to fairly high concentrations (mean values 10-75 million particles per cu. ft., impinger method) of a dust containing about 50% quartz. This dust displayed, with the method of Miller and Sayers (1934), distinct fibrogenic potency in rats and produced lesions in omentum and peritoneum differing insignificantly from those in control tests with pure quartz.

It was more difficult to determine how far spraying with cover-coat and single-coat enamel had contributed to the development of silicosis and whether such work now carries a risk of the disease. The dust concentrations were fairly high in some operations (mean values 9-16 million particles per cu. ft., impinger method), but quartz was present in small amount or could not be demonstrated (< 5%). Two of the enamels produced suspected silicotic lesions in rats. It was therefore considered not unlikely that these two enamels were more toxic than their quartz contents indicated. Attention should be directed to the operations (such as spraying of inner surfaces) in which relatively high dust concentrations occur.

REFERENCES

- Bruce, T. (1945). *Nord. hyg. T.*, 26, 284.
- Gaubatz, E. (1940). *Fortschr. Röntgenstr.*, 61, 233.
- Hatch, T. (1955). *Amer. Industr. Hyg. Ass. Quart.*, 16, 30.
- International Labour Office (1930). *Studies and Reports, Series F, No. 13: Silicosis. Records of the International Conference held at Johannesburg, South Africa, 1930.* Geneva.
- Meures, K., and Gräf, J. (1949). *V.D.R.I.Jb.*, p. 34.
- Miller, J. W., and Sayers, R. R. (1934). *Publ. Hlth Rep. (Wash.)*, 49, 80.
- Troisi, F. (1952). *Industr. Med. Surg.*, 21, 47.